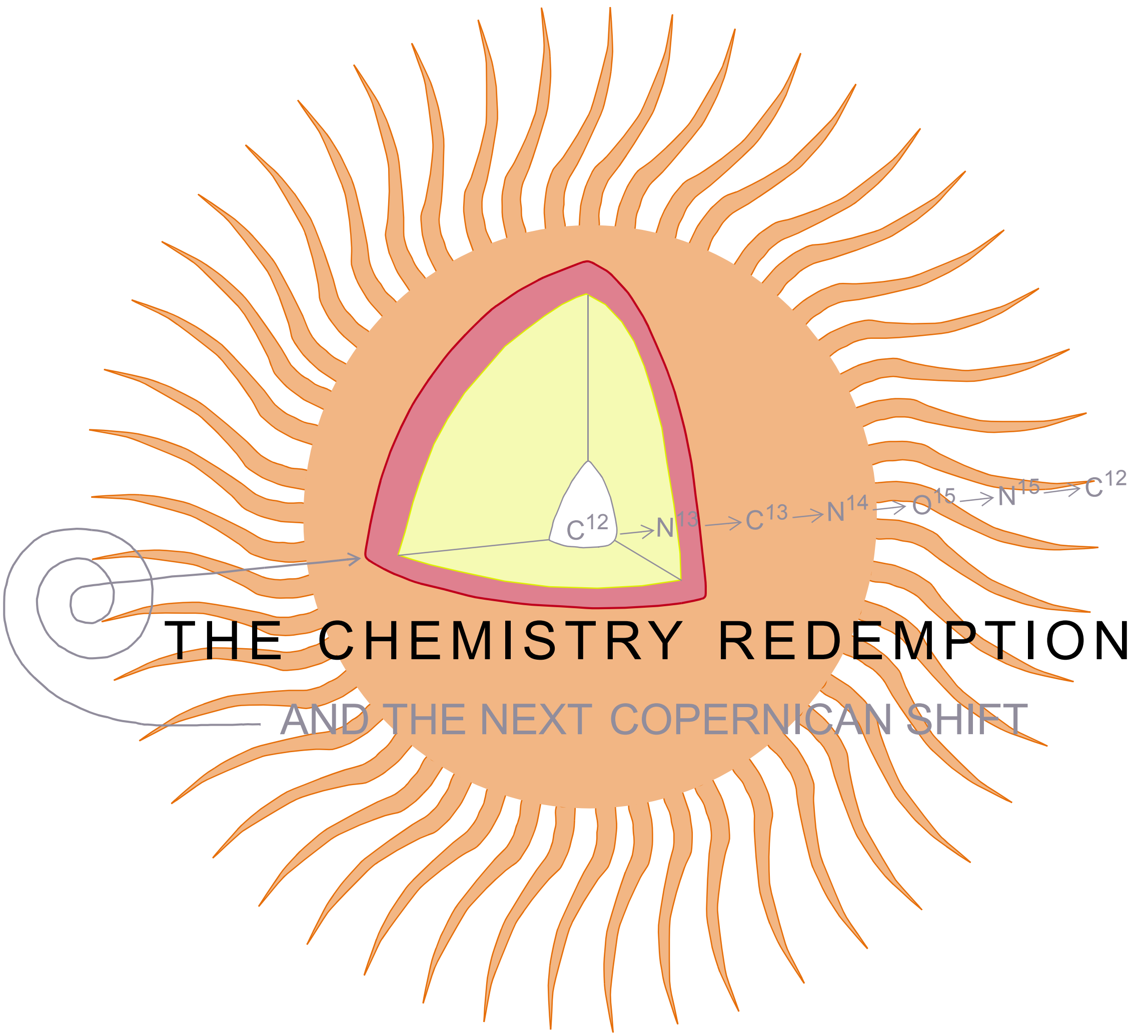

THE CHEMISTRY REDEMPTION

AND THE NEXT COPERNICAN SHIFT

CONAL BOYCE

ISBN 978-0-557-52793-9

www.lulu.com

Printed in the United States of America

Cover design

The design alludes to the Carbon-Nitrogen-Oxygen cycle that occurs inside a stellar furnace. Intriguing though the CNO cycle may be for intrinsic reasons,* this is not a book about astrophysics. Rather, the topic is *basic chemistry* (and one of the book's secondary goals is to warn the undecided student *against* cosmology, both on technical and philosophical grounds; see pp. **96** and **474**). For expedience, though, I've cadged the CNO concept for the cover, where — when presented in graphical form — it can be exploited to help suggest the shift away from our conventional heliocentric viewpoint, inward to the atomocentric viewpoint that I advocate. (But there is a twist: see also page **25**, where I pit the CNO cycle against CHNOPS, so to speak.)

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* Inside the stars, there are two major sources of energy: the proton-proton (PP) chain for hydrogen fusion and the CNO cycle (alias carbon fusion cycle, alias Bethe-Weizsäcker cycle). In stars the size of our sun, the PP chain dominates, with the CNO cycle playing a very minor role. (Only in larger stars does CNO dominate, but CNO was the mechanism I wanted to show on the cover because it has a more "chemical" look than the PP chain.) In its most basic form, the CNO cycle looks like this:

$$ {}_6C \longrightarrow {}_7N \longrightarrow {}_6C \longrightarrow {}_7N \longrightarrow {}_8O \longrightarrow {}_7N \longrightarrow {}_6C $$

If you are musically inclined, you might read off the subscripts as a kind of Music of the Spheres, a stepwise tune in A minor. But realize that this is an astonishingly slow music, progressing at the rate of only one "note" per 830,000 years (= 5 million years per cycle divided by 6 notes per cycle). (At first, this must seem an impossibly slow pace to result in the generation of stellar energy, until one is reminded of the vast number of atoms present in a single star, plus the fact that the star has "nothing but time on its hands" for playing this music. This two-part mind-bend might, in turn, alert one to the possibility that the macroscopic realm where we reside is a grotesque and irrelevant limbo in the eyes of the cosmos, as discussed on page **77**.) Adding some detail, the isotopes involved are these:

$$ {}_6C^{12} \longrightarrow {}_7N^{13} \longrightarrow {}_6C^{13} \longrightarrow {}_7N^{14} \longrightarrow {}_8O^{15} \longrightarrow {}_7N^{15} \longrightarrow {}_6C^{12} $$

On the cover, to reduce clutter I've omitted the subscripts which, in any event, are a kind of redundant, "courtesy" information. (Regarding the SW-NE placement of atomic indices, please refer to page **201**.) Next level of detail:

$$ {}_6C^{12} \xrightarrow{x} {}_7N^{13} \xrightarrow{y} {}_6C^{13} \xrightarrow{x} {}_7N^{14} \xrightarrow{x} {}_8O^{15} \xrightarrow{y} {}_7N^{15} \xrightarrow{z} {}_6C^{12} $$

where 'x' means the nucleus captures a proton (i.e., a *hydrogen* nucleus) and emits a photon; 'y' means the nucleus emits a positron and neutrino; and 'z' means the nucleus captures a proton and emits an α-particle (i.e., a *helium* nucleus).

Thus, one may say that the "point" of the CNO cycle is the creation of one helium from multiple hydrogens. Then, phrased in the parlance of chemistry, the C, N and O are seen in the humble role of catalyst.

Sources: Gamow (1947), pp. 315-317, with the neutrino's role adjusted slightly per [1] csep10.phys.utk.edu/astr162/lect/energy/cno-pp.html and [2] the wikipedia entry for "CNO cycle," both accessed on 04/21/10.

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I THE CHEMISTRY REDEMPTION

This chapter's title can be interpreted two ways: [1] someone should redeem or is redeeming chemistry, or [2] chemistry might be able to play the role of redeemer to *us* — to our ailing human spirit, for example. We'll begin with the former, the idea that chemistry itself is a topic in need of redemption — from some ill or wickedness with which the public has invested it.

Consider the terms *chemistry*, *chemist*, *chemical*, *chemo-*, *chemi-*, and *chemico-*. I'll concede that 'chemist' when used in the British sense of 'pharmacist' might be classified as neutral in its connotations. But for the following list, generally, our associations with anything 'chemical' are overwhelmingly negative:

- acid(1)
- acid rain
- acid smile
- Agent Orange
- ammonia (warnings on the label)
- arsenic ('occurs naturally in chocolate'; and in *you*, incidentally: see **Table 1**, page **10**!)
- bad memories of a ho-hum science teacher in grade school who bored you to the

1. Right at the very heart of chemistry, we have the word 'acid' to contend with, designating the stuff that gets thrown in someone's face in Asian action movies. But what if one were to call it a 'proton donor' instead, borrowing from the technical definition of the acid/base distinction? Then such substances would sound benign, as many of them are, in fact. On the bright side, 'the acid test' is a rare example of a chemistry-related term that seems to have neutral rather than negative connotations.

point of playing a prank (which perhaps got you a suspension?)

- biochemical...warfare?
  Yes, warfare, but *also* The Biochemical Periodic Table, a beautiful concoction (see page 24). But can the long-standing negative connotation be changed so easily as that?
- cadmium and other nasties in a junked personal computer
- carbon monoxide poisoning (accidentally indoors or for suicide in a garage)
- carcinogenic food coloring (to be combatted later in life by 'chemo')
- Chem Lawn™ by TruGreen™ (don't walk here, keep your pets away!)
- Chemical Ali
- chemical cleanup (by the 3M Company, e.g.)
- chemical contamination
- chemical dependency (compare 'drug approval' and its footnote)
- chemical-free athletes
- chemical spill
- chemical weapons, chemical warfare
- chemi-, chemico-, chemo- (curiously, the first and second these prefixes is used only rarely; and the generic meaning of the third one has been hijacked by the next item, for which it has become the quasi-official semi-cute shorthand:)
- chemotherapy (neutral when coined by Paul Ehrlich in the nineteenth century, but now associated rather with the acquisition of baldness, alas)
- dangerous household chemicals (might harm a baby, a cat, a dog)
- deadly chlorine spills
- drug approval[(2)]
- evil geniuses in their laboratories conducting biological warfare
- execution by lethal injection
- formaldehyde
- fluorocarbons
- gas leaks
- greenhouse gas
- hard water minerals and the scum on bathroom fixtures
- industrial pollutants
- iodine toxicity (baby shouldn't drink the pretty violet liquid)
- Jimson weed
- lead poisoning from the paint of old apartment buildings in poor neighborhoods

2. In the context of drug approval and the FDA, the connotations work as follows: a new compound is referred to as a *chemical* (understood to have pejorative overtones, as in 'merely chemical') until the FDA has approved it, whereupon it morphs into something blessèd and desirable: a *drug* for society. But if an individual uses the drug improperly, he may enter the realm of 'chemical dependency', and thus lose society's blessing.

- Love Canal (the toxic waste site near Niagara Falls)
- mercury compounds in fish; mercury compounds in dental fillings
- mercury spills at middle schools (which induce a kind of mass hysteria, since the difference between elemental mercury and mercury compounds is not appreciated)
- money-grubbing pharmaceutical reps and their weekly meetings to 'educate' your nice family doctor
- Multiple Chemical Sensitivity (MCS — a disease presented in the film *Safe* in both a literal and metaphorical way)
- nerve agents
- New Jersey (as in "I don't care if Einstein, Gödel and Gell-Mann all did live there, New Jersey still sounds like one big toxic waste dump to me")
- ozone depletion (by bad chemical villains up above)
- ozone poisoning (at sea level, with ozone itself now the villain, not the victim)
- pesticides
- pathological intoxication (crucial to the plot of the film *Final Analysis*)
- photochemical smog
- polonium-210 poisoning (Or, would this one count as bad press for physics rather than chemistry? Anyway, gotta love polonium, an element known for 'creeping out of its container' and going airborne by itself.)
- preservatives in foods
- psilocybin in hallucinogenic mushrooms
- radon in the basement
- sick buildings
- substance abuse[3]
- thujone (a porphyrogenic terpenoid, "*possibly* implicated in epileptiform convulsions and diverse psychiatric sequelae" comes the warning from specialists at King's College regarding ingestion of absinthe, which is making a comeback worldwide as I write)
- toxic mushrooms or plants (because of harmful chemicals)
- toxic waste sites (other than Love Canal and New Jersey)
- uranium in containers on the wharf
- vinca alkaloids, whereby certain plants are labeled toxic/hallucinogenic
- weed-killers

...and so we reach 'w' in the alphabet. Doubtless some x-, y- or z-nasties also exist, though none springs to mind at the moment.

3. Thus, thanks to Sociology, the only substances in the universe are those in a junkie's bloodstream. Thus, mindlessly, the Social Scientist has usurped one of the most important words in real science.

The ghastly composite image created by the forty-odd bullets above creates a false dichotomy, an us-them wall with Poor Little Humans on one side and Big Bad Chemicals on the other. This is not unlike the false dichotomy of Big Bad Humans vs. Poor Little Nature that runs rampant in academia, except that in the latter dichotomy the Humans beat themselves up as the bad guys whereas in the former dichotomy the Humans extol themselves as the good guys who really *deserve* to ride off yodelling into a chemical-free sunset. If it weren't so sad, it might be funny — all that either/or-ism as a substitute for thinking.

Thus, in the public arena, chemistry is a subject whose status has been wobbling along somewhere between questionable and plain un-sexy for over a century, and there is no reason to think the trend will change anytime soon. True, in academia, chemistry is routinely acknowledged as a kind of prerequisite or gateway subject, as in **Figure 1**a:

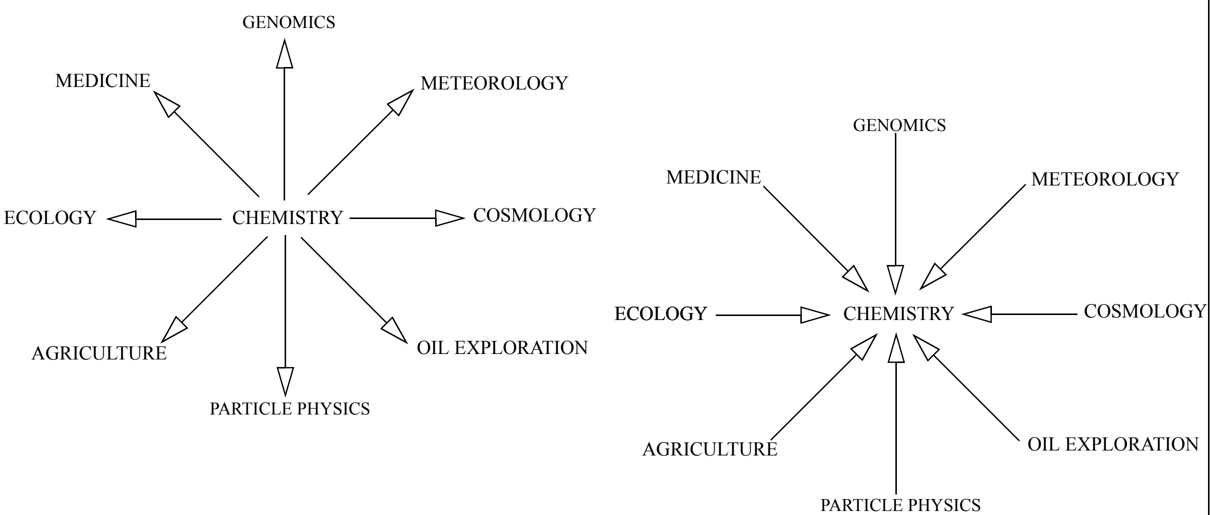

Figure 1(a) Chemistry as Gateway (the conventional view) **Figure 1**(b) Chemistry as 'Rome'

FIGURE 1: Chemistry as Gateway, Chemistry as Rome (where all roads lead)

The distilled message in **Figure 1**a is that chemistry, not unlike freshman English, is a necessary stepping-stone for arriving at certain glamorous subjects, such as genomics and particle physics, or lucrative fields such as medicine, pharmacology, and oil exploration; or 'important' subjects such as ecology and cosmology. On that view, chemistry, once satisfied as a prerequisite, sinks to the status of a kind of academic fly-over state. I would argue, however, that in this kind of representation, the spokes are in fact all pointing the wrong way.[4]

Along with pictures that show chemistry merely as a hoop to jump through (so that all roads ultimately lead *away* from chemistry), we need to develop pictures that say, in effect, "At the end of the day, all roads lead *back* to chemistry [too]," more along the lines of **Figure 1**b and **Figure 6** on page **40**. By contrast, I advocate for chemistry as the *heartland* of science, the home one must return to eventually if one has a genuine desire to understand Nature, to commune with the universe.[5] We should not speak vapidly of 'Chemistry and how it helps us in daily life', as though the subject at hand were something along the lines of 'Friendly microbes and how they help *you*' or 'Get to know the amusing dogs on your block'. Rather, I would say we *are* chemistry. So why not grant chemistry a few hours (or a few decades) of study for its own sake?

On the notion of "chemistry students' misconceptions"

Not surprisingly, the natural tension between chemistry-as-gateway and chemistry-as-Rome (as suggested in **Figure 1**) leads to some neurotic behavior in the ranks of the educators. First we need to set the stage with an analogy: I

magine a kingdom staffed with professional bicycling instructors. Periodically, certain instructors analyze [a] their bicycle-riding students and [b] their own bicycle-teaching methods. First they pose the question of whether bicycle-riding children collide [i] sometimes, [ii] often, or [iii] never, with trees at the bottom of a hill. To lend weight to their analysis, the instructors might even push their data through a sophisticated statistical equation. Since the answer appears to be '[ii] often', the analysts next propose that the instructors improve their teaching methods in the following manner: They should hand out giant teddy bears for the children to hold while riding, thus cushioning the blow from colliding with a tree.

4. Our Figure 1a is derived loosely from Figure 1.12 in Hill & Kolb, page 23, using 8 topics in lieu of their 20 topics and with the implied outward arrows made explicit.
5. We will sometimes use the phrase 'commune with the universe' where 'commune with Nature' might seem more idiomatic or modest. For some readers, the phrase 'commune with Nature' might carry connotations of a sophomoric misreading of Chinese philosophy, with the false dichotomy of Man vs. Nature. By contrast, we hope the phrase 'commune with the universe' will suggest something very small and insignificant trying to connect with something significant (not literally 'the universe'). And at this point, the dynamic is no longer that of a dichotomy, false or otherwise. It just *is*.

But to the outsider, it seems obvious that the problem is neither with the children's biking skills nor with the instructors' teaching methods. Rather, the problem is with the bicycles: they have no brakes!

Replace the badly conceived bicycle with 'basic chemistry', and one begins to have an inkling of the problem: There happens to exist a whole genre of papers whose purpose is to fret over [a] the supposed misunderstandings of basic chemistry students, and [b] deficiencies in classroom teaching methods. Such will always exist for any field, yes; but in the case of basic chemistry specifically, as soon as we stand back we should realize that much of the problem can be traced to the status of basic chemistry itself. This makes for a relatively thin and rushed curriculum, and hence chronically unsatisfactory results in the classroom., never mind the quality of the teachers or the students.

To familiarize oneself with the above genre of papers, one might read Bruck *et al.* or Kelly *et al.* in *J. Chem. Educ.* 2010, 87:1 (on pp. 107-112 and 113-118, respectively). In both papers, the authors allude to a familiar scheme whereby chemistry may be approached 'simultaneously' on three levels: at the symbolic, the macroscopic, and the microscopic level (alias algorithmic, macroscopic, and submicroscopic level). They then express concern over their students' misunderstanding of the third level. In both papers, it strikes me that a straw dog has been erected: Of course some students exhibit weakness in this area. But why? For something such as the meaning of 'aqueous' (*aq*), this might be simply because a student failed to read the assigned chapter in the textbook(!), which is likely to be lavishly and meticulously illustrated in this field. So that's one kind of straw dog, but the second kind is more significant: The gaps alluded to arise chiefly because the basic chemistry course *itself*, in its role of gateway to the 'good' courses, is in far too much of a hurry to give proper attention to all three levels. Thus, turning the 'gap' into a student problem (or even into a *teacher/student* problem) is wrongheaded. Suppose we quiz our Freshman English students on the metaphors in Emily Dickinson, then express dismay that they turned in bumbling papers? That's only a slight exaggeration of the disconnect we find in the chem ed culture as regards "students' misunderstandings".

If we take a broad view of modern society, we can see that the 'gateway' syndrome in chemistry (the rush to get past 'basic' chemistry to 'the good stuff') is part of a much larger pattern, a tectonic shift in the culture. During the first decade of the personal computer revolution, a computer geek was someone who actually understood how *everything* worked; he could trace a problem back step by step through the entire system. Somewhere toward the end of the second decade of the personal computer age, the definition of a geek changed. Now it was someone from a bureaucratic department called 'IT'. He/she would be plenty glib and proficient with subtle forms of one-upmanship, but would probably *not* actually know what was going on under the hood. One aspect of this phenomenon is epitomized by Chloe O'Brian on the television show, *24*. As played by the comedian Mary Lynn Rajskub, Chloe is an admittedly fetching geek. And yes, she knows her way *around* computers and can make them do all manner of astonishing tricks, such as remotely disabling the handheld detonator for a suicide bomber's vest. But does she have any idea what happens inside the keyboard, the primary tool of the trade? Has she ever even heard the term 'ASCII'? Probably not. Similarly, we now have the prospect of a genomics whiz who knows how to clone his pet in the backyard, but who would be at a loss to verify the molar mass of nitrogen at the bench, or to balance a basic chemistry equation. Meanwhile, coming at us from the other direction, we have a real yet untouchable acceleration bug affecting runaway Audis (circa 2000) and runaway Camrys (circa 2010). Not to mention the case of the Airbus that vanished midway between Rio and Paris in 2009, whose woes were attributed by company spokespersons to 'pitot tube icing problems'. Those of us with common sense could surmise that it had been a case of their insanely complex software having *misread* the pitot tube data. (The aircraft 'thought' it was going fast when in fact it was going slow, so it fell 'mysteriously' into the ocean, thus manifesting the perfect mirror image of the Toyota/Audi problem.) And the unifying theme for all the above: In a mad dash to play with hi-tech (to be the technological equivalent of a fast-talking pimp), no one has time any more for the real technology that underpins it. Thus, O-Chem is cool, while basic chemistry is freshman stuff, as though it were the difference between a workshop where one would bang out the first chapter of the Great American Novel and the drudgery of Freshman English. We need a new word for all this madness. Let's call it the lust for *dumbplexity.* (For dumbplexity's flip side, which may be described as a race to the bottom and the cessation of chunking, see page **103**.)

Back to the question of language for a moment: Given that 'we *are* chemistry' (see **Table 1** on page **10**), is there not even one single expression in the language that shows chemicals or chemistry in a positive light?

Happily, yes, one such expression does exist:

> "There is good chemistry between [pick your favorite pair of movie stars]"

And for some reasonably educated speakers, this usage of the term chemistry might in turn be associated with the words 'pheromone' and 'endorphin', which likewise carry pleasant associations. But let's be honest. Any such positive example that one might point to is shouted down by negative ones at the rate of a thousand to one. For instance, Sheldon Glashow has been quoted as saying:

> "From now on, everything is chemistry" (Crease, p. 317)

Translation: "In particle physics, someone will soon hammer out the details of the *neutral currents* and someone else will find *charm*; then the glory days of physics will have passed, and it will just be plain old humdrum chemistry again. Yawn." And who was it that said, "All science is either physics or stamp collecting" thus shunting chemistry off to the stamp-collecting side? None other than Sir Ernest Rutherford, whose 1908 Nobel Prize was *in* chemistry (not physics, as one might assume). Fast forward to the 1981 Nobel Prize in chemistry, awarded to Roald Hoffmann. Some years following that event, we find him writing a book that contains many colorful and progressive ideas about chemistry, a slightly offbeat 'apology for chemistry' (my word) that resonates often with what I'm attempting here, but when it comes to the question of 'the Holy Grail for chemistry',[6] Hoffmann finds none and falls back on the notion of its 'centrality', in a portrayal of the field that is uncomfortably close to my **Figure 1**a. Whereas, my hope was that he might have stood up for **Figure 1**b.

Any signs of progress?

Earlier we mentioned the *one* (!) chemistry-related phrase in the language that involves, for sure, a pleasant association: *good chemistry*. Also, a new word, *chemosynthesis*, is gradually working its way into the language. This bears exciting connotations for the scant few who might have the background to guess that it stands in opposition to *photosynthesis*, and thus refers to the earth's own 'aliens thriving on brimstone' on the ocean floor, i.e., the tribe of *chemoautotrophs* who do not rely on *phototrophs* for life, as all of us *chemoheterotrophs* (or *chemotrophs*) must; see reference to Taq on page **79** below.

Oh, and let's not forget the local co-op. There, of all places, one finds a whispered

6. R. Hoffmann & V. Torrence, *Chemistry Imagined: Reflections on Science*, pp. 128-132, especially p. 130.

truce with chemistry. Note the long aisle where, among others, the following labels appear on the bottles:

Boron
Bromelain
Calcium
Chromium picolinate
Iron complex
Magnesium
Pantothenic acid
Phosphatidyl serine (possibly the most beautiful word in science)
Potassium chloride[7]
Potassium iodide
Pycnogenol
Quercetin
Selenium
Silica complex
Zinc picolinate
Zinc

If one were to traverse this aisle quickly, only glancing at such labels out of the corner of her eye, it would be easy to get the impression that one had stumbled into the showroom of a chemical supply company, not the neighborhood co-op, stocked as it should be with 'natural foods' exclusively. But turn around in the same aisle to look at other products, and you might see almond butter imported from New Zealand, with a label that proudly states:

Made with *no chemicals*

But we *are* chemicals! For the record, in **Table 1** I present a chemical profile of the human animal, expressed in grams:

7. Good old KCl from Chemistry 101? Yes. Think about table salt, NaCl, and the position of K relative to Na in **Appendix A: The Periodic Table**, page **201**, and then it makes sense: KCl is marketed to those with high blood pressure as a clever way of both obtaining more potassium [K] and simultaneously avoiding sodium [Na]. The poetic beauty of it being that sodium is precisely the item in one's diet that has, typically, brought about the potassium deficiency in the first place!

TABLE 1: Your Chemical Profile (in Grams)

CHEMICAL		[1]AMOUNT (g)		CHEMICAL		AMOUNT (g)	
Oxygen	O	43,000		Chromium	Cr	0	.014
Carbon	C	16,000		Manganese	Mn	0	.012
Hydrogen	H	7,000		Arsenic[2]	As	0	.007
Nitrogen	N	1,800		Lithium	Li	0	.007
Calcium	Ca	1,000		Cesium	Cs	0	.006
Phosphorus	P	780		Mercury	Hg	0	.006
Potassium	K	140		Germanium	Ge	0	.005
Sulfur	S	140		Molybdenum	Mo	0	.005
Sodium	Na	100		Cobalt	Co	0	.003
Chlorine	Cl	95		Silver[3]	Ag	0	.002
Magnesium	Mg	19		Niobium	Nb	0	.0015
Iron	Fe	4	.200	Zirconium	Zr	0	.0010
Fluorine	F	2	.600	Lanthanum	La	0	.0008
Zinc	Zn	2	.300	Gallium	Ga	0	.0007
Silicon	Si	1	.000	Tellurium	Te	0	.0007
Rubidium	Rb	0	.680	Yttrium	Y	0	.0006
Strontium	Sr	0	.320	Bismuth	Bi	0	.0005
Bromine	Br	0	.260	Thallium	Tl	0	.0005
Lead[4]	Pb	0	.120	Indium	In	0	.0004
Copper	Cu	0	.072	Beryllium	Be	0	.00036
Aluminum	Al	0	.060	Gold[3]	Au	0	.00020
Cadmium	Cd	0	.050	Scandium	Sc	0	.00020
Cerium	Ce	0	.040	Tantalum	Ta	0	.00020
Tin	Sn	0	.020	Vanadium	V	0	.00011
Titanium	Ti	0	.020	Thorium	Th	0	.00010
Boron	B	0	.018	Uranium	U	0	.00010
Iodine	I	0	.015	Samarium	Sm	0	.00005
Nickel	Ni	0	.015	Tungsten	W	0	.00002
Selenium	Se	0	.015	Radium[5]	Ra	31×10^{-12} g	

1. Source: Indirectly, John Emsley, Third Edition, pp. 16-223 passim: From his mixture of kg/g/mg values, I've converted all items to grams for readability, gathered them into a table and sorted them by decreasing magnitude. His figures assume an 'average (70 kg) person'.
2. Note in passing that Arsenic also occurs in chocolate.
3. Given the very small amounts cited for Silver and Gold, one assumes Emsley is showing us trace element data, nothing to do with dental work statistics.
4. Stored in the skeleton, notes Emsley.
5. Following Radium we could add half a dozen others in still smaller quantities, the ones listed by Emsley as 'n.a. but small' (such as Argon in Emsley p. 24, Krypton on p. 108).

Chemistry the Redeemer and the 'inorganic' misnomer

So much for a narrow reading of the chapter's title, which amounts to: "Let's redeem chemistry (or see who is trying to redeem it already)." Now for the secondary reading, where we take it as a mock-Ludlum title.(8) Read this way, the title means: "Let's allow chemistry to redeem *us*." But it is not the glamorous one, organic chemistry, that I'm talking about here. Forget O-Chem, as it is known in the campus vernacular. The topic at hand is *inorganic* chemistry. (Or we could say the topic at hand is 'basic chemistry' since that course is typically dominated by 'inorganic' topics with only a smattering of 'organic' topics, if we analyze its content in terms of the prevailing dichotomy.) I realize this down playing of O-Chem is a novel idea and it will take time to persuade you that it is not in fact a crank idea. Hence a book rather than an essay.

(Some readers might ask: *Does* such a split even exist anymore, between 'organic' and 'inorganic' chemistry? In a word, Yes, but the establishment throws out some mixed signals. Take the case of *The Norton History of Chemistry* by William H. Brock. On p. 593, Brock quotes Sutton's remark that "[The publication of Sidgwick's *The Electronic Theory of Valency* in 1927] gave a fresh unity to the whole of chemistry: the division between inorganic and organic chemistry was finally broken down." But then, for the remainder of the book, Brock goes on to sing the praises of organic chemistry and synthesis, for the period 1930-1990. One is left with the impression that inorganic chemistry has been magnanimously adopted by the 'important' one, organic chemistry, as a scruffy orphan, an embarrassing guest from the previous century. Some unity, that!)

Imagine an unbiased investigator, not just 'from another world' but from another

8. For those unfamiliar with Robert Ludlum's work here are a random few titles of thrillers he has published: *The Bourne Identity, The Holcroft Covenant, The Aquitane Progression, The Chancellor Manuscript, The Scorpio Illusion, The Scarlatti Inheritance, The Prometheus Deception.* The grammatical recipe seems to be: Take a noun (preferably a proper noun), and force it into service as an adjective, preceded by the article. Just for fun (and by way of starting a new parlor game?), here are a few more mock-Ludlum titles: *The Manx Peccadillo, The Alkane Deposition, The Potassium Pretext, The Lambda Bifurcation, The Schrödinger Catastrophe, The Sequoia Recrimination, The Bali Insemination, The Wales Ostentation, The Patagonia Prudence, The Heisenberg Heuristic, The Kraft Oblivionation, The Corelli Differential, The Pauli Invective, The Copenhagen Covenant, The Paisian Codicil, The Azote Retort, The Calx Manifesto.* With those final two pseudo-titles, I allude to Lavoisier's Twelve Days' Experiment, to be discussed on page 28 below.

universe. (The need for such drastic separation will become clear in a moment.) During part of his journey, the investigator notes one kind of entity whose routine activities seem to involve orbitals and bonding, accompanied perhaps by thoughts or another kind of decision-making process as suggested by **Figure 2**b. During other parts of his journey, the investigator notes a kind of entity that seems preoccupied with finding things to drop into its sack. The sack is filled mainly with hydrochloric acid. Anything dropped into the acid dissolves. This kind of entity is enormous compared to the first kind. Its mode of locomotion is unclear, but whatever it is, it exhibits movements that are clumsy and millions of times slower than for the first kind of entity. Perhaps this second one (see **Figure 2**a) is only a type of robot or some gigantic Tinkertoy® or LEGO® agglomeration — not even a life-form at all? The investigator decides to focus all further efforts on the first kind, the one depicted in **Figure 2**b. That one is *clearly* a life-form, and one with high intelligence.

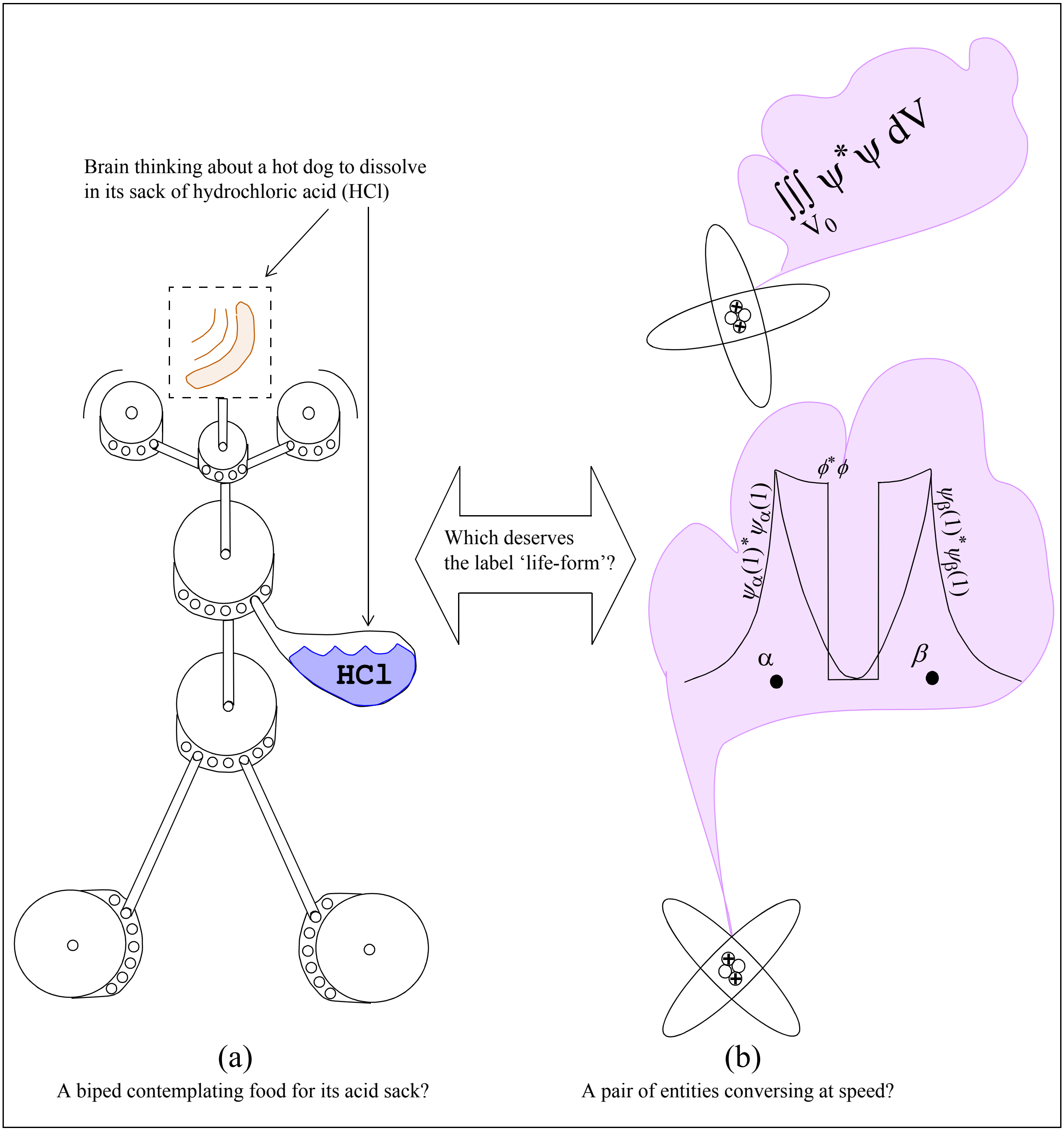

FIGURE 2: Two types of entity as seen by an extra-universal visitor

While **Figure 2**b must be a bit exotic to the general reader,[9] **Figure 2**a you'll recognize, I trust, as a representation of our own kind, humans. In essence, a human is a sack of hydrochloric acid, made ambulatory by a pair of calcium phosphate stilts and two eyeballs for locating objects that are acid-soluble, in other words 'food'. (Note the generous quantities of hydrogen and chlorine and of calcium and phosphorous in **Table 1** above.)

In holding our species up to such a mirror, it's not that I wish to be mean; rather, the opposite: My stark picture is intended to suggest a possible way *out* of the dire human condition, in which one is conscious of being freakishly *in* the cosmos somehow, yet not solidly *of* the cosmos.

So long as one attempts to prop up the human form by rationalizing its stomach (by 'cuisine') and its myriad other embarrassments (by 'civilization' generally), I say the quest for dignification is futile.[10] Whereas, if one adopts a chemico-centric view of the world, then the HCl that dominates the kingdom of the stomach is a proud, beautiful, pristine substance, simply doing what HCl does: dissolving everything but gold, so to say, in its role as chemical shark. (Moreover, one can then meditate on the fact that each individual atom of hydrogen or chlorine making up that pool of acid was once part of someone else or something else in the remote past: the toenail polish of Queen Nefertiti, a pillow case of Ludwig von Beethoven, an optical nerve in a pterodactyl, and what have you.)

There is yet another silver lining to the circumstance suggested by **Figure 2**a. Today there is much soul-searching about the future of humans vis-à-vis the supermachine population we seem destined (or doomed) to create in the near future. However, taking stock of the situation through the lens of the atomocentric philosophy that I advocate, one observes that humans are *already* (mere) machines, so it stands to

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9. The thought bubbles in **Figure 2**b are from Metz pages 302 and 328, Figure 16-4, borrowed just for fun — no abstruse meaning. The atom I've crudely depicted is helium, chosen for its neat, 1950s Sci Fi look. (Regarding the convention of '+' as representing a single positive charge for a proton, see discussion on page **119** regarding integer versus fractional charges for quarks.)
10. While the atomism that I advocate is radically different from that of Lucretius, in the following passage I do recognize a kindred spirit: "Our terrors and our darknesses of mind / Must be dispelled, not by the sunshine's rays, / Not by those shining arrows of the light, / But by insight into nature, and a scheme / Of systematic contemplation." These are lines 146-150 in Lucretius as translated by Humphries, p. 24. Also, they are quoted at the end of the Introduction by Burton Feldman, in Humphries, p. 16.

reason that our kind would be preoccupied with designing ever-higher versions of ourselves — those dreaded technologies of tomorrow that will surely seduce or enslave or even destroy us. This is no one's fault; it's just the way of hideous Mother Nature.

A fear of machines or of spiders (or of spidery supermachines) is really just a fear of *self*, for deep down we know that really we are just glorified viruses (some of which bear an eerie resemblance to all the above). Is there anyone who, upon first encountering a textbook depiction of the lytic cycle for a T-even bacteriophage, has not felt a multilayered twinge of horror and fascination, even kinship or 'recognition'? Intellectually, one may rationalize and denigrate the virus as 'not a true life-form' but in his heart of hearts one suspects a kind of intelligence, even superiority down there. After all, the virus challenges us yearly with debilitating illnesses. After all, without the Hershey-Chase 'blender' experiment of 1952, which analyzed the inner workings of the T2 phage, we might *still* be pondering whether the hereditary code is carried by protein or by DNA (see Watson, p. 80; Tanford & Reynolds, p. 234).

As soon as Mother Nature assembled the first T2 phage some 3,000 million years ago, *that's* when the Machine Age started. As soon as Mother Nature set the first arthropods scuttling on beaches some 500 million years ago, that was a sign of an Advanced Machine Age already. Humans were still far in the future. Much-vaunted 'life' simply *is* machine activity. Why else would Tanford and Reynolds give their history of proteins such an odd, uncomfortable title: *Nature's Robots*? Danchin's title *The Delphic Boat* may seem more appealing at first, but his message that *we* are mere [Turing] machines is relentless and persuasive, if low-key. The punch line comes not in the epilogue, but buried rather in the final sentence of his acknowledgements (!) section:

> This book is pessimistic: it shows that life has no meaning. It is optimistic: it shows that over the dunghill, forever irreducible, the rose still blooms.
>
> — Danchin, p. 340

I find Danchin's argument (Danchin, pp. 210-245) persuasive except for its most crucial 1%, so to say: the question of how life itself is defined. For Danchin, life must be defined in terms of objects on the microscopic-mesoscopic-macroscopic scale (Danchin, pp. 233, 253), and he openly scoffs at Albert Szent-Györgyi for having chased the question all the way down to the level of molecules and electrons:

> But the irony of the story is precisely that molecules and electrons do not have life.
> — Danchin, p. 250

No, M. Danchin, you've barely scratched the surface of the double or triple irony at play. The true irony is that you would dismiss molecules and electrons out of hand, thus missing your one chance at glimpsing the truth, if only in passing. Finally, note that Szent-Györgyi is the very one whose most famous quote is: "Discovery consists of seeing what everybody else has seen and thinking what nobody else has thought."

At any rate, like Danchin, I land in a paradoxical place where I must describe my outlook as simultaneously pessimistic and optimistic. The former because I agree with Danchin that the biped machine (not 'life') is meaningless; the latter because I believe in the possibility of 'salvation' for the biped by communion with the realm where life *does* exist, i.e., the atomic realm.

This brings us back to the pair of entities depicted in **Figure 2**b. These are the entities our prime-time scientists and academic graybeards alike label as 'inorganic'. But how is it that sublime locomotion without feet or wheels and without the need to feed and to defecate, plus an expected lifetime equal to eternity,(11) *fails* to add up to a life-form superior to a yeast or a mouse? In this matter, have generations of earthlings at the whiteboard been just a teensy bit provincial and boneheaded?

Even using the 1913 model-T notion of an atom, an honest observer of the two kinds of entities must sense *already* that the kind depicted in **Figure 2**b is surely more lively, graceful and promising of beauty and intelligence than the Tinkertoy® monstrosity in **Figure 2**a. And, by the way, notice the contrast in their mental lives, too: Something about selection rules for transitions between molecular orbitals seems to preoccupy the one life-form (the integral $\iiint \psi^* \psi \, dV$ represents the probability of an electron's location within a volume V_0), while the other life-form seems preoccupied with thoughts of its next hot dog (whose very hot-dog-ness will be instantly snuffed out upon falling in half-chewed globs into the dark hideous cistern of hydrochloric acid). Please.

Too harsh, you say? In Woolf p. 88, the narrator reminds us of how much "Shakespeare loathed humanity...the sordidity of the mouth and the belly!" In Woolf

11. *Minimum* proton life has been estimated at 10^{27} years; see Crease, pp. 397-403, esp. p. 400. In Taylor, p. 351, the rate of proton decay (to positron plus pion) is given as less than 1 every 10^{32} years. For more on this topic, see the discussion of **Figure 30** on page **100**f.

p. 128, the narrator notes a solemn stroke of Big Ben, "which lay flat like a bar of gold on the sea".[12] Here we have an articulation of the same two extremes[13] that I've tried to depict in **Figure 2**, which in turn represents this book in capsule form. The human as Tinkertoy® with a sack of hydrochloric acid (the belly whose sordidity is undeniable) I juxtapose with the atom. In the atom's kingdom *everything* is beautiful, not just the gold atom, and everything is alive, in ways more convincing than our own. This is what the figure should suggest. Through literary tradition, in passages such as those in Woolf and Conrad referenced above, one is conditioned to think of gold as holding a special place among the elements. By tilting one's perspective slightly, one can begin to see, however, that *every* chemical element is 'special' just like gold, and likewise a molecule such as HCl or HgO. That's the basic-chemist's view of the world, and this is what I mean by 'redemption': From this perspective on the world, the sordidity of the belly is replaced by respect for the beauty of HCl, equal to that of a gold atom. (Indeed, it occurs to me now that long before I juxtaposed them here for my own purpose, these two substances already had their own history of meeting via *aqua regia*, the mixture of hydrochloric acid and nitric acid that uniquely dissolves a 'noble metal' such as platinum or gold.)

Taking a legalistic approach, one might dismiss my concern about a supposed inorganic 'misnomer' as follows: "The organic/inorganic dichotomy pertains to molecules, not to atoms, and thus why do you 'care' (since the object of your discussion is specifically the atom)?" My response: But informally, by implication, the term 'inorganic' *is* made to apply all the way down to the atomic level. Any element that lacks a prominent role in organic chemistry is thrown by default into the inorganic bucket. Moreover, the notion is extended to encompass any pure substance comprised of only one element, even if that element happens to be one of those sanctified elsewhere as a 'life element': CHNOPS (carbon, hydrogen, nitrogen,

12. For some readers, Woolf's phrase might recall Conrad, *Lord Jim*, Chapter 3: "The young moon recurved, and shining low in the west, was like a slender shaving thrown up from a bar of gold, and the Arabian Sea, smooth and cool to the eye like a sheet of ice, extended its perfect level to the perfect circle of a dark horizon."
13. Actually, there exists in literature an image that is perhaps even less flattering to humans than my stilt-creature with an HCl sack slung like a colostomy bag to one side: I refer to Sylvia Plath's image of Buddy Williard's reproductive system on display to the heroine of *The Bell Jar*, which occurs about three-sevenths of the way into the largely autobiographical novel, in the dorm room scene: "The only thing I could think of was turkey neck and turkey gizzards."

oxygen, phosphorus, sulfur). So yes, there is cause for me to 'make it my business' (and we will resume this thread in connection with the organometallics, on page 23).

On a slightly tangential point, it is interesting to note that the typecasting of the atom as insentient goes back at least as far as Lucretius, the Roman philosopher-poet: "At this stage you must admit that whatever is seen to be sentient is nevertheless composed of atoms that are insentient" (Lucretius 2.866; Latham tr., p. 59). Thus, Lucretius glosses over the insentient aspect of the atom as a kind of self-evident truth. Clearly, *this* part of his discourse, entitled *De rerum natura* (*On the Nature of the Universe*), is not even up for discussion!

Against the crushing weight of all that authority on the side of an organic/inorganic scheme (in which the atom winds up implicitly in a third category that might be labeled 'suborganic' or 'insentient'), I propose to elevate the atom as the very locus of life, while discounting entities at the macroscopic level (our level) as a kind of pseudo-life. What could my basis possibly be for advancing such a philosophy? Strange though my viewpoint must seem at first blush, it is one that could result simply from savoring, and following to its logical conclusion, a single, crisp line in Schrödinger.

Schrödinger's Question

In Schrödinger's small classic *What is Life?*, the first chapter is intended only as a foil for the ensuing six chapters. However, it should not on that account be glossed over. In that chapter, taking on the guise of a 'naïve physicist' on loan to the biology department, he poses the following question:(14)

> Why must our bodies be *so large* compared with the atom?

Naïve or not, this physicist is clearly brilliant, having stood on its head the following tedious and mundane question:

> Why are atoms *so small*?

By the end of the chapter, Schrödinger seems to be offering a definition of the

14. Erwin Schrödinger, *What is Life?* (Cambridge University Press 1967 [1944]), p. 6, p. 8, emphasis added. The physicist (Schrödinger) presents himself as 'naïve' because here he is roaming the halls of biology, as a cross-disciplinary outsider. (Later, inspired by his essay, several in his field followed him across this same imaginary border to become biologists or biochemists of note.)

organism; i.e., he seems to be offering us not only an answer to his own question about our bodies but also a preliminary definition of *life itself*. He writes: "...an organism must have a comparatively *gross structure* in order to enjoy the benefit of fairly *accurate laws*, both for its internal life and for its interplay with the external world" (Schrödinger, pp. 17-18, emphasis added). As we might phrase it today, a small entity's organs of perception and locomotion would suffer excessively high error rates for lack of a good error-correction algorithm. In this connection, see also **Appendix F: God IS the Dice**.

In reviewing that chapter, however, we can see that Schrödinger has come dangerously close to constructing a false dichotomy. In his haste, he has accepted certain bacteria as organisms that are *beneath* the threshold for being 'orderly'; i.e., they suffer poor-to-non-existent locomotion skills because "heat motion tosses them like a small boat in a rough sea" (p. 14). Thus, in offering a demonstration of the problem at hand, he actually ruins his own argument, or at any rate paints himself into a corner such that the reader must help him out by redefining the topic in mid-flight, as follows: It is not life, it is not organisms generally; rather, it is the higher organisms — specifically — upon which Schrödinger is focused. The kind that possess *superior* organs of perception and locomotion. *This* is his de facto topic, whether he likes it or not. A (posthumous) embarrassment(15) for him, let's say, but a windfall for me as I seek support for my outlandish-seeming philosophy: For when we meditate upon *that* kind of organism (the kind that is presumed 'higher' and more 'advanced'), juxtaposed with the sublimely scintillating atom, what we see is not life at all, but its opposite: a graceless and embarrassing machine (hearkening back to my own **Figure 2**a). Where, then, has precious life fled?

15. Granted, by the time we begin reading Chapter 2, we realize that Chapter 1 was partially a straw-dog, a mere backdrop for all the ensuing chapters. Still, *internally*, Chapter 1 suffers a lapse in its logic; that's my point here. The lapse is embarrassing in two ways: first, as a flaw in the logic; secondly, because of its undue emphasis on 'higher' life-forms. Nowadays many would consider the bacterium to be more successful than our own species, granted that in Schrödinger's day such a view might have seemed fringe-y or unsupportable. (See discussion of Taq on page **79**.) Not only might they be judged more successful, but also as competitors where intelligence and inventions are concerned. For examples of the microbial *wheel*, *compass*, *pump* and *syringe*, see Tortora *et al.*, pp. 79, 94, 129, and 388, respectively.

Down into the atom[16] (as suggested by **Figure 2**b). This in a nutshell is my thesis. It claims primacy for the atom on *all* fronts, including truth, beauty, ontology, and even 'intelligence' (somewhat redefined). My aim is to challenge the unstated premise that atoms are inanimate *things* while we are animate *beings*; it is a premise that suffers from an unseemly kind of anthropomorphism, reminiscent of the geocentric assumption that was challenged by Copernicus. What is the next Copernican shift? It is a humble realization that the atom is the animate Being, while we are the inanimate Things.[17]

But if I am going to pursue in earnest my vision of the atom as sole legitimate life-form, hadn't I better suggest a way for us to *commune* with the atom? Otherwise, my philosophy amounts to a kind of sneering nihilism, with little to recommend it (unless one is a devotee of Kali). That's where chemistry enters the picture. Not organic chemistry but *basic* chemistry.

My thesis is short — 'The atom alone is an animate being' — but its message is *outré*, even offensive, because of the corollary: *we* are the inanimate *things* (crude machines, soon to be overrun by our own fearsome supermachines). Accordingly, the book is rather long; much space is required to state the case for the Copernican shift that I advocate. Not that such a shift would imply anything necessarily revolutionary or disruptive to one's physical life; rather, it would be hurtful (humbling) on the inside, psychologically. In working out some of its rationale and implications, the journey takes me through a treatise on particle physics, another on so-called 'information theory', and another where I launch the first true Theory of Information. In fact, when all is said and done, we come close to cooking up a Theory of Everything, if you like, though hardly by design. (This thread is picked up on page **477**.) Finally, the book contains several large appendices, though this is only a structural device. Except for **Appendix A: The Periodic Table**, each so-called appendix is an

16. Note that just for an instant, Schrödinger himself grants the atom a status comparable to what I propose: By way of preface to the question quoted earlier, he acknowledges "an incontestable priority of independent existence on the side of the atom." And this, after all, is *why* he takes the jejune question (Why is the atom so small?) and inverts it, magically transforming it into an adult-sounding question. When and if Intelligence arrives from the Beyond, the existence of his inverted question will save the biped race from total embarrassment.
17. And what becomes of the bacterium and the virus in this scenario? In the old order, they were 'less alive' and 'dumber' by fault of being too close to the atomic scale; in the new order that I propose, they are *more* alive, by virtue of being closer than we are to the atomic scale.

integral part of the whole, *not* in the nature of an 'extra' or 'supporting material'.

Of Frog Legs, the Living Heart, and the Electron Sea

Not that all would turn a deaf ear to the shift I advocate. One is heartened to learn of certain remarks attributed to David Bohm regarding the electron sea in metals and its appearance of being 'alive' (in Briggs, pp. 95-96 and p. 167). Later we will revisit a question posed by Rutherford to Bohr, which acknowledges the subtleties (or at least our ignorance) of subatomic 'motivation'; see page **131**. (Also, one might recall Stanislaw Lem's *Solaris*, the story of a planet with 'live' oceans that comprise one immense brain, largely beyond the comprehension of its orbiting biped visitors. This is similar to my atomocentric advocacy, but turned inside-out, the point in each case being: If you learn of an entity whose scale is vastly different from the one on which you find yourself, try to keep an open mind.)

Some eighteen centuries post-Lucretius (page **18**), it was time for the electron, or rather electricity, to be typecast. Like the atom, it wound up in the bucket labeled inanimate or insentient, but this time only after a lively debate between Luigi Galvani and Alessandro Volta. In 1790, it appeared to Galvani that frogs possessed 'animal electricity'. In 1792, Volta was able to "obtain electrical effects, such as had been observed by Galvani, by establishing contact between two dissimilar metals separated by a moist conductor and without using any animal preparation whatever" (Berry, p. 55). Eventually Galvani had to admit that there was no special animal electricity, only plain contact electricity, the latter being able to explain, on its own, both Volta's results and his own, if properly interpreted.(18)

Note that the resolution might have been framed more subtly and from the opposite direction. For instance, one might have said, "Even Volta's 'contact electricity' has something of the animate about it, n'est-ce pas? After all, it can induce twitching in a frog's leg!" That path, however, was not pursued. Otherwise, who knows? By analogy with the 'life elements', the electron might today be classified as a 'life particle'. Instead, we encounter now and then a lingering ghost of the Galvani/Volta debate, whose resolution was perhaps too pat and unnuanced. For instance, I would

18. Originally, Galvani had drawn the conclusion that his frog's leg must be a *source* of electricity. His instincts were correct, in the sense that innate electrical activity does drive the heart, as we understand it today. It's just that *his* particular setup with the frog should not have led him to such a notion as 'electricity in the frog'; rather, the opposite: a reaction *to* electricity in the frog's leg. Hence his reluctant eventual retraction of the 'finding'.

venture that most people, *if* they have any awareness at all of the electricity in their hearts, must view it as intrinsically distinct and qualitatively different from the electricity in a flashlight battery or in the paddles of a defibrillator. Who shall we blame for the confusion? I say it is the fault of the science establishment for having relegated electricity to the lowly status of 'inanimate' circa 1792 (when 'contact electricity' alone was deemed real). That makes it difficult for the nonscientist or nonphysician today to accept it as 'the same thing' when it is manifest in one's 'animate' internal machinery, where it 'doesn't belong'.

A few more remarks about nomenclature: In the list near the beginning of this chapter, we saw already the dire state of the word 'chemical'. As suggested by the following table, given the nature of the universe we live in, we desperately need neutral adjectives associated with the noun 'atom' and with the noun 'chemical', yet no such slot exists in the language. We have only pejoratives. What to do? For the atom, we could try 'a-tomic' (building on hyphenated 'a-tom' in Lederman, p. 3, whereby he reminds us that the word in Greek meant un-*cuttable*). Or one could try 'atomocentric', as I have earlier in this chapter. Not a pretty word, but it brings us back down from the mushroom cloud to the atom itself, where we need to be focused if we aspire to do any serious thinking about the universe. (It is unfortunate that the journalists could not have been satisfied with 'atom bomb'. Evidently, a few thought it sexier to write 'atomic bomb' instead, thus effectively removing one of the most important adjectives in the language from circulation, except for its specialized use by talking heads. Far more easily than a species of animal, a sememe may be shoved into extinction overnight.) As for the noun 'chemical', we can only hope that someday the corresponding adjective might come back with a neutral connotation. For now, it is purely pejorative, witness 'Chemical Ali'.

PEJORATIVE ADJECTIVES	NEUTRAL ADJECTIVES
atomic — in current usage	a-tomic or atomocentric — in current usage atomic — in past (and far future?) usages
chemical — in current usage	chemical — in past (and far future?) usages

Three 'bridge' disciplines: Organometallic Chemistry; BZ Reactions; P-Chem

The three disciplines or specialties cited in the above heading do not directly advance my advocacy for 'coming back home to an atomocentric view'; indirectly, however, they shed light on the arena of ideas (pro and contra my case), simply by the fact of their existence. In different ways, each casts doubt on a certain kind of dichotomy or sorting scheme of the establishment, suggesting that a bridge might be needed for rejoining a pair of wayward ice floes, their center lost in the intervening ice water, as it were.

Bedazzled by the variety and complexity of CHO combinations in nature,[19] it seems the establishment endeavored at first to treat iron in the blood as a trivial exception to the pretty pattern of life elements (CHNOPS), so neatly clustered near the top of the periodic table. Yet far from being *in*organic, certain metals play a role that is both figuratively and literally *central* to the molecules of life. This has been known for a very long time. Grudging acknowledgement of this reality comes finally in the form of a separate field (!) called *organometallics*. A short history of that field is in order. The term 'organometallics' is potentially confusing because it has both (a) a technical, legalistic definition, oriented toward laboratory *synthesis*, and (b) a commonsense definition, based on *discoveries* in nature.

Definition (a): a compound that contains a *carbon-metal bond* (extended later to include various other ligands such as CO and NO; Miessler, p. 412).

Definition (b): any CHO-type compound discovered in a life-form that *also* features a single atom of a metal *as the hub* of the compound (or a pair of metal atoms as the foci of the compound); author's definition.

By including arsenic, a semimetal, in its realm, the field of organometallics may be dated back to Louis Claude Cadet's formulation in 1760 of tetramethyldiarsane. Alternatively, one may say the field begins with the first synthesized organometallic compound, *Ziese's salt* (involving among other substances platinum and ethylene, C_2H_4). This was discovered in 1827, and subsequently followed by similar landmarks in 1867 and 1890 (Miessler, p. 414). Still working with definition (a), we

19. From time to time, one might even have the feeling that 'everything' is some species of CHO or CHNO compound: citric acid $C_6H_8O_7$, D-fructose $C_6H_{12}O_6$, conferin (in fir trees) $C_{16}H_{22}O_8$, lactose $C_{12}H_{22}O_{11}$, lysine $C_6H_{14}N_2O_2$, barbitone $C_8H_{12}N_2O_3$, and so on.

can say the field took off with the synthesis of *ferrocene*, $(C_5H_5)_2Fe$, and various other 'sandwich' compounds, circa 1951-1956 (Miessler, p. 415). Meanwhile, the (sub)branch known as bioinorganics dates back to Paul Ehrlich's work with organoarsenic as a cure for syphilis in 1909.

As for definition (b), the field has enjoyed a sort of de facto, shadow existence for a very long time. We may say it has been invoked whenever and wherever awareness of the following has stirred, however faintly:

- The hub of the 137-atom chlorophyll molecule ($C_{55}H_{72}MgN_4O_5$) is a *single* atom of *magnesium*.
- A *single* atom of *cobalt* lies at the very center of the Vitamin B12 Coenzyme, which is comprised of these 181 atoms: $C_{63}H_{88}CoN_{14}O_{14}P$.
- In hemocyanin, two atoms of *copper* play the same role in octopus blood that *iron* plays in our red blood cells, i.e., in the heme molecule, $C_{34}H_{32}FeN_4O_4$.
- In nitrogenase, two atoms of *molybdenum* play a crucial role; see Miessler, p. 415 or Hoffmann & Torrence, p. 38.

Of late, the organometallics field has grown rapidly and developed its own important subtopics. For example, 'organocopper chemistry' (and, less pleasantly, 'organomercury chemistry') now figure as full-fledged specialties, and entire books have been devoted to each. Meanwhile, note that metals occupy the lion's share of the periodic table (say 60%, when computed as 54 out of 92, stopping at uranium). Thus, once the term 'organometallics' is christened, it doesn't just pay lip service belatedly to the crucial role of Mg, Fe, Co, Cu and Mo in various life-forms. It also implicitly opens a window on all 54 metals, i.e., on the whole remainder of the periodic table. Accordingly, even *osmium*, with atomic number 76, now makes regular appearances in the literature; see Miessler, page 506, Hoffmann & Torrence, p. 61-62. In fact, uranium itself is featured in the sandwich compound *uranocene*; see Miessler, page 449.

Especially encouraging is the Biochemical Periodic Table fashioned by Steve Toeniskoetter, Jennifer Dommer and Tony Dodge at University of Minnesota. In their version of the table, they use color-coding to assign the first 102 elements to one of eight categories:

1. Major, essential, all life (CHNOPS)
2. Major anions, all life (there is only one in this category: Cl)
3. Major cations, all life (Na, Mg, K, Ca)
4. Essential, trace, all life (there is only one in this category: Se)

5. Major biological transition metals (V, Mn, Fe, Co, Ni, Cu, Zn, Mo, W)
6. Specialized uses, some life (B, F, Si, As, Sr, Cd, Ba)
7. May be bound, transported, reduced, and/or methylated (this category contains 58 members)
8. Inert or unknown biological function (this residual category contains only 16 members, dominated by the He column)

See umbbd.msi.umn.edu/periodic; accessed 04/19/10.

Together these various developments amount to a tacit admission that the old organic/inorganic dichotomy is too rigid, possibly even blasphemous. What could be 'blasphemous'? Take the premise of CHNOPS as the life elements, and recall the CNO cycle, which serves as catalyst to the processing of H and He inside a stellar energy plant (see page **iii**). Now macroscopic creatures blithely place CHNO at the top of their list of six 'life elements', but a less narcissistic way to look upon those four elements would be to recognize them as the 'stellar elements'. Isn't that their primary role in the cosmos? Only coincidentally do they turn out to be the building blocks for spiders and us in certain dim crevices of the macroscopic limbo. In our attempt to usurp their primary role in the stars, we commit a kind of blasphemy. (Here, admittedly, I am only 'using' the CNO cycle by the logic that 'an enemy of my enemy [CHNOPS] is my ally'. Ultimately, it is still the atom I believe in, not the stars. This was just a side show.)

Meantime, as if by pincer attack along the opposite front, we have the mounting interest in BZ reactions — *self*-organizing reactions of *in*organic chemicals, some of which are dramatic enough to remind one of an organic process. Surprisingly 'chaotic' and/or lifelike, some BZ reactions even *seem* to break the rules of thermodynamics; see the footnote on page **35**, which might be read in conjunction with the following historical note: Early work in the field of mathematical chaos theory was written off by the Establishment first as 'spawned by a bug in your TI calculator design, Dr. Feigenbaum' (mathematicians simply *hated* calculators and computers at first, did you realize?). Later they were admitted as "phenomena that are real (on mainframe computers) but 'mathematical monstrosities' so who cares anyway, Dr. Mandelbrot?" Similarly, BZ reactions met with years of stubborn denial by the Establishment in Russia, Europe and the U.S. This was partly because those who investigated them dared to work so close to the sacred organic/inorganic line, where the impetus for studying them was the insight they might offer into phenomena such as cardiac arrhythmias in human patients; and partly because the Establishment thought BZ reactions could be brushed aside on theoretical grounds anyway, as thermodynamically invalid and therefore impossible, surely just the result of fraud or gross incompetence; see Winfree, p. 161. Today, chaos theory and BZ reactions (which are closely related, incidentally) are both firmly entrenched in their respective ivory towers and growing rapidly, with the blessing of high priests everywhere.

That's nice. But let's step back and look at the broader implications of the BZ reactions, which stand right on the (supposed) border between inorganic and organic: Originally they were developed in the spirit of a mathematical modeling tool, for studying cardiac arrhythmias in humans, as when supercomputers are used to model the weather. But what if the similarities between BZ reactions and biochemistry are real? (For some persuasive examples, see Winfree, pp. 173-186: Rotating Biochemical Waves in Living Media.) In other words, what if the relation between them is 'cognate'? (That's the term a linguistic would use when seemingly related words in different languages are found to be actually related by their genealogy.) This in effect would point to a bridge joining one realm to the other. (Such a direct path leading 'up' from the atomic realm to the macroscopic realm would lend support to the Flimsy Foam Cubed idea to be introduced in **Figure 24**b on page **82**.)

Another bridge topic is Physical Chemistry (or 'P-Chem' in the campus vernacular). If one were to tour the current academic landscape in search of something that might satisfy my need for the atomocentric, P-Chem would be the best candidate: unlike Particle Physics, P-Chem has no obsession to go quark hunting and thus fall prey to **Bottom Turtle Relativism** (page **121** f.); in contrast to O-Chem (and, to an extent, General Chemistry), where the fascination seems to be with big complex molecules, P-Chem might seem at first blush to represent a return to the atom as the primary unit of currency. But ultimately, I do not derive much solace from the existence of P-Chem, and this for the following reasons: It is, after all, a bridge topic, inherently not at the center of anything, and like all of contemporary math and science, it is really just a handmaiden to engineering and technology, an example of 'applied' science. Examples: See the parts of **Chapter V** and **Appendix** C that document the travesty of the *Limit* — a concept that is trashed on a daily basis, often by the very ones who at first make a fetish of the Limit's *sanctity* (which is actually well-deserved; I have no quarrel *there*). In **Appendix I: Myths & Realities**

of Electrochemical 'Flow' (page **429** f.), see the discussion of how the fairy-tale of 'electron flow' almost always wins out over *electron drift*, a complex reality that is perfectly well-known to the grown-ups, as it were, though habitually banished to oblivion in their text books, and never so much as hinted at in a footnote.

As for P-Chem specifically, when translated to plain English, the question it poses and attempts to answer would be: "To make chemistry do our bidding, how much particle physics and quantum mechanics and thermodynamics do we need, minimum?"

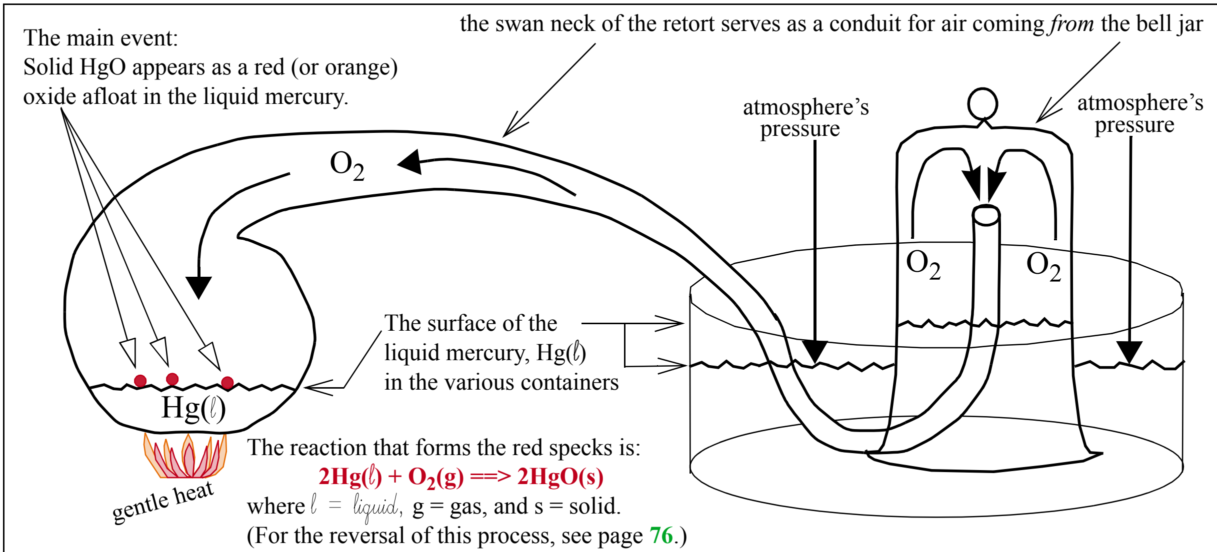
That's not science. That's technology. But the difference is routinely sloughed over by the phrase 'science and technology'. At first sight, the phrase looks innocent enough, but it is one of the primary tools used *by* technology to usurp science: All must bow down before the great American stampede to a toilet bowl swirl that is faster-fresher-bluer (and nicely automated, too, unless a bug in the CdS cell algorithm were to raise its ugly head). And if P-Chem might seem vaguely atomocentric at times (e.g., as sampled so prettily on page **44**), that would be only by happenstance, because that's where practicality leads the engineer in this case, by his/her nose, not because of a coherent ontological viewpoint.

With the deck stacked so heavily against me, what can I, as an erstwhile sinologist, possibly find (in this technical landscape masquerading as science) that might help me further the argument for an atomocentric view? In a word, nothing. What I can offer, though, is an invitation to *look* at that landscape clearly, and to understand the potential chemistry has for providing a *downward* window on the atom, in contrast to its usual assumed role as a gateway leading 'up' to the bigger, better chemistries. Then, assuming the reader might be at least willing to entertain my advocacy for this atomocentric view, I offer the hands-on experiments (and semi-hands-on exercises) for trying to approach the atomic scale and make it real, in particular these two:

- **Avogadro's Number via Electrolysis**, pages **56-70**.
- Twenty Degrees of Separation: an exploration of the Koch snowflake as it pertains to the atomic scale; page **252** f.

Unsung Heroes of the The Twelve Days' Experiment

In the annals of science there are certain experiments that a majority agree are landmarks. One such landmark was Antoine Lavoisier's Twelve Days' Experiment. Consider its early date of 1775,[20] on the tail end of medieval alchemy, still 130 years before the work that would confirm the existence of the Atom to *everyone's* satisfaction;[21] consider its elegance, with its swan-necked retort and gentle combustion of liquid mercury to form mercury calx, as mercuric oxide was then known. It is on this basis easy enough to see why some might elevate the experiment to such a position of prominence, especially since its upshot was the discovery of nitrogen, the naming of both oxygen and nitrogen (then 'mofette' or 'azote'), and a debunking of the phlogiston doctrine in favor of the nascent oxidation theory of combustion.



In this abstract picture of Lavoisier's apparatus, we use notional 'waves' only as a graphical device to indicate where the mercury is in the three vessels: (1) in the bottom of the retort to which gentle heat is applied for twelve days, (2) in the open-air container subject to atmospheric pressure, and (3) inside the bell jar. As the reaction in the retort (formation of HgO) uses up oxygen, air is depleted inside the bell jar. The progress of the air (oxygen and nitrogen) is right-to-left through the apparatus (which will seem odd at first, for going 'against the shape of the retort', as it were). This creates a partial vacuum in the bell jar, which causes the level of the mercury there to rise, as it seeks a new equilibrium point with the atmospheric pressure outside. (I.e., the mercury in the open container and the mercury inside the bell jar are one body of liquid, an aspect of the apparatus that cannot be seen clearly in this graphic.) The formation of HgO stops after 12 days when the oxygen supply is depleted. Hence the name of this famous experiment.

FIGURE 3: Lavoisier's Slow-Motion Demonstration of Combustion

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20. In 1775, Lavoisier gave a summary report (to the academy) on a *series* of repeated experiments, and in 1777 he gave another such report on a related series of experiments. References in the literature to the date when '*the*' famous Twelve Days' Experiment was supposedly *performed* are consequently rather muddled, splitting about fifty-fifty between 1775 and 1777 it seems. Happily, in the current context, the choice of one date over the other is of no consequence; I only note the discrepancy in passing.
21. Einstein's 1905 Brownian movement paper and Einstein's 1905 photon paper.

Now let's step back for a more objective look at the experiment (which I've chosen 'at random', just so we have something interesting to contemplate while considering the general idea I wish to propose): It turns out there are two more characters in the drama besides Antoine Lavoisier himself: there is Time and there is the Atom. A billion years before 1775 or a billion years after 1775, those atoms of mercury and oxygen would have been found doing their very same dance of incredible speed and intricacy, ready at any moment across that vast stretch of time to form HgO, i.e., to exercise certain properties of their orbitals which, in a crude *static* picture,[22] may be represented as shown in **Figure 4**.

22. **Figure 4** is redrawn from a diagram for HgO at http://theochem.chem.rug.nl/publications/PDF/ft540.pdf.
(The letters s, p, d [and f] are vestiges of 19th century spectroscopist's lingo, used nowadays as arbitrary labels, synonymous with $\ell = 0, 1, 2, 3$ = 'the second quantum number'. The subscripts x, y, z refer to the orbitals' relative orientation in three-dimensional space.)

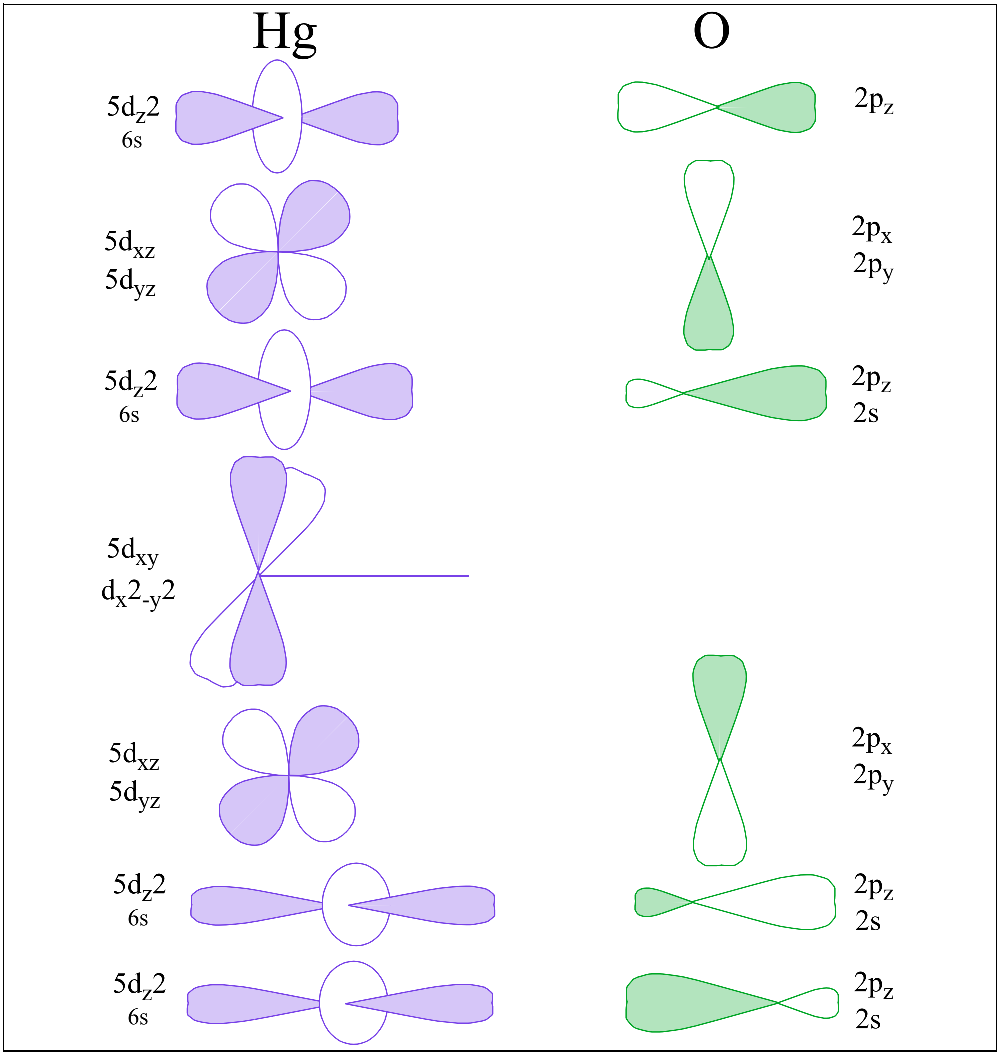

FIGURE 4: Molecular orbital diagram for HgO bonding

Is it so difficult to see the Atom as another kind of 'actor' on the stage, a kind of Being even more remarkable than Lavoisier, our hero? In case the viewpoint I am promoting still seems too fantastic, consider the following 'evidence' that I offer in its support, only semi-facetiously: There is a very particular way that electron shells and orbitals get filled. The rules that govern this process are known by the name *buildup principle* or *Aufbau principle*. Stated baldly, the rules might seem rather arbitrary and technical. But there is a way to easily remember them by imagining them as 'personality' traits of the electron. What follows is an elaboration on an idea that science teachers sometimes use to help their students visualize the rules:

The overriding principle: A given orbital may be occupied by zero, one or a maximum of two electrons. In that context, an electron's nature is to be *lazy*, *private*, and *distinguished*, as follows:

The electron is *lazy* in the sense that it will occupy an orbital in the lowest-energy shell it can find. (This choice is associated with *Bohr's model* and is represented by the primary quantum number, $n = 1, 2, 3...$)

The electron is *private* in the following sense. Rather than become the second and final occupant of an orbital, it would rather find an empty orbital and be the sole occupant of that orbital instead, at least until joined by a second electron. (This is *Hund's rule*, which can be expressed in terms of the second quantum number, $l = 0, 1, 2, 3$, synonymous with *s*, *p*, *d*, *f*; see footnote **22**on page **29**.)

Now for an exception: Just like people, electrons have quirks. To wit: *laziness trumps privacy* in the following sense: Given a situation where an electron must choose between [a] privacy in a higher-energy shell, and [b] lack of privacy in a lower-energy shell, the electron will choose the latter, and gladly share an orbital with a cousin if it means avoiding a higher-energy shell.

Finally, there is the question of being *distinguished*: Just as two princesses at the ball will avoid at any cost the mistake of wearing the same evening gown, whenever two electrons do share a given orbital, then the second electron will adopt a spin value opposite to that of the first. This choice of 'what to wear at the ball' is represented by the 4th quantum number, $\mathbf{m_s} = 1/2$ or $\mathbf{m_s} = -1/2$ (which is notated as a refinement of the third quantum number, $\mathbf{m_l}$, where the number of possible three-dimensional shapes plays out). Reflected in the values of this 4th quantum number is the *Pauli exclusion principle*, a concept so powerful that it extends right down into the province of the nuclear shell model (with its own Magic Numbers; Gamow [1966] pp. 77-78) and even into quarkdom as well.

And since we're talking about the atom here, one might ask: Hey, why chemistry, why *not* physics? Let's begin exploring that question by summarizing the various technical and cultural barriers to entry into these two fields. This tabulation won't reveal much of a contrast (yet), but **Table 2** provides a point of reference, at least, for the ensuing discussion.

TABLE 2: Technical & Cultural Barriers to Entering Physics and Chemistry

<table>
<tr><th>TYPES OF BARRIER</th><th>BASIC PHYSICS</th><th>BASIC CHEMISTRY</th></tr>
<tr><td rowspan="5">COGNITIVE CHALLENGES
(hard science is hard!)</td><td>Scientific notation and SI units (Light speed as ‘186,000 mi/sec’ can be understood, after a fashion, but light speed as ‘2.99 x 10^{10} cm/sec’ is gibberish to the uninitiated.)</td><td>Scientific notation and SI units

(ditto — see Physics column)</td></tr>
<tr><td>Maxwell’s equations: If you want to understand them, you’d better have three years of calculus under your belt already. Then, maybe...</td><td>Photosynthesis: Here, even Schrödinger (1944, pp. 70, 73) and Gamow (1947, p. 230) fall into the unnecessarily weird lingo of ‘negative entropy’. Tricky topic.</td></tr>
<tr><td>Crystal set receiver theory:
This is emphatically not kid stuff; see Appendix H: The Crystal Set Mystique.</td><td>Hybrid orbitals and 3D molecular shapes (see Methane Geometry on page 70, e.g.)</td></tr>
<tr><td>Rotational motion; turbulence; gradients in 3D (vector calculus)</td><td>Setting up ICE tables to study equilibrium concentrations.</td></tr>
<tr><td>Relativity</td><td>Quantum numbers, orbitals and spin</td></tr>
<tr><td rowspan="3">QUALITATIVE ROADBLOCKS
(Something seems silly or geeky or unreal: Here one is tripped up not by technical challenges but by one’s own prejudices and other childhood baggage.)</td><td>Isn’t that just an egghead’s fetish on the white board, that square root of minus one in the schematic of an electrical circuit?</td><td>Connotations of ‘mere’ kitchen chemistry or grade school pastimes with baking soda and vinegar. Kid stuff. (Familiarity breeds contempt.)</td></tr>
<tr><td rowspan="2">“c is too fast to have any meaning on the human scale, isn’t it?” (Here I’m inclined to agree with the rhetorical question of a putative freshman. This becomes part of my rationale for abandoning one’s anthropocentrism.)</td><td>“Avogadro’s Number is too large to mean anything on the human scale.” Not quite true; see page 56f.</td></tr>
<tr><td>The danger of acids, the hazard of ammonia fumes, the all-around nastiness of all things ‘chemical’.</td></tr>
<tr><td rowspan="2">LABORATORY GOTCHAS
and laboratory technique</td><td>The ‘brushes’ on a model electric motor; see Figures 58-60 on pages 208-210. For more gotchas, see also Appendix H: The Crystal Set Mystique.</td><td>The valves on a model heat engine; see discussion of Figure 57 on page 207.</td></tr>
<tr><td>The Wilson cloud chamber as kitchen physics: Its concept is simple elegance, but the troubleshooting list for a homemade cloud chamber is longer than your arm. (But see also footnote 178 on page 480.)</td><td>Thorough drying, requiring the patience of hours not minutes; accurate weighing and accurate observation of titrations.</td></tr>
</table>

TYPES OF BARRIER	BASIC PHYSICS	BASIC CHEMISTRY
EXPENSE BARRIERS	Physicists are notorious for fiddling with broken household appliances (or fiddling with them until they *are* broken), playing with styrofoam cups, turning garden hoses into musical instruments, and so on. All essentially 'free' activities. But to see *why* some very simple and cheap gadgets work, you need expensive diagnostic tools. See **Appendix H: The Crystal Set Mystique**.	To do one of the most *basic* of all experiments regarding the atom (calculation of Avogadro's Number via electrolysis, page **56**f), one might feel compelled to make a significant monetary commitment, say $1,500 on the low end for an analytical balance. (But see page **57** for the rest of this story.)
LACK OF GRADUATED STEPS	Serious problem; see text and **Figure 5** on page **38**.	A problem of only moderate seriousness; see text and **Figure 5** on page **38**.

Too familiar, too alien, too hard, too expensive. Too everything: Small wonder that so few bipeds succeed in communing with the atom, whether it be through physics *or* chemistry!

Picking up where **Table 2** leaves off, with the issue called LACK OF GRADUATED STEPS, let's consider computer programming and music as counterexamples. These are fields that *do* offer graduated steps. In each of them, there is a very low-level entry point that leads smoothly to higher and higher levels of skill and complexity. For instance, in many computer programming languages, one may begin with a statement that looks like this:

```
print ("Hello, world");
```

While it is obviously meant to be whimsical, it is not a toy. Humble though it looks as a 'computer program', that's a genuine *entry point into the field*. Why? Because by modifying and embellishing it in small increments, one can very quickly get a feel for 'what computer programming is all about'. Granted that the work may become fantastically complicated at some later date in one's career. But the point is this: Your path from the entry point to the difficult stuff, should you choose to follow such a path, will be *smooth and continuous*, in computer programming. (For more about programming, see discussion of **Figure 61** on page **213**.)

Similarly, the C-major scale in music is a genuine entry point into the field, not just a toy or a fake beginning to deceive the parents of small children. By doing variations on that scale (e.g., a C-major triad or a major seventh chord or its relative Lydian mode from F to F, all likewise involving only the white keys), one can soon get the flavor of 'what music is all about'. Granted that the material may become tricky later on, as when a conductor looks at low E for the oboe, high D for the bass clarinet and high D for the French horn, and must grok in real time that what will *sound*, vertically, is just a garden variety C-E-G triad with the

French horn on top (after he or she works through the transpositions of down a major ninth for the bass clarinet, written in B-flat, and down a perfect fifth for the French horn, written in F). In the meantime one may have a blizzard of meters such as 7/8 and 3/16 to deal with in real time, horizontally, if the score happens to be Stravinsky's *Rite of Spring*. Yes, it is complex. But again, your path from the entry point to the difficult stuff, should you choose to pursue a career in music, will be *smooth and continuous*.

Meanwhile, in both physics and chemistry, one can point to various 'science fair' or 'kitchen science'-type projects of low-to-moderate difficulty. These may seem roughly analogous to "Hello, world" or the C-major scale, but in my opinion the resemblance is illusory. The illusion is especially cruel in physics, somewhat less so in chemistry. Let's look at a few examples.

As suggested already in the Basic Physics column of **Table 2**, the crystal set is *not* a (true) entry point into the field of electromagnetism. In fact, it is so far from being a comfortable entry point that I've written a separate essay devoted to the myriad dangers in perceiving it mistakenly as such; see **Appendix H: The Crystal Set Mystique**.

Similarly, though a miniature steam engine kit or Stirling engine kit (see page **224** f.) may fascinate a child, it will teach the child almost nothing about its theory of operation. This theory requires an understanding of thermodynamics, the *rudiments* of which appear late in the second semester of freshman chemistry. A miniature engine is just an intriguing gimmick that may *attract* one in a general way to the field; it does not count as a portal *into* the field. That's the crucial distinction I'm trying to draw here.

One may fervently *wish* that the **Cabbage Indicator** (page **49**) were a comfortable bridge to the Vitamin C/Iodine Clock,(23) which in turn might serve as a prelude to understanding the world of *BZ reactions.*(24) However, in reality these different kinds of color-changing reactions are separated from one another by cognitive leaps, and these appear smoothly joined only from a distance.

Similarly, while the **Tomato Battery** (page **55**) is certainly related to **Avogadro's Number via Electrolysis** (page **56**f.), the relation is a distant one, spanning the whole continent, as it were.

Nor is 'H_2O' the entry point into chemistry that the public often assumes it is. To the contrary, H_2O is a very unusual substance, whose peculiarities you can begin to appreciate only *after* you have a whole year of chemistry under your belt. To mention only two of the surprises associated with H_2O: [1] Even the purest of 'pure' water is characterized by a faint background hum of self-ionization activity that puts minute amounts of hydronium and hydroxide ions (H_3O^+ and OH^-) into the mix. This is to the tune of about two ions per billion molecules at any given moment; see **Chemical Poetry: The Secret Life of Water and Other Substances**, page **73**. [2] Water's hydrogen bonds are capable of pulling ions out of crystalline structures in such a way that reactions occur that otherwise would take 1000+ °C to occur.

Before leaving **Table 2**, I should add a few counter-examples with which to modify

23. The reference here is to the fairly impressive figure-8 logic that propels an Iodine Clock or Vitamin C Clock under the hood.
See **Figure 9 (Details of How the Sloppy Clock Ticks)** on page **52**. But the kind of 'liquid chemical clock' referred to in the *next* footnote is a whole different animal: so exotic that the Establishment at first trotted out half a dozen arguments intended to prove its nonexistence.
24. In the context of oscillatory reactions (aka chemical rotors, liquid chemical clocks, self-organizing chemicals), one encounters phrases quite uncharacteristic of Inorganic Chemistry, such as '...*far* from equilibrium', or '...seems to *contradict* known chemical behavior' or '...is *thought* [!] to form hypoiodous acid, HOI' or '...tempting to suggest that the *origin of life* may be related'. For book-length surveys of the subject, from two different perspectives, see the **Literature Cited** entries for Winfree and for Prigogine. For a quicker, on-line glimpse into this world, try googling 'BZ reaction', short for Belousov-Zhabotinsky reaction. ("Belousov undertook to create an inorganic caricature of the citric acid cycle [Krebs cycle] by oxidizing citric acid...with the metallic ions that enzymes commonly carry in their active sites. He chose cerium, giving the solution a faintly yellowish tinge, and...inorganic bromate in a solution of sulfuric acid"; Winfree, p. 160.) For a concise but detailed history of the topic (including the Bray-Liebhafsky and Briggs-Rauscher reactions), see polymer.matscieng.sunysb.edu/OH_handouts/OSCILLATING%20REACTION.doc.

its simple scheme and thus paint a more balanced picture: In physics, it is true that the general public *does* like to say 'E equals $m\,c$ squared' and they do like the sound of 'uncertainty principle' and 'theory of relativity'. To that extent, we may mitigate the QUALITATIVE ROADBLOCKS row for physics. Similarly, people *do* like to say 'H_2O' and they do like to talk about 'energy' and even 'entropy'. Thus we may similarly mitigate the QUALITATIVE ROADBLOCKS row for chemistry, too, in **Table 2**. Also, looking at the row entitled LABORATORY GOTCHAS, we can return to the **Tomato Battery** (page **55**) for a moment and mention that it is just about foolproof, and quite gratifying in its results. This experiment I count as possessing *no* gotcha to disappoint the parent or child. In the physics column, one might cite the crystal set in this category. However, while free of a *technical* gotcha, the crystal set can still prove irksome or even frightening to a parent because of the need for stringing a long antenna and then 'grounding' the whole circuit to a faucet in the kitchen or the bathroom. (Will little Jakey electrocute himself in there or what?) This becomes a psychological gotcha instead of the usual technical gotcha, and *then* comes the far greater difficulty of crystal set theory, already covered. (And if you're thinking cloud chamber or small electric motor, think again: these I've placed in the Laboratory Gotchas row of **Table 2** already, with a cross-reference to the appendix where I discuss the latter in detail.)

Note in passing how a very particular flavor of irony appears repeatedly in these considerations, confusing in its circularity and apparent contradiction:

[a] Upon learning that he might need to put out $1,500 to $3,000 on an analytical balance(25) just to find an *entry-point* into a certain field, one will likely feel that "this is an alien field, one about which I can scarcely get excited or afford to invest any philosophical capital or monetary capital."

[b] BUT, for this particular 'alien field' it is precisely its distance from one's daily life that forms part of the argument for studying it in the first place: the idea that humans are 'too large' relative to the atom (see page **18**), and should therefore *find* ways to bridge the gap down to atomic reality where the action is. Otherwise, risk a kind of Hell or a sense of meaninglessness in one's so-called 'life' up at that higher scale? (Here I am anticipating **Figure 24** on page **82**.)

Learn to recognize this irony in all its forms, and meet it head-on!

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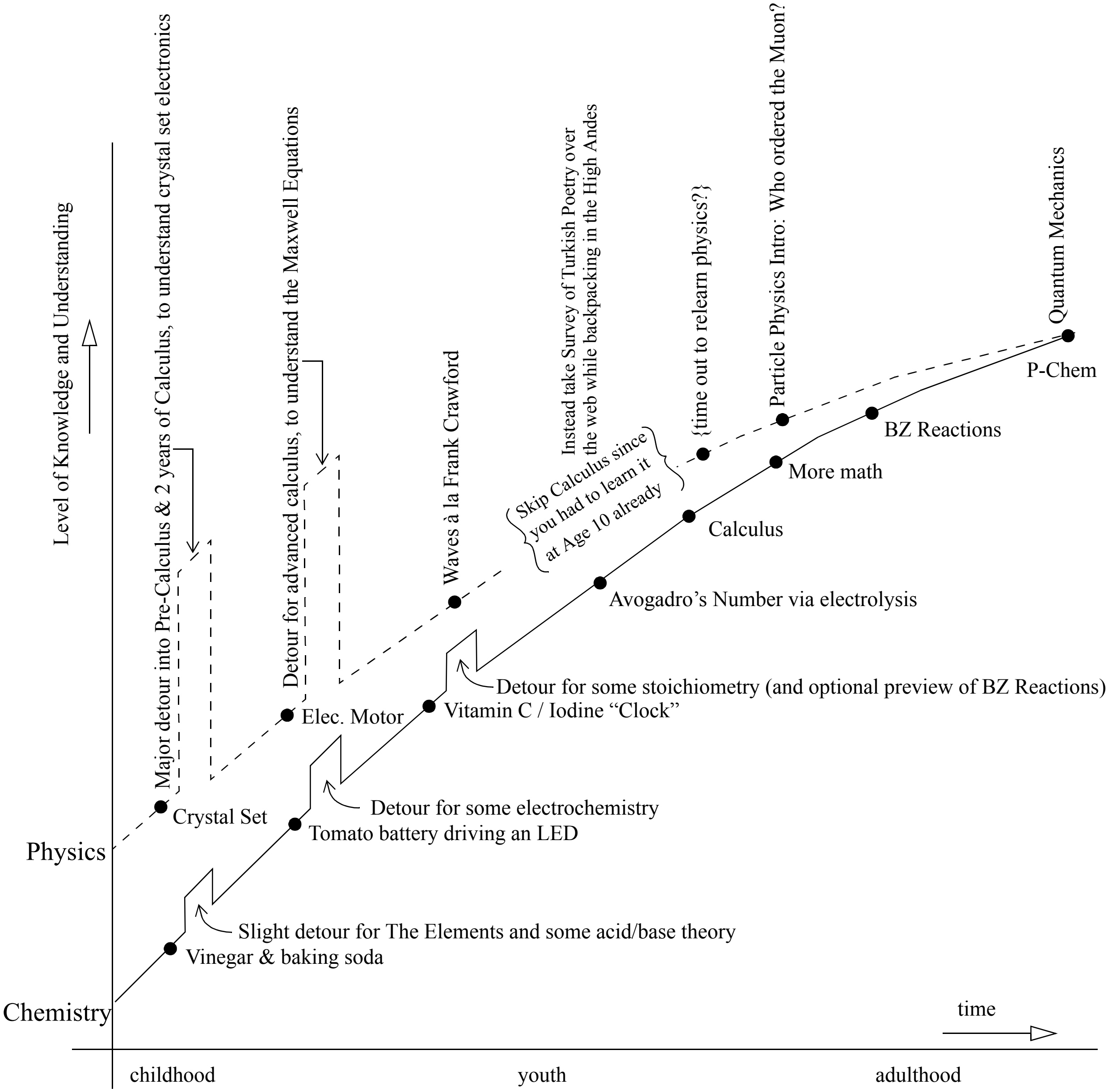
25. I think it would be easy to jump to that conclusion, but see discussion on page **57**.

From **Table 2**, we might conclude that it's a toss-up between physics and chemistry, so far as 'barriers to entry' are concerned. But there is another way to look at these subjects, in terms of their educational paths and milestones, as presented in **Figure 5**, next:



LEGEND

- - - - - Physics path: jerky except for a Wunderkind with money (to hire tutors who can explain Differential Equations to a 10-year old, and to purchase fancy diagnostic tools; see Appendix G for details).

——— Chemistry path: relatively smooth for anyone — rich, poor, clever or dull!

BZ reaction = Belousov-Zhabotinsky reaction, a kind of oscillator that is self-organizing but *in*organic; see page **35**.

Caveat: In reality, the two paths touch more frequently than shown, notably because of electrochemistry and thermodynamics. Here I show only their one BIG rendezvous, where they actually merge at the level of Physical Chemistry (P-Chem) and Quantum Mechanics, and thereafter remain happily married.

FIGURE 5: Why Chemistry, Why Not Physics?

From the standpoint of **Figure 5**, chemistry presents a markedly smoother path than physics. Physics demands extravagant detours (notably into Differential Equations, which means fourth semester calculus, at age 10, if one is to have even the first shadow of an inkling of how that crystal set under the Christmas tree works). Chemistry, on the other hand, holds the potential, at least, for a relatively smooth progression, with only modest detours (with the *option* for longer detours, if one is so inclined). And yet, both paths arrive ultimately at quantum mechanics.(26)

Not only is the chemistry path smoother, but I believe an objective observer(27) must place chemistry at dead center of the whole intellectual panorama, as suggested by **Figure 6**. The graphic is presented here only as a kind of mandala to peruse; in **Chapter III** it will appear again, in its primary role as road map for following detailed arguments that point the way to our 'next Copernican shift'.

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26. As an example of the convergence, consider the following passage in *Group Theory and Chemistry* by David Bishop: "Of much more importance [than the X-ray crystallography connection] is the work of Hermann Weyl (1885-1955) and Eugene Paul Wigner (1902–) who in the late twenties of this century developed the relationship between group theory and quantum mechanics" (Bishop, p. 6). Thus, in its opening chapter, a book ostensibly 'about chemistry' traces its roots directly to the work of two physicists. For more about Wigner, see page **151**.
27. Concerning 'an objective observer': My academic background is in Chinese linguistics, and my vocation is music composition, so I can hardly be painted as one with a vested interest in chemistry.

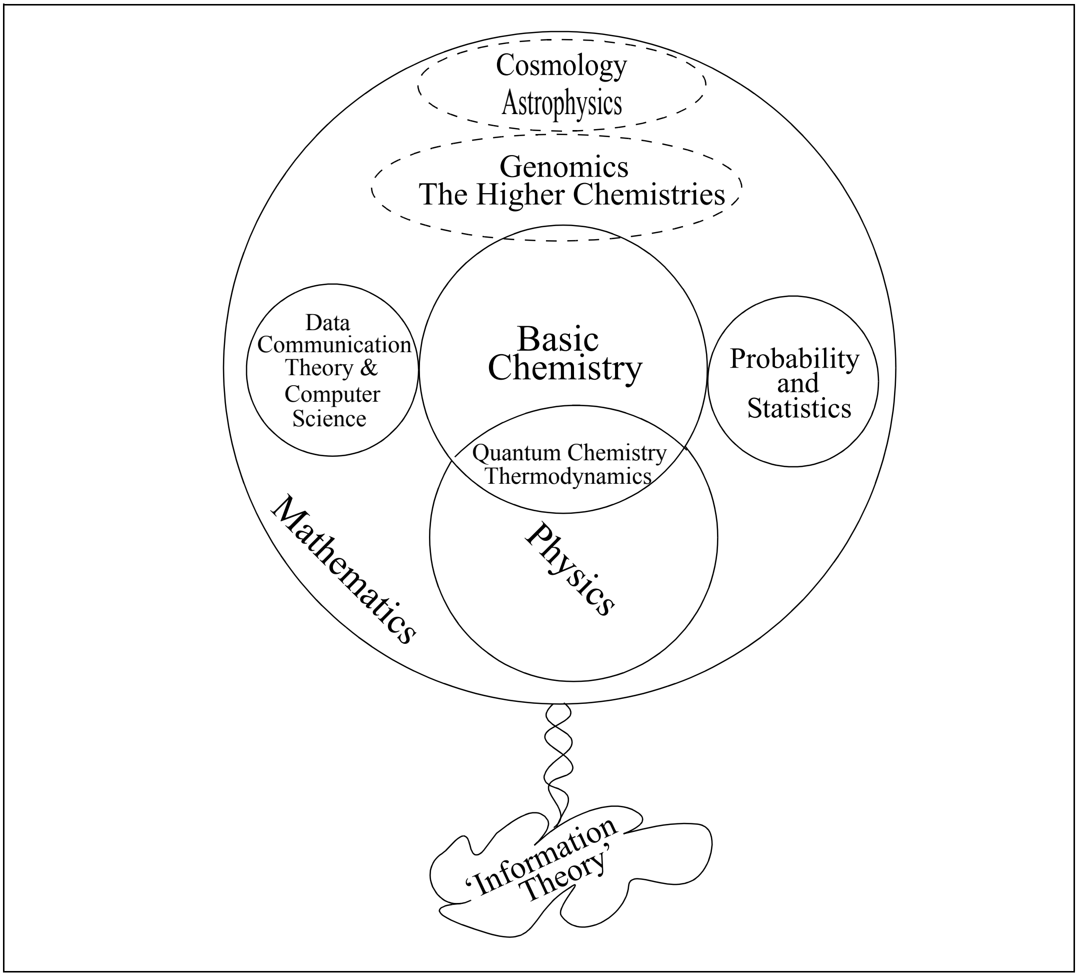


FIGURE 6: The Mandala — a preview of **Figure 29** on page **95**

II Doing Chemistry — from kitchen chemistry to quantum chemistry

This chapter contains some actual chemistry — plenty of 'stuff to do' — just as the title implies. At the same time, it is important to realize that I'm not writing a chemistry text here; rather, my primary goal is to show *what chemistry is* across the whole gamut. Often this will involve 'stuff to do', such as fun with vitamin C (or orange juice) and iodine; but in other cases, I'm presenting chemistry only as a kind of 'spectator sport', as with the discussion of this equation...

$$\int \psi * \psi \, dV = 1$$

...which is meant to give you some of the flavor of a Physical Chemistry class. (This is where the two lines finally meet in the northeast corner of **Figure 5** on page **38**.) I admit that chemistry is not an easy path (only *relatively* easy, in terms of the two paths contrasted in **Figure 5**); however, I advocate chemistry as our 'redeemer' because it happens to be the *only* path that allows one (*sometimes*) to study atomic events 'down below' while keeping one foot in his native macroscopic realm.

But why the qualifier '(*sometimes*)'? This matter of experiencing the connection between the macroscopic realm and atomic realm requires more than just handling materials and manipulating numbers; it relies equally on a huge psychological component. For example, in the water glass experiment, the first one to be presented below, I intend that the experimenter take *everything* on faith: the 18 grams molecular weight of water; its correspondence to 18 milliliters of liquid; the rough correspondence of 18 milliliters to 4 teaspoons; and a rough approximation of Avogadro's number (N_A) as 6 x 10^{23}. *The whole thing is mental*, save for the spooning of water into the glass! With so much simply given by the author, the experimenter might very well feel gypped and impatient for a 'real' experiment, something where one can get his hands dirty and wrestle with some data and computations. Fine. If we peek ahead at the experiment spanning pages **56**-**70**, where N_A itself is estimated with the aid of a multimeter attached to a primitive setup that involves little more than vinegar and a 6V battery, one's first reaction might be the excitement of retracing history by figuring something out from scratch. But upon closer inspection, we see that it is *not* really from scratch: Regardless of which version of the experiment we look at, the author *always* assumes that the student will gladly take *certain pieces* of the puzzle on faith, namely: the atomic weight of copper; the readings on the ammeter (which will likely be part of a multimeter, a proverbial 'black box' whose innards one implicitly trusts); the ionization mode of copper, not to Cu^{+} but to Cu^{2+}(which is true, although the equivalence of current with 'electrons counted' is a white lie, to be explored in due course); and the standard value for charge-per-electron (see **Figure 13** on page **66**). All of that is on faith. Nor is this just a matter of being 'nice to the student' or 'saving the student some distractions'; each of the potential 'distractions' in this case would cost the student months or even years to figure out independently. Thus, the percentage of things 'given' to the participant in this experiment is — objectively — huge, even though subjectively it makes one *feel* 'connected' in ways that the water glass experiment may not (because in this one you get to handle sulfuric acid and watch pure hydrogen bubbling up through its surface).

Again, consider the case where one uses a reaction of sulfamic acid with sodium nitrite to find the molar volume of nitrogen (not represented in this book), i.e, *the* molar volume of *any* gas, which is a constant 22.4 L. This time you really are doing something from scratch; however, the setup of the apparatus involves so much finesse one can easily become lost in the *mechanical* process of making that work, and miss having any emotional connection with the salient *chemical* event: the appearance of water in a beaker, in a volume just equal to that of the N_2 evolved in the Erlenmeyer flask. Depending upon how you *feel* about it, this can be [a] one of the most memorable of all first-year experiments (starting with the enchanted adjective 'sulfamic' and ending with the magic of visible water as proxy for the invisible nitrogen, and confirmation of the lyrically beautiful constant **22.4 L**); or [b] just a matter of fiddling with two heaps of white *powder*, avoiding some pitfalls about flying *stoppers* and fees for broken laboratory *glass*, and waiting for some stupid invisible *gas* to force a cup-and-a-half of *water* into an empty beaker — big deal. That too is a kind of 'reality', though a sad one which the dedicated instructor strives to avoid.

In summary, individual powers of imagination and personal temperament play a crucial role here. Thus, as I conceive it, the term 'doing chemistry' is very broad and flexible, in both the technical and psychological dimensions.

To show just how wide the range of possibilities is, we'll begin with two extreme cases (a kind of Alpha and Omega) before presenting the main body of examples of 'doing chemistry':

Water Glass Experiment

- Tip four teaspoons of water into a glass. (**Figure 7**a)
- On your report, write ‘1 mole of H_2O’

That’s it. But the mini-‘experiment’ above *implies* all the following: Learn/review the wonderful versatility and terseness of chemistry’s ‘overloaded’ notation, whereby ‘H_2O’ doesn’t *just* mean, ‘2 Hydrogen atoms and 1 Oxygen atom’. It can *also* mean ‘2 times the atomic weight of Hydrogen plus 1 times the atomic weight of Oxygen’, *and* it can also mean, implicitly, ‘[1 mole of] H_2O’, depending on its context. We look up the atomic weights for Hydrogen (≈ 1) and for Oxygen (≈ 16) in the Periodic Table (most editions of which contain both atomic numbers and atomic weights; see **Appendix A: The Periodic Table**). Then, by simple arithmetic, H + H +O ≈ 1g + 1g+16g = 18g, which must be the molar mass (m.m.) of water. And where water is concerned, it happens that 18g = 18mL (milliliters), which one can approximate as being about four teaspoons. It is thanks to the atomic weight definition and mole definition working together that we can say with assurance that ‘4 teaspoons of water equal 1 mole of H_2O’. Finally, 1 mole is defined as 6.02×10^{23} of *anything* (e.g., 1 mole daffodils means you’re looking at a field with 6.02×10^{23} daffodils). In this case, then, by measuring out four teaspoons, you have, in effect, counted out 6.02×10^{23} water molecules or, rounded down to a more reasonable degree of precision, let’s say 600,000,000,000,000,000,000,000 H_2O molecules.

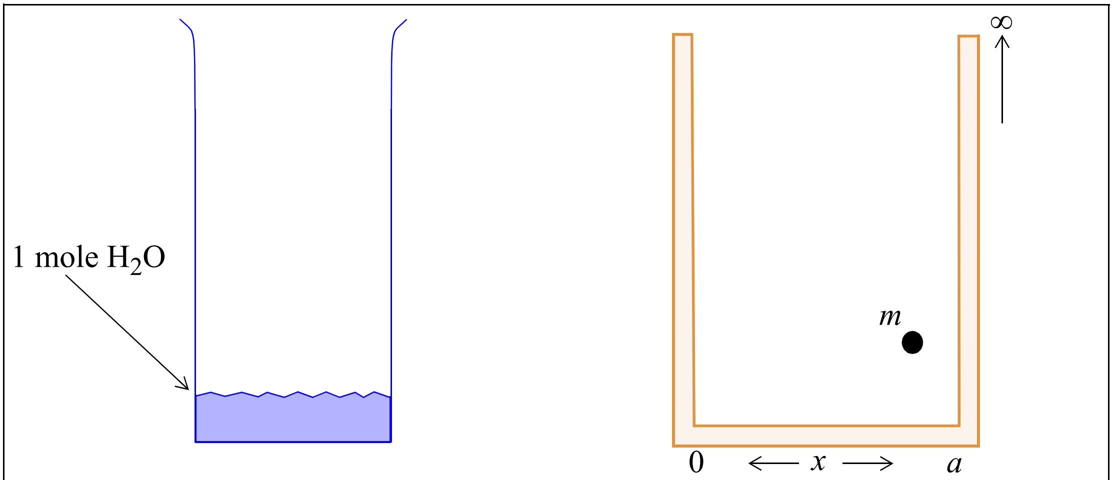


Figure 7a: A glass with four teaspoons of water in it **Figure 7**b: An infinite square well (abstract)

FIGURE 7: A Notion of the Alpha and Omega of Doing Chemistry

Energy Well Calculation

Next, we'll consider a particle having mass m located in a one-dimensional potential-energy well (box) with infinitely high walls[28], as shown in **Figure 7**b.

Given: The wave function describing the system is:

$$\psi_n(x) = K \sin(n\pi x/a) \text{ for } 0 \le x \le a \text{, otherwise } 0$$
where K is a constant and $n = 1, 2, 3, \ldots$

Required: Determine $K^*K = |K|^2$.

(Note: There is no need for you to understand any of this Omega example. In fact, it works best for my purpose if you don't understand it!)

Solution:

The above definition of ψ can be substituted into...

$$\int \psi^* \psi \, dV = 1$$

...which one might recall from the speech balloon for **Figure 2**b on page **13** above. After we've done the substitution for both instances of ψ, the equation looks like

28. This is based on Metz, pp. 282-283, Example 14.4, with some parts excluded and other parts expanded to give the general reader a flavor of the calculation steps, most of which are only implied in Metz.

this:

$$\int (K^* \sin (n\pi x/a))(K \sin (n\pi x/a))\, dx = 1$$

Now, by stages, we move as many items as possible out of the integral, to its left side:

$$K^*K \int \sin^2 (n\pi x/a)\, dx = 1$$

Next use 'w-substitution': Let $w = (n\pi x/a)$, then $dw/dx = n\pi/a$, so $dx = dw/(n\pi/a)$. This allows us to rewrite the integral (and turn the equation around) as follows...

$$1 = K^*K \int (1/(n\pi/a)) \sin^2 w\, dw$$

...and solve it this way, via calculus tables:

$$1 = K^*K\, (a/n\pi)\int \sin^2 w\, dw = K^*K(a/2)$$

Finally, using garden variety algebra: $1 = K^*K(a/2)$, so $K^*K = 2/a$.

Here we've traveled in the space of one page-turn from the kitchen[29] to the realm of quantum mechanics, alias quantum chemistry. (Having arrived at this point, one might find the remarks on page **189** about specifying the state of one raindrop more plausible.) Across the extremely wide range implied by the two examples above, there must be *something* that will have immediate appeal to almost *anyone* on the planet regardless of his/her aptitudes or educational level. That's the take-away.

So much for the extreme cases, my personal notion of the Alpha and Omega. What follows is a representative sampling of chemistry activities that lie closer to the center of the vast range suggested above. Here is a mini-Table of Contents of the ensuing examples:

29. Kitchen Chemistry has at least 3 meanings/connotations: [1] experiments that can be performed at home without expensive lab equipment (but only after stoking the kitchen with some things *not* normally found there!); [2] old-style experience-based chemistry (in the kitchen *or* in the classroom) contrasted with the new computerized chemistry with emphasis on theory; [3] the chemical properties of things found in the average kitchen.

Beethoven's Mother

Problem: Estimate the number of atoms of silver and of gold in Herr Ludwig von Beethoven's mother.

Solution: No, this has nothing to do with crypto-paleo-forensics, with poisoning by arcane methods. Rather, this is a trick question, simply inviting you to consult **Table 1** on page **10** above and note that *any* person weighing 70 kg can be assumed to contain, on average, approximately 0.002 g of silver and 0.0002 g of gold (as trace elements, that is; nothing to do with dental work). For the molar mass of silver (Ag) and of gold (Au), see **Appendix A: The Periodic Table**. Then:

0.002 g of silver divided by 108 g/mole (the molar mass of Ag) = 1.85×10^{-5} mole.

Multiplying 1.85×10^{-5} times 6.022×10^{23} (1 full mole) gives:

1×10^{19} silver atoms in Beethoven's mother

0.0002 g of gold divided by 197 g/mole (the molar mass of Au) = 1.015×10^{-6} mole. Multiplying 1.015×10^{-6} times 6.022×10^{23} (1 full mole) gives:

6×10^{17} gold atoms in Beethoven's mother

Part of the lesson here is to not take *too* lightly the statistics for trace elements such as arsenic, lithium, silver or cobalt. Counted in atoms, these constituents of the body are suddenly of 'astronomical' scope instead of 'negligible'. (But which perspective is 'the Truth'?)

Molar Mass Magic

The substance portrayed in **Figure 8** is hydrated cobalt chloride ($CoCl_2 6H_2O$).

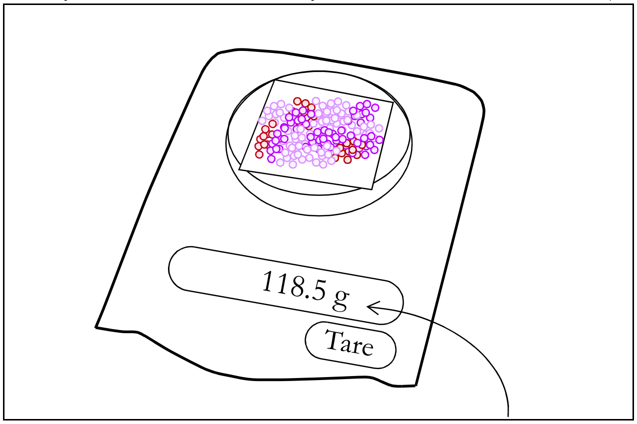


FIGURE 8: The Epiphany: How many *moles* of cobalt chloride are portrayed?

In **Appendix A: The Periodic Table** we can find approximate atomic weights for cobalt, chlorine, hydrogen and oxygen. Then, multiplying by two for Cl_2 and for H_2, and multiplying the H_2O subtotal by six, we find that the molar mass of $CoCl_2•6H_2O$ is 237 grams. Meanwhile, the readout on the scale is about half that amount, so the amount of cobalt chloride shown in the picture must be one half mole or $6.02 \times 10^{23} / 2 \approx 3 \times 10^{23}$ molecules. (We're counting as negligible the weight of the paper on which the powder rests.)

Accordingly, just prefix 1/2 to [$CoCl_2•6H_2O$] (or write ½$CoCl_2(H_2O)_6$) and you're ready to write any number of formulas for reactions involving cobalt chloride. For example, in connection with the chemistry of 'blue silica gel' as desiccant and humidity monitor, the following formula can be found on the web:

$$[CoCl_2•6H_2O] + 6SOCl_2 ==> CoCl_2 + 12HCl(g)\uparrow + 6SO_2$$

In words: Add thionyl chloride (solution) to hydrated cobalt(II) chloride (crystals), and the result will be anhydrous cobalt chloride plus sulfur dioxide, after the hydrogen chloride gas escapes, as suggested by the vertical arrow. (Somewhat counter intuitively, the *hydrated* form of cobalt(II) chloride is pink or violet, while the *an*hydrous form on the right side of the equation is blue.)

Now, knowing that you have 1/2 mole of hydrated cobalt(II) chloride on hand (**Figure 8**), you can 'halve the recipe' just given, to match that quantity as follows...

$$½[CoCl_2•6H_2O] + 3SOCl_2 ==> ½CoCl_2 + 6HCl(g)\uparrow + 3SO_2$$

...and try out the reaction[30] (assuming you also had the 3 moles of thionyl chloride handy).

The above was just a random example. The idea is to extrapolate from it and think about the *general* power of moles that it implies.

Yes, it may seem like so much tedious bookkeeping at first, but sooner or later it will strike you that this little dance of weighing a compound and noting its number of moles is a kind of magic. This will be *the* moment of epiphany in your study of chemistry. On the one hand, the technique is so simple — place a sample on the scales and look up a few atomic weights in a table — and on the other hand so powerful, since the number of moles can be fed directly back into an equation that will predict with great accuracy the behavior of two reactive compounds when mixed together.

A rough analogy: In computer science, the computer is sometimes referred to as an 'anything machine', to remind one of its great versatility — its ability to execute a moon shot navigation program OR a word processor program, for instance, on demand (once the software applications have been written). Here too we have a kind of 'anything machine' consisting only of (i) a table of atomic weights (meaning a periodic table with its standard annotations), (ii) a sheet of paper with a chemical formula written on it, and (iii) measurement scales. Viewed one way, these are primitive tools — a list of the elements, paper, pencil, and a ruler (in one takes the option for using **Understanding Molar Mass as it relates to Avogadro, Cannizzaro, and Loschmidt** as described on pages **61-66**) — but in the chemist's hands this minimalist setup has endless possibilities. It extends the notion of an 'anything machine' into new realms limited only by the imagination.

Counting Moles at the Apothecary

The problem: Without scales, estimate the moles in a bottle of aspirin.

The chemist's name for aspirin is acetylsalicylic acid. Its molecule is represented by $C_6H_4COOCH_3COOH$ or by $C_9H_8O_4$ for short, with all the C's, H's, and O's

30. Expected result: After addition of 3 moles $SOCl_2$ (the thionyl chloride solution), the violet color of the hydrated cobalt(II) chloride should be replaced by the blue of anhydrous cobalt chloride. The reaction is endothermic, dropping the temperature from 21ºC to 5.9ºC over a period of seven minutes. It should be carried out with a protective hood, because of the escaping hydrogen chloride gas. Source: www2.uni-siegen.de; see also Kotz, p. 108.

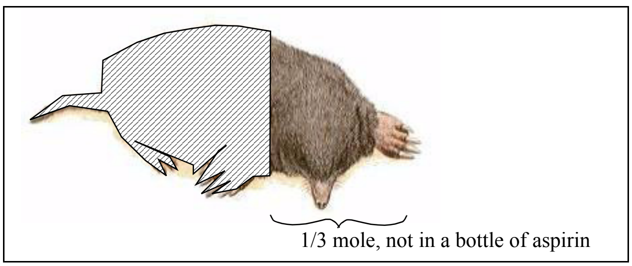
consolidated.

From **Appendix A: The Periodic Table**, we see that the atomic weights for carbon, hydrogen, and oxygen are approximately 12 g, 1 g, and 16 g, respectively. Molar mass arithmetic, based on the above data:

Carbon: 9 x 12 g = 108 g
Hydrogen: 8 x 1 g = 8 g
Oxygen: 4 x 16 g = 64 g
Combined: 108 + 8 + 64 = 180 g

In other words, one mole of $C_9H_8O_4$ weighs 180 g. Meanwhile, from its label we learn that a typical bottle of aspirin contains '200 x 325 mg tablets', which is to say 200 x 0.325 g = 65 g.

Taking 65 g as a fraction of 180 g, we obtain a ratio of 65/180 = 0.36111 ≈ 1/3. So a bottle of aspirin contains 1/3 mole of $C_9H_8O_4$, meaning $6.02 \times 10^{23} / 3 \approx 2 \times 10^{23}$ $C_9H_8O_4$ molecules.

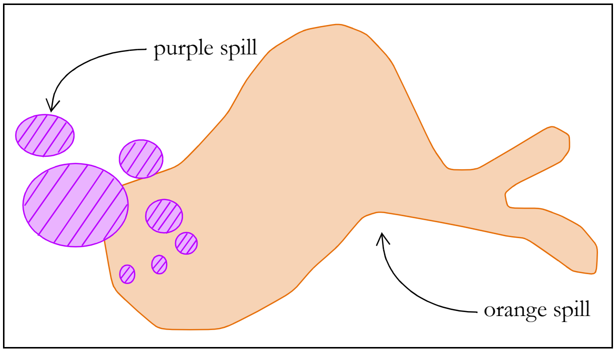


Cabbage Indicator

Tear up one or two leaves of 'red cabbage' (which is actually purple), toss them into a pot of water and warm the mixture up for a few minutes on medium heat. You now have a good quantity of purple juice on hand, suitable for use as an *acid/base indicator*. Pour some out into a pair of juice lasses. To the first glass, add a teaspoon of vinegar, and see the purple shade of the liquid move in the direction of pink or red, indicating the presence of acid. To the second glass, add a teaspoon of household ammonia, and see the purple shade of the liquid move in the direction of green, indicating the presence of a base.

Part of the appeal here is the instant gratification of a 'kitchen chemistry' project; in addition, we have Nature herself commenting, as it were, on the presence of a proton-donor (aka acid) or proton-acceptor (aka base). This makes one aware that while litmus paper may be a contrivance of technicians in lab coats, its *idea* is simply there in Nature. Litmus paper is just a way of standardizing and packaging that idea.

Sloppy Clock



This next experiment contains another kind of color-changing reaction. Usually it goes by the name of Vitamin C Clock or Iodine Clock. Here I call it Sloppy Clock to make it stand out as my 'protest experiment'.

What is there to protest?

Answer: The mixed message in some activities that are billed as (or implied to be) Kitchen Chemistry but whose materials are specified with an inappropriate level of precision, suggesting technocrats in lab coats. After all, a chapter-one concept in every chemistry textbook is this: In choosing the number of decimal places to compute and to show, don't imply more precision than your experimental circumstance can justify (i.e., be careful of Significant Digits). That's the theoretical motivation for Sloppy Clock — a desire to 'tell it like it is' and to adjust the description of the experiment to its expected down-to-earth circumstance: a literal or figurative kitchen. More important, though, is our practical motivation: Always, one wishes to scare off as few people as possible from *doing chemistry*!

This is a good one. Pick a column from **Table 3** below — sloppy version or persnickety version — and try it now!

TABLE 3: Sloppy Clock and Persnickety Clock

MY PREFERRED ‘SLOPPY’ VERSION OF THE VITAMIN C CLOCK EXPERIMENT	A REPRESENTATIVE ‘NORMAL’ VERSION OF THE VITAMIN C CLOCK EXPERIMENT
Materials	**Materials**
two drinking glasses (standard 8 oz. to 10 oz. size) tap water [approximate water levels will be established using the ‘two fingers’ method of mixing drinks] Vitamin C, one 500 mg or 1000 mg tablet hydrogen peroxide (3% H_2O_2) tincture of iodine (2% I_2) liquid laundry starch (e.g., Sta-Flo in blue bottle)	2 - 250 mL beakers distilled water 100 mL graduated cylinder, 25 mL graduated cylinder Vitamin C, one 500 mg tablet hydrogen peroxide (3% H_2O_2) tincture of iodine (2% I_2) starch
Preparatory Step	**Preparatory Step**
Crush the Vitamin C tablet in a plastic baggy; empty the baggy’s contents onto a small saucer; obtain a chopstick or swizzle stick for transferring the powder later from the saucer to a solution where it will be stirred in.	Crush the Vitamin C tablet in a plastic baggy, empty the baggy’s contents into a [third] beaker containing 30 mL of distilled water. Mix. Call this mixture your ‘Vitamin C stock’.
Procedure	**Procedure**
Solution 1 preparation	*Solution 1 preparation*
Pour ‘two fingers’ of tap water into glass 1. Add 1 tablespoon hydrogen peroxide. Add ½ teaspoon liquid laundry starch.	Place 60 mL distilled water in beaker 1. Add 15 mL hydrogen peroxide. Add 2 mL starch.
Solution 2 preparation	*Solution 2 preparation*
Pour ‘two fingers’ of tap water into glass 2. Add 1 teaspoon tincture of iodine. Use a chopstick to transfer about *one fourth* of the pulverized 500 mg tablet into glass 2. (If you used a 1000 mg tablet of Vitamin C, then start by transferring about *one eighth* of the powder instead.) Stir for 15 seconds. Important: We want this solution to lose its dark brown hue of the elemental iodine and *become colorless*. If necessary, add more pulverized Vitamin C *in small increments* until this happens. (The reaction is explained in **Figure 9**.)	Place 60 mL distilled water in beaker 2. Add 5 mL tincture of iodine. Add 3.5 mL Vitamin C stock. “The solution is now colorless.”
The demonstration	*The demonstration*
Randomly pour liquid back and forth between glass 1 and glass 2. After you’ve done this for 1-2 minutes, the liquid in both glasses (and any that happens to be airborne at the moment!) will suddenly go from colorless to blue-black	Add solution 2 to solution 1. It should take approximately 1-2 minutes for the solution to turn blue-black.

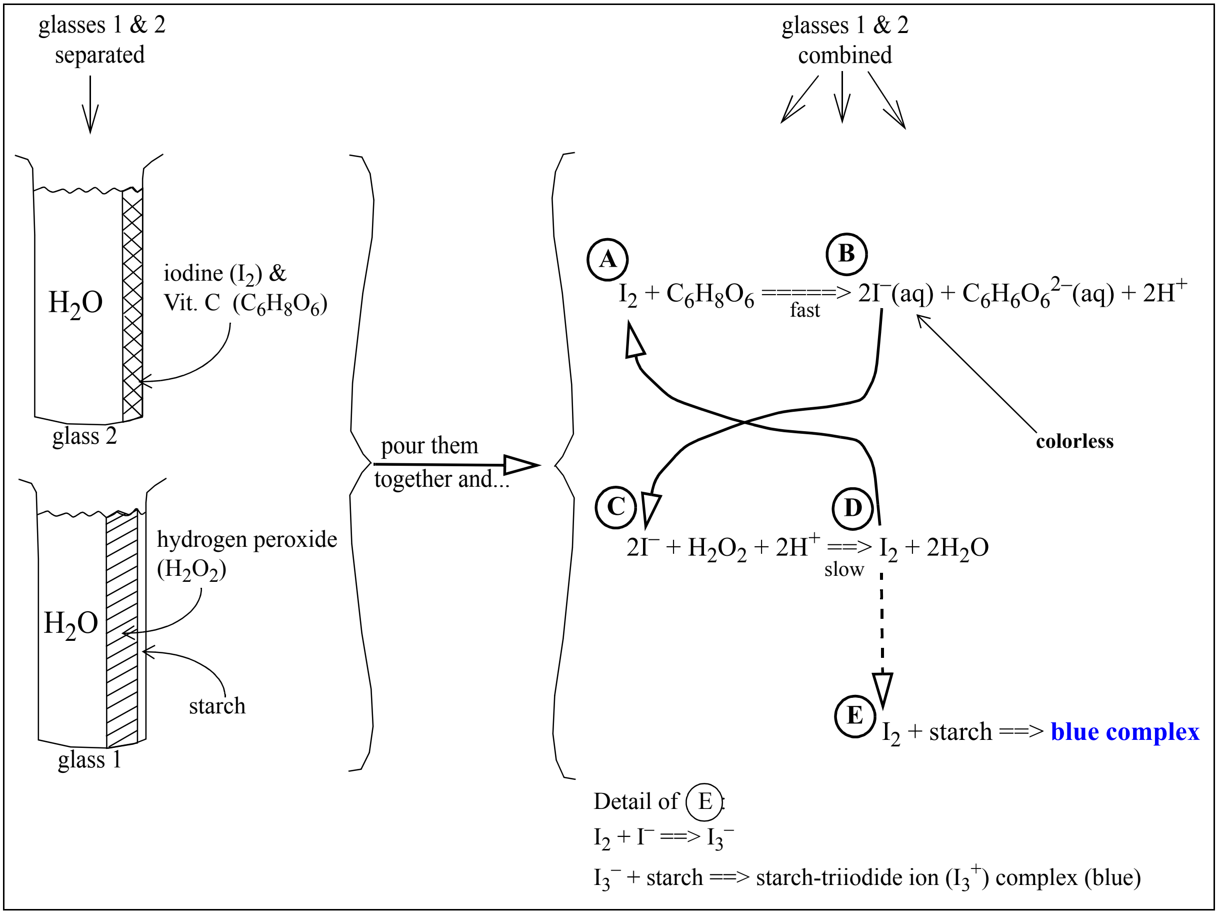


FIGURE 9: Details of How the Sloppy Clock Ticks

Tour of **Figure 9**: In glass 1 (the lower one depicted in the figure) we have both hydrogen peroxide (1 tablespoon) and starch (½ teaspoon) mixed into 'two fingers' of water. These added liquids are not reacting with the water or with one another (at least not strongly, in a way that we care); they're just waiting in the wings. The vertical bands are intended to convey the mixed-but-dormant state that they're in (not drawn to scale).

In glass 2, the elemental iodine (I_2) in the tincture *is* reactive with the Vitamin C already, so I've used a slightly different graphical device (cross-hatching) to represent this state. In **Table 3**, the 'sloppy' version of 'Solution 2 preparation' indicates a mini-experiment to perform before the main event: There has to be *enough* Vitamin C present so that the I^- can overwhelm the I_2 and turn the solution in glass 2 from dark brown (I_2) to colorless (I^-) *before* the experiment proper begins. Conversely, one must avoid the temptation to dump Vitamin C in indiscriminately to achieve this, because then the (main) reaction (The Demonstration in **Table 3**) might take as much as 10 or 15 minutes to occur instead of the desired 1-2 minutes. This is where the 'sloppiness' of our method catches up with us and forces a compensatory step to make our version, ultimately, as good as the persnickety version, where one author asserts smugly, "The solution is now colorless." (In passing, note that our mini-experiment on the side, in the 'sloppy' column of **Table 3**, amounts to an introduction to the concept of titration, sans fancy laboratory glass.)

Turning to the right-hand side of **Figure 9**, note that the **(A)==>(B)** part of the 'combined' picture is *already* going on in glass 2 even when the two glasses are still separated. Then, after the solutions are combined, the **(A)==>(B)** reaction is *reinforced* by feedback around the figure-eight path labeled **ABCD**. As soon as you start pouring glasses 1 and 2 back and forth into one another, the hydrogen peroxide comes into play, and the section labeled **(C)** springs to life. Here, iodide ions from **(B)** react with hydrogen peroxide (H_2O_2) to form elemental iodine (I_2) anew at **(D)**. But this I_2 is immediately absorbed into the original fast reaction with Vitamin C at **(A)**. This in turn generates more iodide ion (I^-), which keeps the overall hue of the solution(s) colorless...until all of the Vitamin C has been consumed, and then the **ABCD** cycle stops. At this juncture, some I_2 remains, however, as a product of the slow reaction, and *this* I_2 at **(E)** is what reacts, finally, with the starch, to turn the solution suddenly blue-black.

The reason for pouring the solution back and forth between glasses 1 and 2 is partly theatrical: when **(E)** arrives, it arrives on the instant, adding color to the liquid in both glasses simultaneously, and to any liquid that is airborne at the moment. That's the drama, but it is also educational, making one realize the all-of-sudden-everywhere nature of the reaction. (And, in a rather loose analogy, this is the 'tick' of the clock alluded to in the experiment's conventional names: Vitamin C Clock or Iodine Clock.)

Variations on the theme: In lieu of Vitamin C one may use orange juice. In this case, don't bother putting water in glass 2. Just fill the glass half full with orange juice and add the tincture of iodine. Then comes the mini-experiment (titration) in this form: If necessary, stir in more orange juice in small increments until the solution turns yellow instead of dark brown. Then proceed as before. Why use orange juice instead of Vitamin C? The gimmick is to obtain Halloween Colors (sort-of: yellow = orange, blue-black = black). But there is a drawback: the color change may be stretched out over a 10-second interval rather than occurring instantaneously as in the Vitamin C version. That's anticlimactic. But if one's heart is set on Halloween

Colors, there's another way: try the mercuric chloride ($HgCl_2$) version of the experiment, which one can google as 'mercuric chloride clock' or 'Halloween colors clock reaction'. I suspect this one is free of the timing problem I observed in the orange juice variant given above.

Summary: Not only have I given you an improved version of the physical experiment (in the left-hand column of the table above), but I've also provided a technical explanation which is much better, in quantity and quality, than many you will find elsewhere, where the tendency is to reveal only random bits and pieces of the mosaic, as driven by the author's convenience or the author's special agenda. For more about color-changing reactions, including reversible color changes (oscillatory reactions), see page **35**, especially the footnotes.

Elemental Iron for Breakfast

Crush a sample of Wheaties® flakes in one Ziploc® bag, and crush a sample of Total® flakes in a second Ziploc bag. Pour the pulverized flakes out and see if you can collect the iron in them with a strong magnet. The surprise here is that unadorned, elemental iron is just 'sitting there' in certain breakfast cereals, ready to be eaten as is. It is not locked up in some fancy chemical compound that would make it seem more like proper 'food' (more like the iron content of blackstrap molasses, for example). But this experiment works only with certain brands, notably Total. In other brands of cereal, the iron content may be too slight to detect this way.

Tomato Battery

This one perhaps becomes irksome from overexposure, but I assume it is popular for a reason: the experiment is simple and foolproof, and it provides some thought-provoking fun. You take 3 tomatoes, pierce each one with a pair of metal strips, say copper and zinc. Use alligator clips to connect the electrodes (the metal strips) in series, and presto, you have an actual battery that can illuminate, say, a 2 volt LED (available in various colors at Radio Shack for a modest price) or cause the needle to move on a homemade galvanometer (= a wire wrapped around a hiking compass).

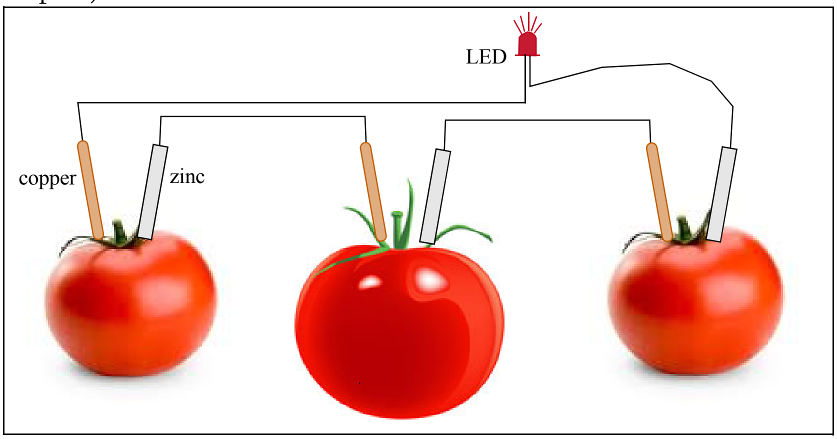


FIGURE 10: Tomato Battery with Red LED

Or, going a bit crazy with the idea, if you took 9 tomatoes and hooked them up in series, the output should be about (2.25 * 3 =) 6.75 V, enough to drive a 'tuna tin motor', the description of which starts on page **208** in **Appendix B: Heat Engines and the Cycle-Design Gotcha**. (Both the 3-tomato battery driving an LED and the tuna tin motor driven by a commercial 6 V lantern battery I can vouch for, but I'll admit I've never seen the combination deal, where the motor is driven by a 9 tomato battery. It would be a hoot, though.)

The tomato battery (an example of a galvanic cell) works nicely as a quick introduction to the next item, an electrolytic cell, put to a special use. It will involve hard work, but it should be rewarding, as it goes right to the heart of the main topic of this book: forming a personal visceral *connection* with the atomic realm.

Avogadro’s Number via Electrolysis

[This I call my ‘carat scale’ version of the experiment. For a different approach, see **Appendix J: Avogadro Again - Sequin Scale Version**.]

If you google ‘electrolysis Avogadro’ you will find a number of experiments whose purpose is to rediscover Avogadro’s number from scratch (or rather to develop it anew by counting coulombs and grams, which is *not* really ‘from scratch’, as remarked earlier, on page **41**). The experiments are surprisingly diverse, some based on anode mass loss, some on cathode mass gain, others on the quantity of hydrogen gas bubbled. Some make it sound as though the procedure can’t be done unless you place a variable resistor in the circuit. One version involves two separate beakers, with an ammeter completing the circuit between them. Yet another involves temporarily switching the anode and cathode to help prevent ‘hairiness’ in the zinc that will plate out later and need to be weighed.

Ours will be one of the *simplest* possible implementations, with *no* such headaches to distract us! Partly our impetus is the minimalist ethos itself; partly we are motivated by the ‘significant figures’ concept which, in lay terms means, “we’re *not* aspiring to extremely fine-grained measurements, so let’s downgrade the design of the experiment accordingly, to match that general plan.” Before the formal Materials List, here is a quick preview of the apparatus we’ll use:

A battery. A beaker. A pair of copper strips. A multimeter. A wire with two alligator clips.

That’s it. Deliciously minimal,(31) considering the big theoretical bang to be delivered shortly by the overall experiment.

31. One might imagine that an even simpler approach would be some variation on ‘copper plating with pennies’, seen sometimes at science fairs, or one of the methods used by hobbyists to do electroplating (e.g., of copper onto a car key or onto a quarter). But in that realm, the focus is always on the quality/durability/appearance of the deposit at the cathode, or worrying that “a voltage higher than 3V might ‘burn’ something,” and so on. Whereas all we care about here is a way to *quantify depletion* of the anode metal (and a way to quantify the current as it passes through for x seconds).

Materials List

- White vinegar, 100 mL[32]
- Salt, 1 teaspoon
- Hydrogen peroxide, 1 teaspoon (that's H_2O_2, available at the pharmacy)
- Direct current source: I recommend a 6V lantern battery because alligator clips can be easily attached to the spring nipples on such — no battery holder or special cable required to hook it up. (By the way, voltage is often left *un*specified in this kind of experiment, since it's all about amperage.)
- One piece of insulated wire with an alligator clip on either end
- Two strips of copper
- One 250-mL beaker
- Multimeter, preferably the kind with a built-in alligator clip at the end of each lead[33]
- Wrist watch or wall clock for counting minutes. (True, you'll do a gross conversion of your minutes *into* seconds later on, but you don't need a stopwatch to *count* seconds.)
- Scales (for measuring metal mass loss)
  I recommend a *carat scale*, the kind used for jewelry making or for do-it-yourself gun powder, etc. These are readily available for about the price of a modest meal for two. They are sold in both digital and mechanical form, typically with resolution down to 0.05 carat, which is to say 10 mg or 0.01 g. (Our objective here is to 'make atoms real' by building a bridge between the macroscopic realm and atomic realm.[34] Given the very large and very small numbers involved, one could easily jump to the conclusion that he must have on hand an *analytical balance*, the kind seen in the chemistry lab at school, with a price tag somewhere between $1,500 and $3,000. But as we shall see, it is possible to come surprisingly

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32. There is no magic in the quantities '100 mL, 1 tsp, and 1 tsp'. These are simply the ones I tried at random the first time, and they worked to my satisfaction. Next time, some other ingredients/proportions might work even better. (Hydrogen peroxide is said to be a strong oxidizing agent, and since it is also 'a household item', I added some. But whether it actually accelerated the process here I don't know.)
33. Comment: What you're buying (or rummaging for in the closet or garage) is a garden-variety *multimeter* for checking voltage and amperage. In **Figure 11**, we represent this component in the circuit by a boxed 'M' for multimeter. Conventionally, you'll see this represented by a circled 'A' for ammeter. I disagree with that notation convention; one doesn't go shopping for an ammeter, rather for a multimeter that includes ammeter functionality. Outside of a do-it-yourself physics lab, one is not likely to see a literal 'ammeter'.
34. In this connection, see also Koch's Snowflake and the Koch Machine Thought Experiment, starting with **Figure 75** on page **253** in the **Twenty Degrees of Separation** section of **Appendix C: Gabriel's Horn for Eternity, not to Infinity**.

close to N_A without bringing in such heavy artillery for the job.)

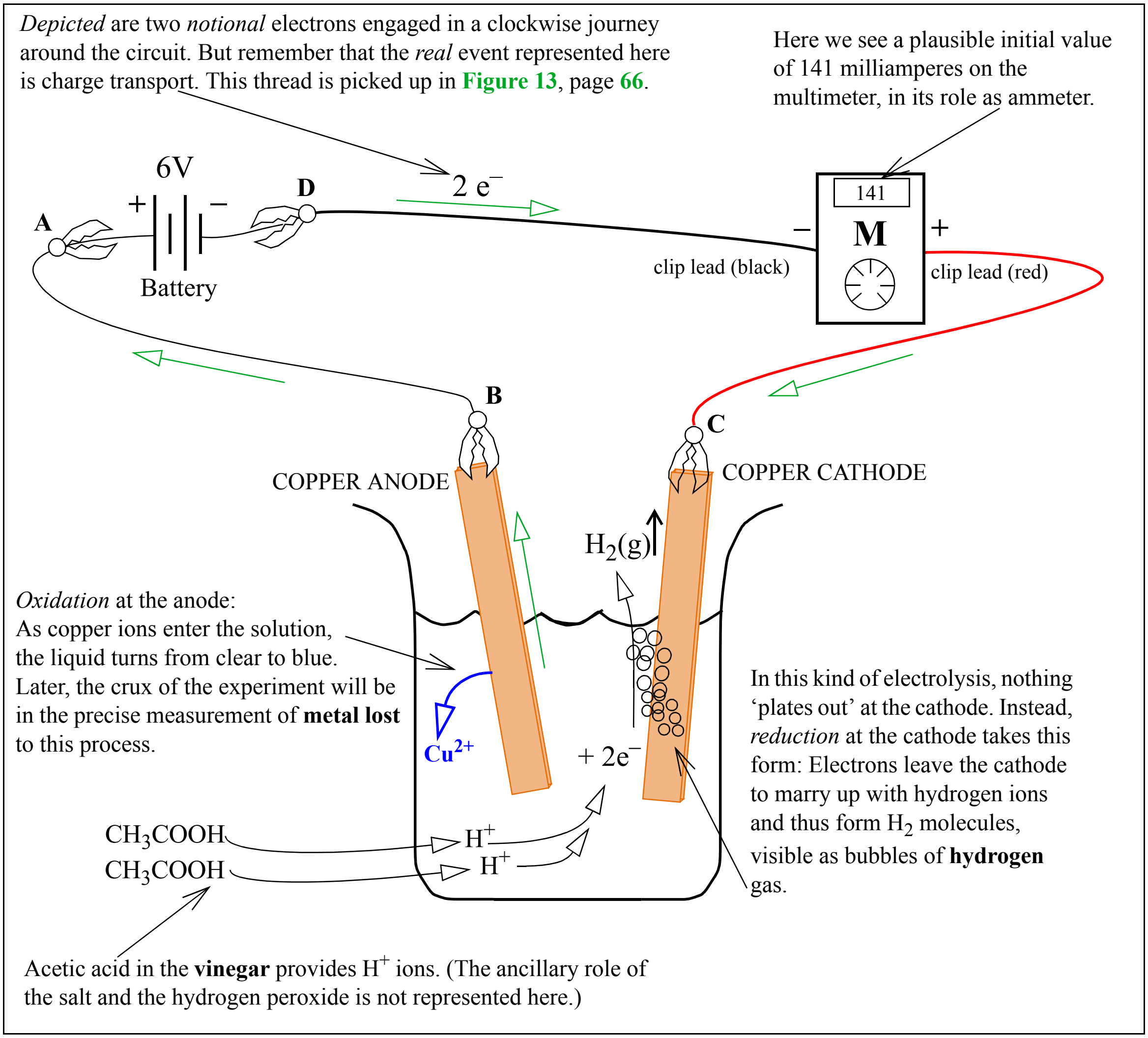


FIGURE 11: Apparatus for Estimating Avogadro's Number in the Kitchen

Procedure

Pour vinegar into the 250-mL beaker, to the 100 mL mark, approximately.

Add 1 teaspoon of table salt and stir

Add 1 teaspoon of hydrogen peroxide and stir

Clean the copper strips using rubbing alcohol (preceded by use of light sand paper if necessary, depending on the condition of the copper).

Weigh one of the strips to the nearest one hundredth of a gram. This copper strip is the one that will be the anode (see **Figure 11**).

Attach alligator clip A to the positive terminal of your power source, as indicated in **Figure 11**. At the other end of that wire, attach alligator clip B to the copper strip that you weighed.

Immerse this copper strip in the beaker.

To the other copper strip, attach the positive lead[35] from the multimeter (probably red), using its built-in alligator clip, labeled C. Immerse this second copper strip in the beaker. Take care that the two copper strips do not touch one another.

Prepare a table for recording times and ammeter (multimeter) readings.
Since this version of the apparatus is built without a variable resistor to control (smooth out) the amperage, we must cope somehow with varying amperage during the experiment (for which I recommend a run of 30 minutes). The workaround is to record sample values along the way and later average them. Here is one of many possible approaches that should work: For every three-minute period, jot down a rough, impressionistic average of the half-dozen values you've seen on the display during those three minutes. Then, when you're finished, take the arithmetical mean of the ten or eleven values you've written down for the 30-minute run.
(For example, here are the milliamp readings from my first run of the experiment, summed and divided by eleven to obtain a crude estimate of average current:
$141 + 160 + 175 + 190 + 220 + 245 + 275 + 280 + 270 + 175 + 100 / 11 = 203$ mA or 0.203 A.)

Complete the electrical circuit by attaching the negative lead from the multimeter (probably black) to the negative terminal of the battery (at D in **Figure 11**), and switching on the multimeter box. (The completed apparatus will be reminiscent of **Figure 10** locally, and also **Figure 114** on page **431** in **Appendix I: Myths & Realities of Electrochemical 'Flow'**. However, relative to those figures, the logic is turned around: Here the cell is being driven *by* an external battery, whereas in **Figure 114** the cell [or rather the pair of half-cells] *is* the battery, driving some external device such as a light bulb.)

At the conclusion of the 30-minute run, disconnect the battery and remove the anode (the copper strip depicted on the left in **Figure 11**). Carefully detach its alligator clip. Rinse the anode by dipping it in some rubbing alcohol. With a soft cloth, rub as hard as necessary to

35. If it is not clear which is the positive lead and which the negative on your multimeter, don't worry about it. Even if you attach the leads 'backwards' it just means the number on the display will have a minus sign prefixed to it. Ignore the sign and treat the displayed number as positive amperage. No harm done.

remove any white crust from the surface of the copper. Note that beneath the white crust, the copper itself will be discolored (darkened), where loss has occurred; don't try to alter that aspect.

Re-weigh the anode to see how much mass was lost.

That takes care of the data collection phase, but before using the data to 'rediscover' N_A, I propose that we take a longish detour into the history and theory of *molar mass*. Why in the world would *that* be necessary? Because the basic idea of molar mass has had some 200 years to drift off course. Such random drifting, gemination and morphing (followed sometimes by ossification at the worst possible moment) occurs in the terminology of all fields and may be considered perfectly 'normal', if troublesome. But in this particular case it would be especially worthwhile stopping to attempt some course correction,[36] given the crucial role of molar mass and N_A, at the very heart and soul of chemistry. The problem is subtle, though: It's not quite that we have a set of 'mistakes' to work through and correct.[37] Rather, consider the redshifted light from a distant galaxy (or the 'bent' sound of a train's horn, due to the Doppler effect). Such redness can hardly be attributed to the sender's having 'lied', and neither does it result from the mistaken perception of a receiver; nevertheless, it can still deceive the unwary.

36. For another such effort, see Stephen DeMeo's 2006 article in *J. Chem. Educ.*, whose Abstract reads: "It is often confusing for introductory chemistry students to differentiate between molar mass, atomic mass, and mass number as well as to conceptually understand these ideas beyond a surface level. One way to improve understanding is to *integrate the concepts, articulate their relationships, and present them in a meaningful sequence.* The integrated conception, what is described as the 'atomic mass conception', involves the description and sequencing of these three concepts based upon IUPAC terminology and findings from educational researchers. The sequencing and detail of these concepts run counter to how these three ideas are presented in popular textbooks." (italics added) I have not read the article itself, but it appears that Professor DeMeo and I have similar motivations.

37. For details, please refer to **Appendix I: Myths & Realities of Electrochemical 'Flow'**, starting on page **429**.

Understanding Molar Mass as it relates to Avogadro, Cannizzaro, and Loschmidt

(...*and* **Maxwell**, one should add, but that might look funny if introduced too soon, only cluttering up the heading; hence the usual triumvirate to start, already confusing enough on its own)

My presentation of molar mass and Avogadro's number (N_A) will be aimed toward your complete understanding of the idea, not just 'how to get the answer'. Consequently, it will look different from presentations you may have seen elsewhere. Some authors tell us that 'Avogadro's number' is actually Loschmidt's number, discovered after Avogadro's death in a foreign land. That's a nice gesture, but it only scratches the surface of the real story (and perpetuates some half-truths). To actually understand this topic you need to know about Stanislao Cannizzaro, whose most important work falls in–between that of Avogadro and that of Loschmidt. See the Technical Sidebar below, so named because it looks like a collection of *biographical* sketches but is in fact crucial to one's understanding of the *technical* details to follow:

Technical Sidebar on Avogadro, Cannizzaro, and Loschmidt

- In ***1811,*** Amadeo **Avogadro** (1776-1856) developed a hypothesis (now known as Avogadro's *hypothesis*): equal volumes of gases contain the same number of molecules.
- In ***1858***, Stanislao **Cannizzaro** (1826-1910) established the atomic weight scale; this in turn allows the calculation of Gram Atomic Mass, alias molar mass, from an (annotated) periodic table, the bread and butter of modern chemistry.
- In ***1865***, Josef **Loschmidt** (1821-1895) made calculations of molecular size. This in turn allowed Maxwell, Kelvin and Perrin to start giving reasonable estimates of N_A (Avogadro's number, which is called Loschmidt's number in German-speaking countries).

Note that in *both* the Italian and German cases the assignment of the name is *honorary*, not literal: contrary to entrenched scholarly myth and popular belief, it was *neither* Avogadro *nor* Loschmidt who first estimated the number known as N_A (6.02×10^{23}). Rather, **Maxwell** did it: In **1873**, building on the work of Avogadro, Cannizzaro and Loschmidt, Maxwell estimated N_A to be 4.3×10^{23}.
I mention this as a 'public service'. If you become interested in the earliest estimates, you need to know that Loschmidt did not author one of them. So don't go wasting hours hunting for a crumb of information about 'Loschmidt's estimate', as it doesn't exist! For more on this subject, see the list of values on page **69**.

It is thanks to Cannizzaro[38] that we can perform the kind of arithmetic shown above in the **Water Glass Experiment**, in **Molar Mass Magic**, and in **Counting Moles at the Apothecary**. When one speaks of molar mass in such contexts, it is implicitly the *pre*-Loschmidt meaning of mole that is relevant. And somewhere along the way one must come to realize that molar mass is a very broad term, encompassing three specific

---

38. For understanding the role played by Stanislao Cannizzaro, I rely on Langford & Beebe, pp. 28-31. Also, on Cannizzaro's own 'Sunto di un corso di Filosofia chimica'; see Literature Cited.

extensions of the general idea of *relative* atomic mass:

(1) Gram Atomic Mass (**GAM**), alias 'gram weight' alias 'atomic weight'[(39)]:
This is the relative atomic mass of an element, 'converted' to grams by appending the letter 'g'. E.g., the relative atomic weight of Cu is '63' (<== with no units); the GAM of Cu is '63 g'.

(2) Gram Molecular Mass (**GMM**), alias 'gram molecular weight' alias 'molecular weight':
This is the sum of the *amu* of the elements of a compound, 'converted' to grams by appending the letter 'g'. E.g., the *amu* sum for CO_2 is 12 + (2*16) = '44'; the GMM is '44 g'.

(3) Gram Formula Mass (**GFM**), alias 'gram formula weight':
This is the sum of the atomic masses of an ionic compound, 'converted' to grams by appending the letter 'g'. E.g., the GFM of NaCl is 23 + 35 = '58 g'.

Numerically, this is all kid stuff — just read values from the periodic table and multiply and/or add them as needed. But conceptually, the ideas are slippery. The definitions above represent the *Cannizzaro* state of the art (1858). Only *after* Loschmidt (1865) can we say...

GAM[(40)] *also* means the mass of *one mole* of any element, aka its *molar mass.*
GMM *also* means the mass of *one mole* of any molecular compound, aka its *molar mass.*
GFM *also* means the mass of *one mole* of an ionic compound, aka its *molar mass.*

...because only then do we know 'what a mole is'! Only then do we begin to have some plausible values for the number N_A (by whatever name) that was always assumed but unknown before Loschmidt (as estimated by Maxwell and by Kelvin and by Perrin, but not by Loschmidt himself).

Here are the two *basic* definitions of 'mole' (with variants to follow):

39. The term 'atomic weight' is a popular misnomer for 'atomic mass' (Kotz, p. 57). In items (1), (2), (3), I've tried to buck that trend a bit by playing down the synonyms that include 'weight' and highlighting those that use the word 'mass'. (The word 'weight' can become messy and problematic in a technical context because it alludes to mass *in the presence* of a gravitational force, often a moot point but...) Yet another synonym is 'mass number'.
40. **GAM** is the important one to know. **GMM** and **GFM** are going along for the ride. I included the latter two only for the sake of completeness.

Definition 1: a mole of gold is one Gram Atomic Mass (**GAM**) of gold.

(This definition can be obtained by reading the GAM line backwards, so to say.)

Definition 2: a mole of gold is N_A atoms of gold, where $N_A = 6.022 \times 10^{23}$.

But for each of the two definitions above there is a twist. In connection with *Definition 1*, it's not always a whole GAM that is meant: 'moles' can also allude to *fractional* moles (e.g., '0.23 moles of gold' shortened to 'moles of gold'). Also, *Definition 1* can easily induce circularity into the reasoning, or at least a disturbing *appearance* of circularity; see **Figure 15**. And in the case of *Definition 2*, the speaker/author might be counting some object other than atoms, such as electrons or water molecules. This definition, then, is the one that teachers sometimes analogize with 'a dozen', as in: "How many dozens of butterflies are there in a mole of butterflies?" At the end of the day, it's just a *number*, albeit an exotically huge number, keyed *arbitrarily* to a certain quantity of carbon on the scales. (I.e., it contains no 'magic'; it's only a tool.)

Here is a text book author who (atypically, I think) highlights the fact that two definitions exist, rather than leaving the student to puzzle this out over the course of several chapters:

> One mole of an element is *both* one atomic weight of an element *and* one Avogadro's number of atoms of an element.
>
> — Carroll, p.126 (italics added)

That covers both the GAM definition (as 'atomic weight') and the N_A definition, in one fell swoop. But the following are more representative of what one will likely find in a text book:

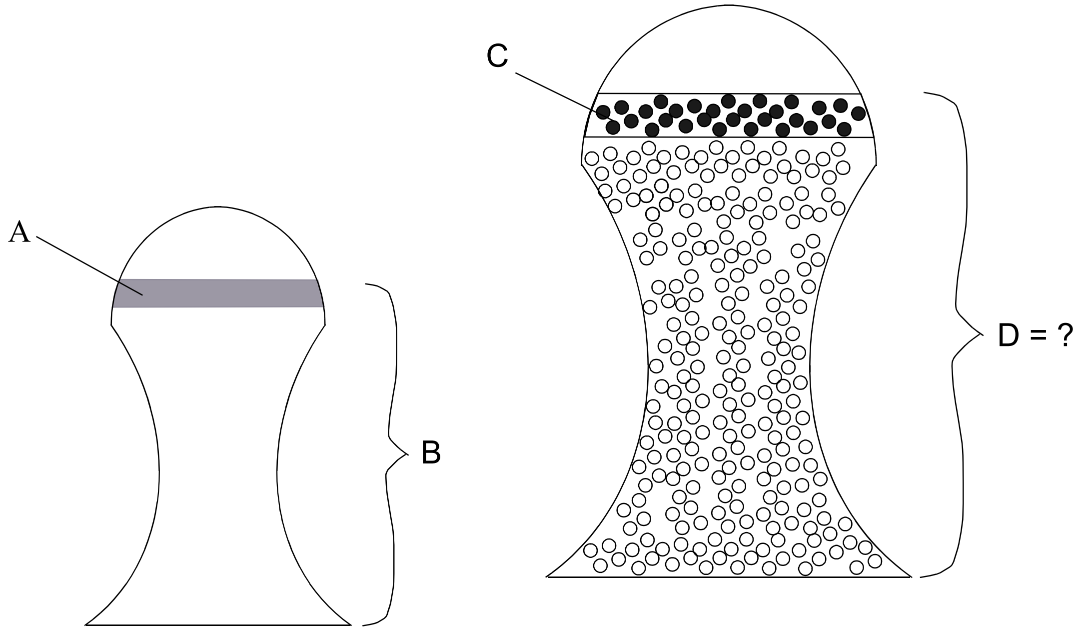
> ...an amount of substance that contains the same number of elementary units as there are atoms in 12 g of carbon-12. That number is 6.02×10^{23}, Avogadro's number. — Kolb, p.156

> ...defined as the amount of substance that contains as many atoms, molecules, ions, or other nanoscale units as there are atoms in *exactly* 12 g of carbon-12.
>
> — Moore, p. 59

Note that the innocent-looking words 'amount' and 'quantity' are technical terms in chemistry: "The *amount* of a substance is the number of moles of that substance. *Quantity* refers to the mass of the substance" (Kotz p. 60). Accordingly, a kind of circularity creeps in above: We ask what a mole is, and both authors tell us it is a certain 'amount of substance', but elsewhere they say the word 'amount' is defined as the number of moles of a substance. I mention this in passing, only because the quasi-circularity is amusing. What concerns me, though, is the absence of our *Definition 1* from the two passages cited (from two popular text books). The student of Chemistry 101 needs to know, early on, *all four ways* of using the word 'mole' (two ways for *Definition 1* and two ways for *Definition 2*) but a textbook is likely to mention only *Definition 2*. (To Moore's credit, he does cover both facets of *Definition 2*, i.e., he brings to the forefront the usage where 'mole' might denote hoards of ions or for that matter hoards of butterflies, not necessarily atoms.)

In computer programming, a variable name is sometimes 'overloaded' on purpose. With the word 'mole', we see a kind of overloading that seems to have occurred unintentionally over a long stretch of time, creating something of a mess.

But hold that thought for now (the overloaded nature of 'mole'), and let's go to the opposite extreme for a moment, so as to draw the simplest possible picture of what our upcoming Computation section must accomplish. For the sake of having a clear point of reference, we'll begin with a gumball machine analogy.



Sample data:
A = mass of sample removed, say 15 g (represented by the shaded horizontal band)
B = total mass of all the gumballs, before any were removed, say 200 g
C = number of items removed as a sample, say 30 gumballs (the darkened ones)
D = the unknown, corresponding by rough analogy to Avogadro's Number, N_A

One can see that the four variables above are related by a proportion: A is to B as C is to D.
Or, in symbols, **A:B :: C:D** Translating this proportion to a pair of fractions (ratios), we have: $\boxed{\frac{A}{B} = \frac{C}{D}}$

And solving for the unknown, we have: $D = \frac{B * C}{A}$

Finally, plugging in the sample values, we have: $D = \frac{B * C}{A} = \frac{200 \text{ g} * 30 \text{ gumballs}}{15 \text{ g}} = 400$ gumballs per gumball machine

FIGURE 12: Gumball Machine Analogy for Estimating Avogadro's Number

In **Figure 12**, we see the same gumball machine from two perspectives, first with regard to weight measurements (variables A and B), then with regard to counting up gumballs (variables C and D). Even without algebra, just using the concept of proportions, the answer D = 400 gumballs is readily obtained.

In **Figure 13**, I present the corresponding scheme for actually estimating N_A. It differs from the procedure outlined in **Figure 12** in the following ways:

[i] For the part corresponding to variable B in **Figure 12**, we rely on a the Gram Atomic Weight for copper, which is 63.5 g. (But see the caveat about this tricky step, in the small font note at the bottom of **Figure 13**.)

[ii] For the part corresponding to variable C in **Figure 12**, instead of counting atoms

directly, we infer the number of atoms involved in the electrolysis by calculating the number of electrons involved. Also, once we have the number of electrons, we divide it in half to obtain the number of atoms. (This halving is just a 'correction' step, required because copper in this context is ionized to Cu^{2+}, meaning each atom gives up two electrons when ionized, not the one electron we might wish, for a neater recipe.)

This is the computation scheme introduced in **Figure 12**. Here we will use essentially the same method again, but with variations.

$$D = \frac{B * C}{A}$$

$$\text{Est. } N_A = \frac{\text{Copper's GAM} * \text{Atoms of Copper Lost}}{\text{mass lost}}$$

When tallying up the electrons involved in electrolysis, it is difficult to resist the notion of each such electron (nearly) 'completing a lap' around the cell, and one may indeed 'work the numbers' this way with impunity. But the physical reality is wildly different; to get beyond the fairy-tale, see **Appendix I: Myths & Realities of Electrochemical 'Flow'** (page **429**).

$$\textit{where } \text{Atoms of Copper Lost} = \frac{\text{Number of Electrons}}{2}$$

Here we divide by 2 to 'correct' for the fact that copper is ionized as Cu^{2+}, giving up 2 electrons per atom, not 1.

$$\textit{and } \text{Number of Electrons} = \frac{q}{\text{charge-per-electron}}$$

$$\textit{where } q = I * t \qquad \text{from } I = \frac{q}{t} \text{ or amperes} = \frac{\text{coulombs}}{\text{second}} \text{ or flow} = \frac{\text{charge}}{\text{time}}$$

$$\textit{and } \text{charge-per-electron} = 1.602 \times 10^{-19} \text{ coulombs}$$

The two givens:
[1] We accept **Copper's Gram Atomic Mass** of **63.5** as a 'given' of sorts, but conceptually we do *not* obtain this by consulting a present-day periodic table. (To some that might appear to introduce circularity, since nowadays a value in the periodic table may be read as either a relative atomic weight *or* a molar mass.) Rather, we take it from **Cannizzaro** himself, who calculated the atomic weight of copper as **63**[a], which we correct in hindsight to '63.5'. Saying it another way, we are trying to perform a pre-Loschmidt, pre-Maxwell calculation, as close to first principles as is practical from such a chronological distance.
[2] The value **1.602 x 10^{-19} coulombs** we must take as a given, since **charge-per-electron** is probably far beyond our home chemistry skills! For an overview of this rather distressing problem of 'givens', see page **41** above.

[a]In the year 1858 no less! See the table of relative atomic weights for copper-chlorine compounds in Cannizzaro, p. 26.

FIGURE 13: Calculation Scheme for [Re-]'Discovering' Avogadro's Number

In **Figure 14** I show an excerpt from the source[41] of our algorithm for estimating N_A:

A = 0.3554 g (mass lost)
B = Copper's Gram Atomic Mass = 63.5 g / mole of copper
C = 3.380×10^{21} Cu atoms (from electron count divided by 2)
D = the unknown to solve for = Cu atoms / Mole of Cu = an approximation of N_A

$$Z = \frac{C}{A} = \frac{\text{number of Cu atoms}}{\text{mass lost}} = \frac{3.380 \times 10^{21} \text{ atoms}}{0.3554 \text{ g}} = 9.510 \times 10^{21} \text{ Cu atoms/g}$$

$$D = Z * B = \text{Cu atoms/g} * \text{Copper's Gram Atomic Mass}$$

$$= \frac{9.510 \times 10^{21} \text{ Cu atoms}}{\text{g}} * \frac{63.5 \text{ g}}{\text{Mole of Cu}} = 6.040 \times 10^{23} \text{ Cu atoms / Mole of Cu}$$

FIGURE 14: Excerpt from the Algorithm's Source

Note that some circular logic seems to have crept into the algorithm, or at least an 'appearance of circularity', which is almost as bad.

$$\text{One mole of atoms} = N_A = \frac{\text{Cu atoms}}{\text{Mole of Cu}}$$

FIGURE 15: Moles going in Circles? Not a pretty picture

In **Figure 15**, I bring out that certain aspect of **Figure 14** to show how slippery the term 'mole' can be. Here, the moles seem lost in a fog of circular reasoning, prompting one to ask: "Since the definition of the mole is linked so intimately to Avogadro's number, how can we claim to *determine* Avogadro's number by setting up an equation that uses a molar mass as *input* to the computation?" (I.e., the equation is reminiscent of certain approaches to Buffon's Needle where — absurdly — the

41. **Figure 14** is based on steps 4 and 5 of the Sample Calculation in Dr. Helmenstine's 'Experimental Determination of Avogadro's Number'. In the source, there is a typo for mass lost in the first fraction's denominator: '0.3544 g'. In **Figure 14**, I've corrected that value to 0.3554 g. (Also, I've assigned labels to show the rough parallel with **Figure 12**. For continuity with the surrounding text, I refer to a Gram Atomic Mass of 63.5 g/mol Cu rather than molar mass of 63.546 g/mol Cu as in the original.) I cite this piece not for the sake of 'attacking' it; rather, I offer it as a random but representative example of a surprisingly widespread problem concerning algorithms in the chemistry lab culture, specifically: vagueness and anachronisms which lead sometimes to circular logic.

aid of *pi* is enlisted for the purpose of 'finding' *pi*; see page **167**.) But in **Figure 15**, the equation *is* legitimate, I would say (given present-day usage), though it might give someone a headache trying to read between the lines. But we won't need to do that (read between the lines) since Figures **12-14** above have already shown us just what it is that **Figure 15** is *trying* to express, albeit in a dubious way.

Sample Calculation of Avogadro's Number from Electrolysis Data

Here I use the method outlined in **Figure 13** to process the raw data from my own run of the experiment, in its 'carat scale' version.(42)

Part 1: Atoms of Copper

Total charge passed through the electrolysis circuit:

$q = I * t = 0.203$ amp * 1800 s = 365.4 coul
where 0.203 amp is the mean average of eleven readings(43) and
1800 seconds = (60 sec/min) * 30 minutes, the duration of the run.
Note: one ampere = 1 coulomb/second, so 1 coul = one amp-second

Number of (notional!) electrons that passed through the electrolysis circuit:

q / charge-per-electron = 365.4 coul /(1.602×10^{-19} coul/electron)
= 2.281×10^{21} electrons

Atoms of copper lost from the anode = copper ions gained in the solution
= number of electrons halved:

2.281×10^{21} electrons (1 Cu^{2+} / 2 electrons)
= 1.140×10^{21} Cu^{2+} ions gained in solution = 1.140×10^{21} Atoms of Copper

42. The same scheme applies if working with **Appendix J: Avogadro Again - Sequin Scale Version**.
43. The eleven readings are given on page **59** above.

Part 2: Mass Lost

Mass lost at the anode, as difference between its weight before the electrolysis and after the electrolysis:[(44)]   0.14 g = 7.12 g – 6.98 g

Part 3: The Estimate

D = (B * C) / A (<== referring back to **Figure 12**)
D = 63.5 g * 1.140 x 10^{21} / 0.14 g = 5.18 x 10^{23} copper atoms per 1 whole GAM for copper

The specific result immediately above we then generalize to this:

5.18 x 10^{23} atoms per 1 GAM for *any* element

In other words, that's our estimate of N_A. (In passing, note that the so-called Avogadro's *number* is really a *ratio* of something-to-one, just as the 'number *pi*', so-called, is really a ratio of 3.14-to-one.) Thus, using a carat scale whose resolution is a modest 0.01 g, we've come within shouting distance of the famous number, 6.022 x 10^{23}. (Here I've glossed over the semi-sacred topic of significant figures. For a more rigorous approach to that and other aspects of the experiment, see **Appendix J: Avogadro Again - Sequin Scale Version**.)

To put our estimate in context, here are four points of reference:

1. Maxwell, 1873: $N_A \approx$ **4.3 x 10^{23}**, using calculations that estimated the number of molecules in a given volume of gas, based on Loschmidt's 1865 calculations of molecular diameter.

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44. Here is a little 'sanity check' that one may wish to perform at this juncture, before proceeding to Part 3: Using the calculated number of atoms from Part 1, confirm that it jibes with the lost mass measurement in Part 2. Note that this may not be considered as 'part of the experiment' itself, as that would introduce circular reasoning. Here we will 'cheat off-line' by *using* N_A to gain confidence in our results (whereas the whole point of the experiment is to pretend we don't know N_A and to try to *discover* it). So, with that caveat out of the way, here goes: Set up a ratio, similar to the one in **Figure 12** but turned sideways and with a different unknown, like this:
63.5 g / 6.022 x 10^{23} atoms = L / 1.140 x 10^{21} atoms. Then solve the ratio for L grams lost:
6.022 x 10^{23} * L = 63.5 * (1.40 x 10^{21}), so **L = 0.147 g**. This matches our mass lost measurement (at the scales) of **0.14 g**. All is well. I.e., the amount of copper theoretically predicted by the averaged amperage measurements jibes with the amount of copper actually lost on the scales. Whew! Safe to proceed.

2. Kelvin, somewhat later: N_A ≈ **5.5 x 10^{23}**.
3. Perrin, 1908: N_A placed between **6.5 x 10^{23}** and 7.2 x 10^{23} from studies of Brownian motion.
4. Fletcher, 1914, working under Millikan: **6.03 x 10^{23}** (≈ the modern value, 6.022 x 10^{23}).

Source for the four values above: Berry (1954) pp. 122 and 124.

Test Tube Stirling Engine

See page 224f in **Appendix B: Heat Engines and the Cycle-Design Gotcha**.

Methane Geometry

When a group of atoms, say one carbon and four hydrogen atoms, come together to form a molecule, they do so with specific bond angles. These in turn have a bearing on the molecule's chemical behavior. In the case of methane, CH_4, the bond angle between the carbon and each hydrogen is 109.5º, for instance. Using a ball-and-stick representation, the bond angle for methane can be depicted this way:

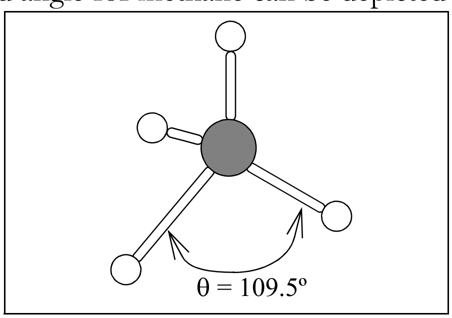


FIGURE 16: Ball-and-stick picture of methane

But how do we *arrive* at the number 109.5º in the first place? (short of building a physical model and trying to measure the angle!) Clearly this a very different situation from that of boron trifluoride (BF_3), for example, where the bond angle can be determined simply 'by inspection', as they say:

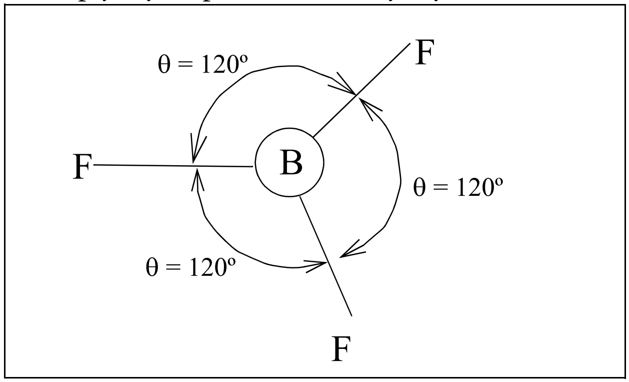


FIGURE 17: Boron trifluoride geometry (flat)

If we assume symmetry (i.e., uniformly distributed repulsion between the atoms), then the 4 hydrogens of CH_4 must be the vertices of a pyramid, while the carbon would be the centroid of the pyramid (tetrahedron):

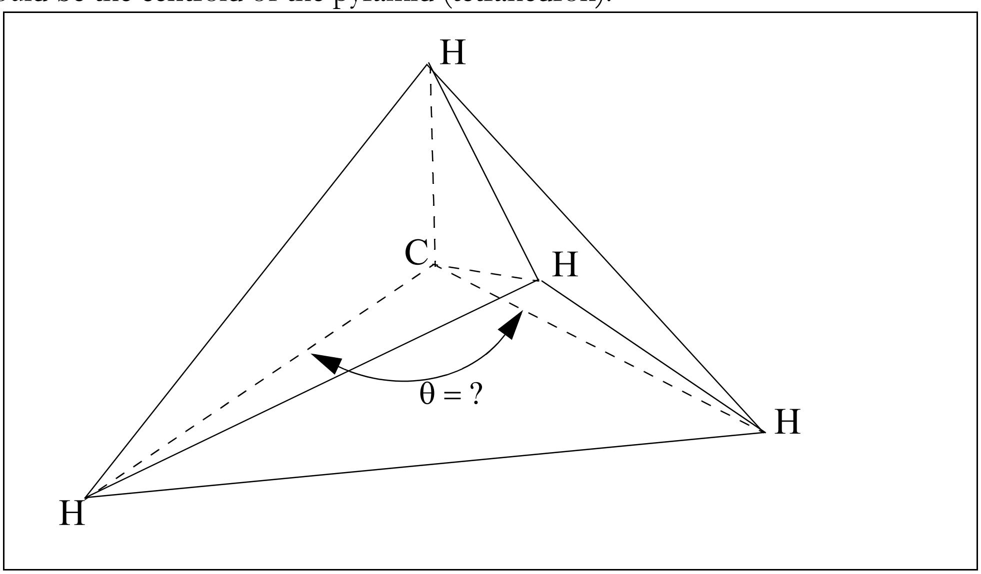


FIGURE 18: Methane as a pyramid (no coordinate system)

So far so good. But where to place this structure relative to a coordinate system? One author (Stewart, p. 837) proposes that we construct the tetrahedron with vertices at (1,0,0), (0,1,0), (0,0,1), and (1,1,1):

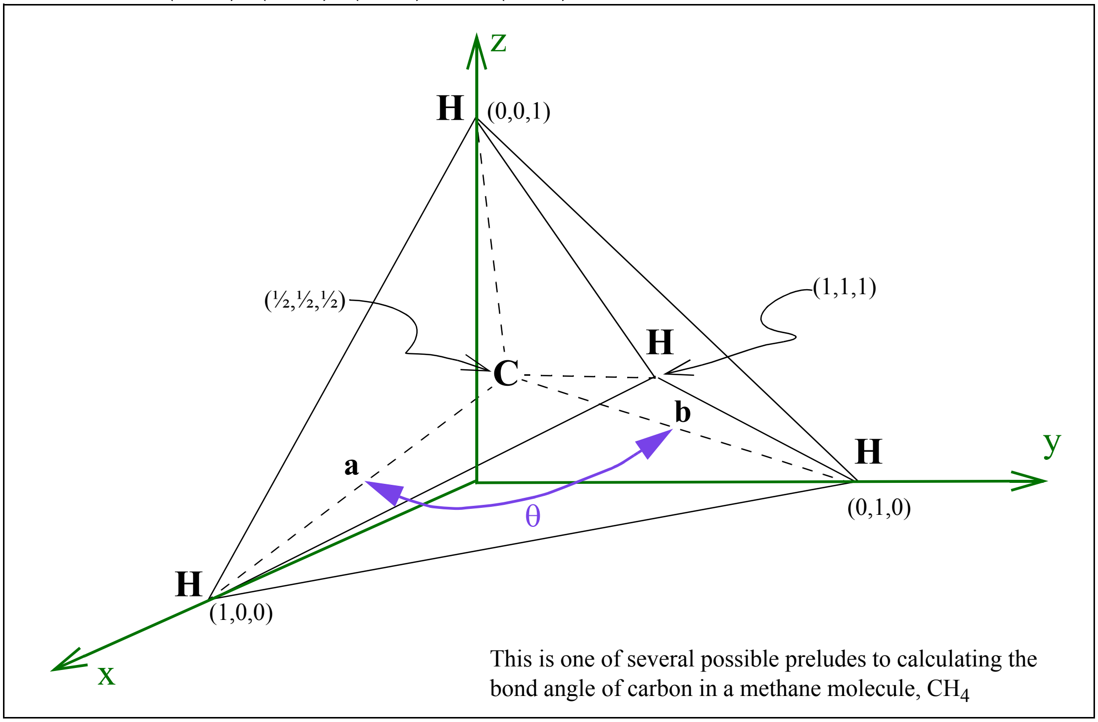


FIGURE 19: Methane pyramid attached to xyz coordinate system

Now we can use a combination of trigonometry and vector algebra to do the calculations:

Let the dotted lines **a** and **b** be the two vectors whose intervening angle we wish to find. (This is an arbitrary choice. Any two neighboring vectors will do, since we've assumed perfect symmetry for CH_4 based on other similar molecules, let's say.) Expressed in terms of point coordinates, vector **a** extends from (½, ½, ½) to (1,0,0). Thus, via the final-minus-initial rule (Stewart, p. 824), its value is $<+\frac{1}{2}, -\frac{1}{2}, -\frac{1}{2}>$. Vector **b** extends from (½, ½, ½) to (0,1,0), evaluated similarly as $<-\frac{1}{2}, +\frac{1}{2}, -\frac{1}{2}>$.

We will use the following theorem to calculate the angle between the two vectors:

$$\cos\theta = \frac{\mathbf{a}\bullet\mathbf{b}}{|\mathbf{a}|\,|\mathbf{b}|}$$

where **a•b** tells us to take a dot product:

$$<\tfrac{1}{2}, -\tfrac{1}{2}, -\tfrac{1}{2}>\bullet<-\tfrac{1}{2}, \tfrac{1}{2}, -\tfrac{1}{2}> = -\tfrac{1}{4} + (-\tfrac{1}{4}) + \tfrac{1}{4} = -\tfrac{1}{4}$$

and $|\mathbf{a}|$ tells us to find the magnitude of vector **a**:

$$\sqrt{(1/2)^2 + (-1/2)^2 + (-1/2)^2} = \sqrt{1/4 + 1/4 + 1/4} = \sqrt{3/4}$$

and $|\mathbf{b}|$ tells us to find the magnitude of vector **b**:

$$\sqrt{(-1/2)^2 + (1/2)^2 + (-1/2)^2} = \sqrt{1/4 + 1/4 + 1/4} = \sqrt{3/4}$$

Plugging these three values in, we obtain:

$$\cos\theta = \mathbf{a}\bullet\mathbf{b} / |\mathbf{a}|\,|\mathbf{b}| = -1/4 \,/\, (\sqrt{3/4}\,\sqrt{3/4}) = -1/4 \,/\, 3/4 = -1/3$$

Solving for θ: $\boxed{\theta = \arccos(-1/3) = 109.5^{\circ}\ !}$

(True, there are plenty of other ways to calculate the bond angle for methane, using only two-dimensional trigonometry, for instance. However, I think the above method that combines trigonometry with three-dimensional vectors is the most elegant and appealing. And it demonstrates one of the possibly surprising byways of chemistry, which is not all about squinting at titrations or shaking test tubes over hot flames. The theorem employed above is a delicious variation on the Law of Cosines, $c^2 = a^2 + b^2 - 2ab \cos C$; see Stewart, *Calculus*, Fourth Edition, p. 831-832.)

Chemical Poetry: The Secret Life of Water and Other Substances

This next item will be purely conceptual, since the reader is unlikely to possess the instruments necessary to investigate/replicate the phenomenon to be related.

Question: When you juxtapose H_2O with H_2O what happens?

Upwards of 99.99% of the time, the result of such juxtaposition is simply 'water' as common sense would predict. But there is also an exceedingly rare yet predictable event whose equations look like this:

$$\boxed{\underset{\text{(liquid)}}{H_2O + H_2O} \Longrightarrow \underset{\text{(aqueous ions)}}{H_3O^+ + OH^-} \Longrightarrow \underset{\text{(back to liquid)}}{H_2O + H_2O}}$$

This reaction, the creation of a hydronium and a hydroxide ion from two water molecules (then quickly back to water again) is predictable, although not in a rigid, clock-driven sense; rather, in the statistical sense: Given a quantity of water, at any moment a tiny fraction of its molecules (about two per billion) will be exhibiting this behavior. It's as if certain pairs of molecules carried these subscripts...

$$H_2O_{\text{ACID}} + H_2O_{\text{BASE}} \Longrightarrow\ ?$$

...although in Nature there is no such subscripting, not even figuratively; hence my notion of a Secret Life to describe this odd facet of H_2O chemistry. (Recently I learned the term 'emergent property' from one of my daughters. That would probably be the formal name for what I've called the Secret Life of water.)

Faint though its background hum may be, it is this scarcely audible ACID/BASE music of H_2O that forms the foundation of the whole pH system, which runs from strong acids at pH = 1, through water with a neutral pH of 7, to strong bases at pH = 14.

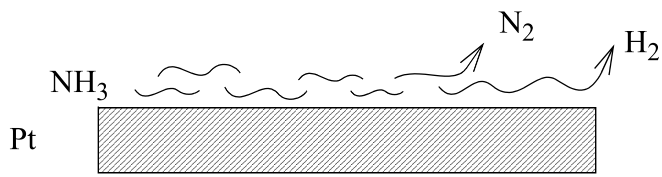
Another example of 'silence' during a reaction:

In a popular chemistry set (the Thames & Kosmos *C1000*), one of the experiments is the creation of invisible ink to be faded slowly to legibility by exposing one's text to ammonia fumes. But for my money, the real magic in that experiment is the method for producing the ammonia: in a shallow dish, one mixes two white powders: calcium hydroxide, $Ca(OH)_2$, and ammonium chloride, NH_4Cl. Subsequently, there is no movement, no sound, no liquid added or produced — seemingly no activity at all, except that a minute later the writing turns visible, confirming the presence of ammonia, created by a reaction between the two inert-looking powders.

In a similar vein, platinum (and various other metals) may serve as a catalyst, yet paradoxically 'do nothing'. For example, we have the following formula (from Kotz,p. 610):

$$2NH_3(g) \xrightarrow{Pt(s)} N_2(g) + 3H_2(g)$$

which can be represented graphically as follows (unbalanced)...



...or expressed in words this way:

When passed over platinum (Pt), ammonia (NH_3) decomposes into nitrogen (N_2) and hydrogen (H_2). The *presence* of the platinum is the catalyst, yet the platinum experiences no ‘chemical reaction’ in any normal sense.

FIGURE 20: A Surface-Catalyzed Reaction

As it happens, ammonia (NH_3) plays a prominent role in the previous two examples. If ammonia sounds ‘unpoetic’ at first blush, think again. In the progression that goes CH_4, NH_3, OH_2 (to which I apply the nicknames full tetrahedron, squashed tetrahedron and ghost tetrahedron, as reminders of the respective geometries), note that ammonia is the closest neighbor to water (H_2O, which I write backwards as OH_2, so as to emphasize the pattern as this family of compounds progresses along the periodic table: C, N, O...). If that’s not poetry, I don’t know what is.

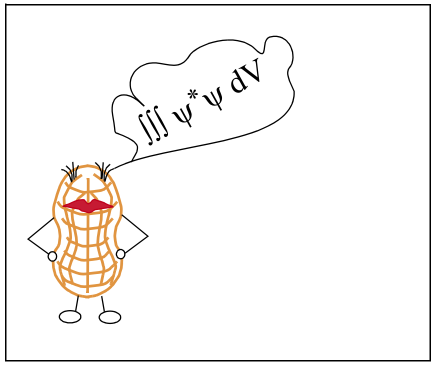
Modern Alchemy: Red Powder turns to Silver Liquid

It is one thing to see a liquid heated until some of it evaporates and leaves behind a dry crust. This could be salt as the residue from sea water. Not very surprising. But the reverse of this process would seem like a kind of alchemy or magic. And this is exactly what happens when you apply intense heat to mercuric oxide powder in a test tube: *a reddish-orange powder* (or its yellow-orange variant) is seemingly *transmuted into quicksilver*. This is a natural follow-on or coda to the Twelve Days Experiment that we introduced on page 28: After Lavoisier coaxed the mercury in the retort to combine with oxygen (in effect 'burning' his liquid mercury in extreme slow motion), he also *recovered* the oxygen and *quantified* it. This is what makes his experiment so significant — its implicit debunking of the phlogiston doctrine and demonstration of oxidation as the mechanism of combustion, *plus* his discrimination of the nitrogen component of the air inside the apparatus! Happily, running the experiment backwards requires no special equipment such as a retort or a bell jar that communicates with a pool of mercury. All that is required is a test tube[45] to hold the HgO powder, and a flame (the 450 °C 'cool' part of a Bunsen burner flame) to provide the necessary intense heat. Together, the two halves of the experiment may be summarized this way...

$$\boxed{2Hg(\ell) + O_2(g) \underset{\text{gentle heat}}{\overset{\text{intense heat}}{\leftrightharpoons}} 2HgO(s)}$$

...where ℓ = liquid, g = gas, s = solid. The forward arrow represents the procedure detailed on page 28 already. The reversed arrow represents the procedure introduced in this section.

45. A test tube is all you need, assuming you don't care about capturing and quantifying the evolved oxygen as Lavoisier did. In his initial procedure, described on page 28, Lavoisier noted 8 cubic inches of oxygen depleted; then he recovered and measured that same quantity of oxygen when reversing the procedure, with the endothermic reaction $2HgO(s) + 181.7$ kJ $\Rightarrow 2Hg(\ell) + O_2(g)\uparrow$. However, if we exclude this recovery step it becomes a deliciously simple procedure, almost like kitchen chemistry. Its popularity in the high school chemistry lab — back in the day before mercury-in-the-food-chain — is owing to its simplicity. Sadly, our awareness nowadays of harmful mercury compounds leads to avoidance of *elemental* mercury, too (although real trouble would ensue only if one were grossly negligent of the minute vapors and their potential for forming the dreaded mercury *compounds*).



III Letter from a Proton

Dear biped,

Salutations and condolences. It cannot be easy trying to be a good citizen, when your very existence is so iffy. More like that of a glacially slow android than that of a quick *living* entity (such as yours truly). Way up there in that grotesque no-man's-land you wander, the one your scientists call the macroscopic realm. Which is no realm at all, more like the True and Ultimate Limbo, afloat between the microscopic and the cosmic.

Along with the illusion of 'existence', God has granted you the illusion of 'vision', they tell me. So you'll want an image to associate with my voice. That of a perfect bland sphere perhaps? That's the way your scientists have portrayed us protons until very recently. They were at pains to point out that we are all (supposedly) *identical* spheres to boot — mutually interchangeable and indistinguishable, 'because' we all weigh 1.672×10^{-27} kg exactly. You may have missed this on the 6 o'clock news, but of late that model has been gloriously enriched to allow for varying shapes such as those depicted in **Figure 21**.

Source: Indirectly, Gerald A. Miller (2003). From his series of 14 computer-generated graphics we've selected three shapes to introduce here, in low-tech fashion. Contrary to expectation, though, the peanut and bagel similes do come straight from the ultra technical paper itself. We're guilty only of adding the grape analogy and the 3 alliterative adjectives.

FIGURE 21: Proton Mug Shot Gallery: Feeling Like a Grape, a Peanut, a Bagel

The grape shape pertains when my quarks are quiescent. The peanut shape occurs when my trio of constituent quarks are spinning at high speed in the same direction that I myself am spinning; me, myself and I as one happy family. And the bagel shape? That occurs when my three constituent quarks are screaming along in one direction (clockwise, let's say) while 'I' am spinning the opposite way. As for a self-portrait, I find myself drawn to the peanut shape; hence the peanut icons in these pages where the author permits my voice to take over. And, by happy coincidence, that is the model your average biped reader can appreciate, too, I believe. The grape would be boring for the reader and a reminder to me of past insults, and the bagel would be too difficult to visualize. A final note about my physical aspect: my possible shapes are now acknowledged by your physicists to encompass everything in-between the three shown, in "an *infinite* variety of nonspherical shapes" (Miller 2003, p. 1, my emphasis).

Someday they'll discover that we're not all psychologically identical either. For instance, I'm the odd proton — the one gal in a googolplex, let's say — who finds it worthwhile communicating with an entity of your ilk: never mind how implausible you earth-walkers are as a life-form, how absurdly huge and lumbering, though wispy and ephemeral in your dreadful macroscopic 'existence': the worst of all worlds: neither Cyclops nor ghost, yet somehow a little of both. Yes, the proton is queen, enthroned at the core of the one true life-form in the universe, the atom; yet some of us care about those less fortunate than ourselves — droll misbegotten agglomerations like yourself suffering an illusion of life. So it's not *quite* fair to paint us protons as hopeless conformists.

With my mug shots and biographical sketch out of the way, we should now be able to begin my open letter to biped-dom in earnest. First, I would like to bring to your attention a book by Richard Dawkins called *The Ancestor's Tale* (2004). Toward the end of that work, there is a piece written collaboratively by Dawkins and Yan Wong, where we hear the imagined voice of one *Thermus aquaticus*,[46] alias Taq. In Taq's view, all you higher life-forms are little more than a 'fancy froth' riding the surface of bacterial life. And, adds Taq, "We [bacteria] were here [a billion years] before you arrived, and we shall be here after you are gone" (Dawkins, p. 558).

Building on that image, we shall endeavor to paint a complete picture of the relation between your world and mine, in Figures 23-26. But first, to set the stage, let's recall from history what a bone-crushing mind-bend the Copernican Revolution was:

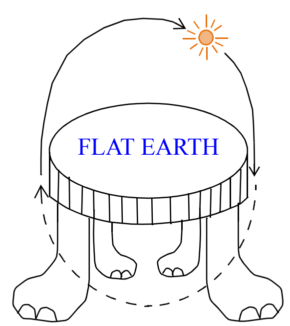


Figure 22a:
The earth as a *broad static stationary wafer*, with a tiny sun that must thread its way between four supportive elephant legs to complete its daily circuit. But where do the elephant feet find purchase? In some versions, they rest on the back of a giant turtle. But then what does the turtle stand on? For the answer, see page 121.

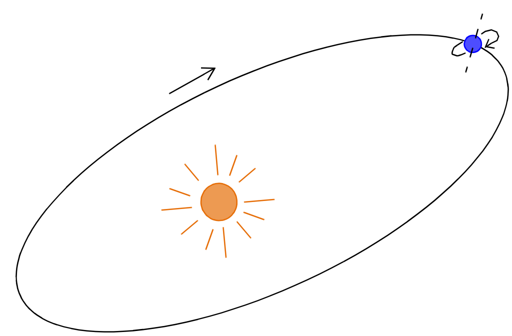


Figure 22b:
The earth as a planet that is *tiny*, *spherical*, *tilted* & *spinning* while elliptically *orbiting* a large star (which in turn travels elliptically around the fringe of a galaxy). This is not to say all of this was understood in a flash at the Moment of The Revolution (or that some of it hadn't been inkled long before Copernicus himself), but still the full list of adjectives now pertaining to the word 'earth' cannot fail to impress us.

FIGURE 22: Geocentric View vs. Heliocentric View: the Copernican Revolution

46. A thermophilic chemotroph bacterium discovered at Yellowstone National Park in 1969.

One might ask, “Wasn’t one Copernican Revolution enough? Why would we need another one?”(47)

True, it *was* a major mind-bend for you bipeds, embarrassing in its revelation of how comfortable one can be with a model of reality that is wholly wrong. But think about what it *said*. Not to take anything away from the great effort and overall achievement of its author, but all it *said* was this:

> The earth is not central, its traveling sun is.

And for any species capable of space travel, that’s hardly a revelation, only a statement of the obvious. At best such a statement might be used as the *jumping off point* for philosophy; it should not be used as an excuse to stop *thinking*! That so-called Revolution of yours must now be recognized as your first baby step, only, on a terrifically long journey toward true understanding of the universe, scarcely begun (and in the wrong direction, I might add), even now, 500 hundred years after the death of Copernicus.

47. Mano Singham has unraveled the actual content of the Copernican Revolution from various fairy-tales that have grown up around it and been accepted by science. (See http:// blog.case.edu/singham/2005/04/25/the_myth_concerning_circular_orbits.) For our particular purpose here, we need the Copernican Revolution only as a kind of (far distant) foil, so that we can say, “...but what we *should* do is move in the *opposite* direction, gazing ever *inward* to arrive at an atomocentric view.” Approaching the events from such a distance, I find that we don’t care if resistance was offered first by other astronomers, not the church; or if actually it was the Protestants who opposed Copernicus first, long before the Catholics. Accordingly, when alluding to the Revolution, I may at times append *–esque* (‘Copernicanesque’) acknowledging the important scholarship in this field while simultaneously distancing myself from it in this context, where I think it is largely irrelevant.

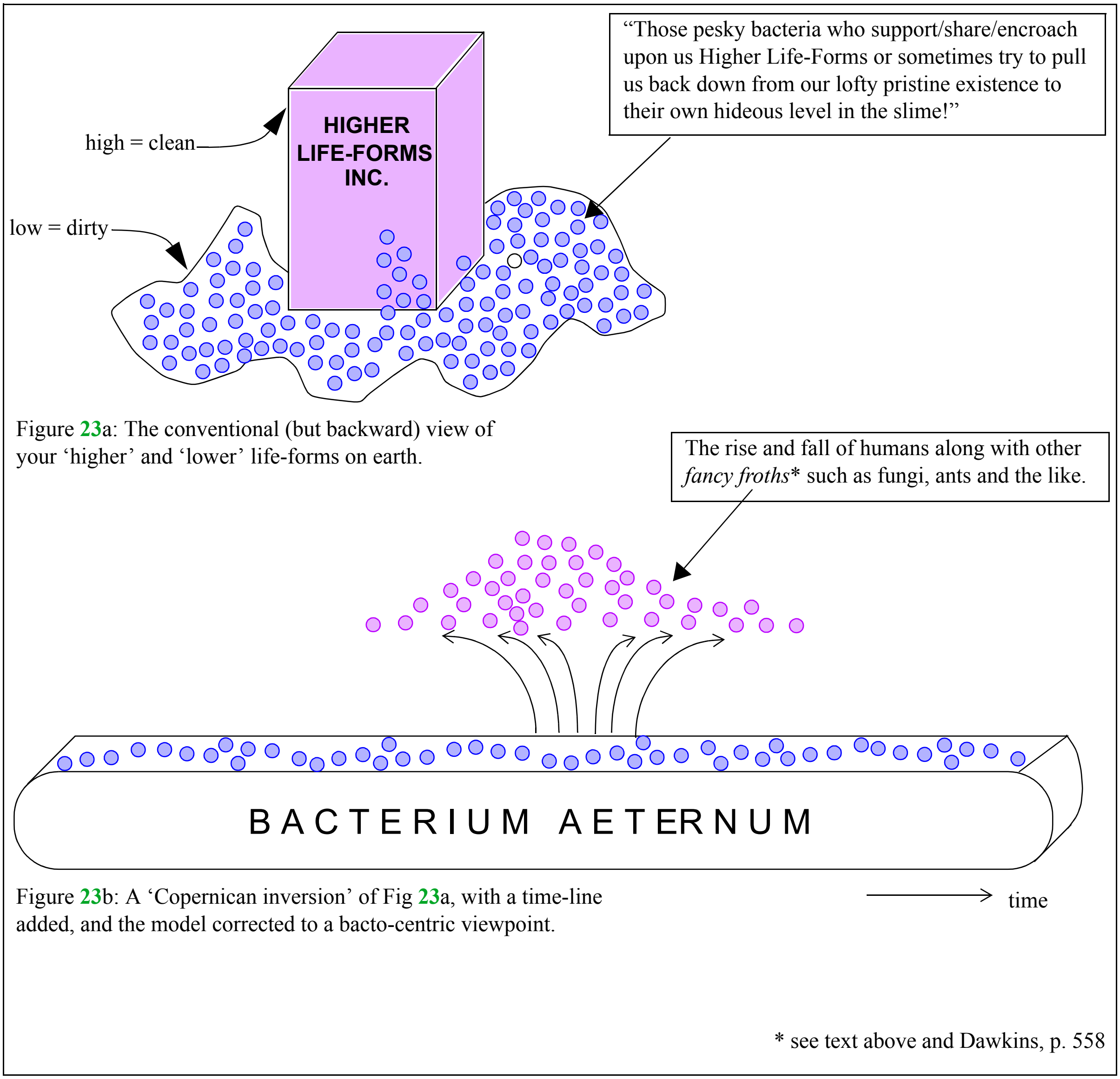


Figure 23a: The conventional (but backward) view of your ‘higher’ and ‘lower’ life-forms on earth.

Figure 23b: A ‘Copernican inversion’ of Fig 23a, with a time-line added, and the model corrected to a bacto-centric viewpoint.

FIGURE 23: Anthropocentric model vs. Bacteriocentric model of Life

Figure 23 is an attempt to illustrate the idea already quoted from Yan Wong (in Dawkins), and to point up its quality of a Copernicanesque *inversion*, which is what it implies if taken to heart.

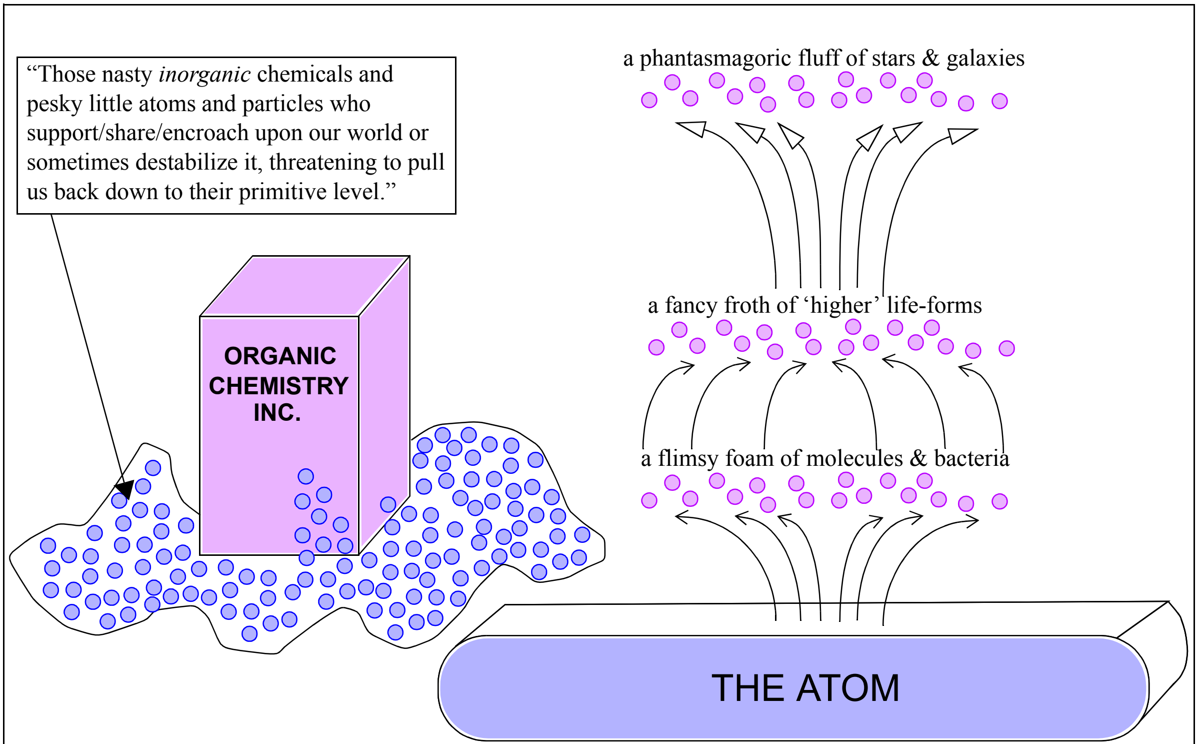


Figure 24a: The conventional (but backward) view of organic chemistry relative to 'inorganic' chemistry and particle physics.

Figure 24b: A 'Copernican inversion' of Fig 24a, in which the model is corrected to show the atom as *the* foundational life-form and all the rest as Flimsy Foam Cubed, so to say.

FIGURE 24: A Map of the World: Corrected (Further) to Flimsy Foam Cubed

Figure 24 takes us still further away from an anthropocentric view, by going both 'above' and 'below' the scale of the forms portrayed in Figure 23. This brings us to our main theme: the primacy of the atom *as a life-form*. The salient idea of Figure 24 is that the atom is the only genuine life-form, and everything 'higher' is some kind of Tinkertoy® agglomeration believed by some to be 'life-forms', or the glorified über-fluff known to the general public as 'stars' and 'galaxies'. (If they're so big they must be important,[(48)] no?)

This series of graphics concludes with Figure 25 (next page); the graphic repeats Figure 24, now with its left side very much extended and 'exploded' to show details of the proposed Copernicanesque shift.

48. Since the stars *are* important as the crucibles for the heavy elements, I am forced to admit a weakness in the layout of my map. Still I hold to the design, for its sole aim is to shock one into seeing the world inside-out, and this broad concern trumps any internal logic flaw. (Also, to mitigate the discrepancy regarding nucleosynthesis, one might argue that only big fluffy entities such as humans have a vested interest in the heavy elements. The latter are not the be-all and end-all of atomic existence.) There are related discussions on pages 25, 96 and 475.

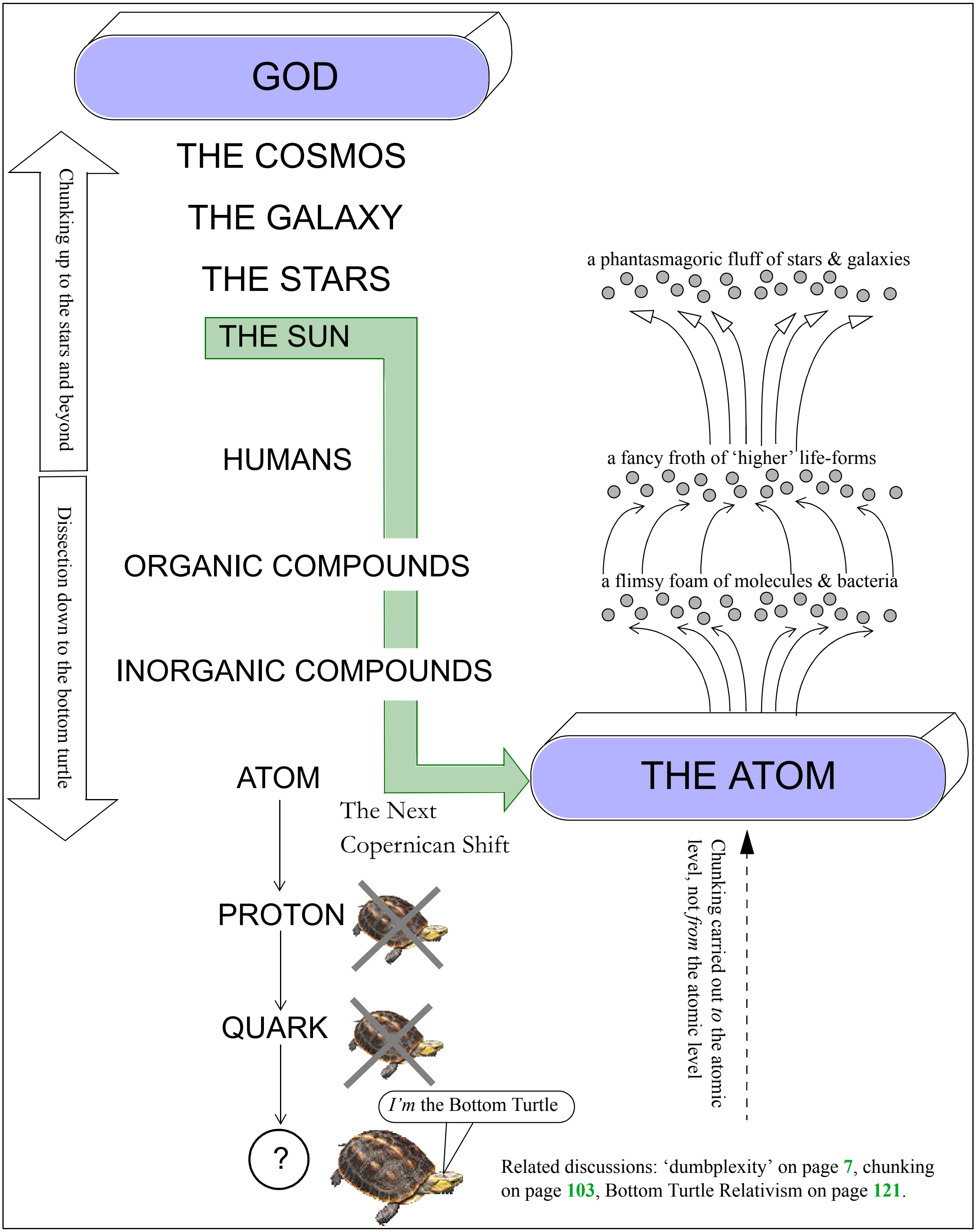


FIGURE 25: Today and Tomorrow: Road Map to the Next Copernican Shift

At first sight, the images of foam or froth (in Figures **23** through **25**) may seem to be overintellectualized abstractions, too far removed from the ordinary Theater of Ideas to be reasonably contemplated. Something on the lunatic fringe. But signs of Flimsy Foam Cubed *are* present in some familiar places. It's just a matter of knowing what to look for. For example, your biped discipline called anthropology provides a good framework for exploring the idea. The anthropologist is aware that by adopting a very slight shift in perspective, one can see how nearly all those components of 'reality' that supposedly define one's identity are mere cultural constructs built on thin air:

"I'm a senior at Berkeley High School."

"I'm a blue team fan, he's an orange team fan."

"I'm the class president, she's a math teacher."

To the extraterrestrial observer (or to a proton like myself), it is a challenge to try making sense of those assertions. How do they differ from the ravings of a mental patient? They don't, really. Because in the universe, there is no such thing as 'a senior' or 'the blue team' or 'a president' or 'a math teacher'. That's all nonsense, the biped equivalent of so many frogs croaking in a pond or bees abuzz in their hive.

One kind of toy for hamsters is a hollow, hampster-sized sphere, made of clear plastic, with a little trapdoor. Suppose a hamster is inside the ball with the door shut, using his paws and shifted weight to make the ball roll here and there on the carpet. Suppose the hamster can talk and it says to you, "Look at me! I'm a hamster-ball rolling to and fro on the carpet." In a way, his self-description is accurate: until you let him out again, he pretty much *is* 'a hamster-ball', having been induced by you to merge his own identity as hamster with that of the plastic ball. But as an outside observer, you also recognize the absurdity of his self-description. You know that he is not a 'hamster-ball', but rather a hamster stuck inside a clear plastic ball. Just so, the human who all day long wears the identity of 'I'm a senior' or 'I'm a blue team fan' or 'I'm the class president' or 'I'm the math teacher'. Each of these identities is a kind of self-inflicted 'hamster-ball' state which one *could* step out of. But only one in ten thousand is likely to do so. Unless they happen to choose Anthropology 101 or Philosophy 101 as an elective in college (*and* appreciate the content!), they'll never even realize that they are *in* such a state, much less have a notion of how to break *out* of it for a fleeting glimpse of the world as it is. Please forgive the impudence, but I have to ask: Does that really sound like your idea of an 'intelligent life-form'? Or does it sound more like a fish in water who cannot possibly be taught what water is?

Here's a related idea: Consider the case of someone who does contract work *for* IBM, sitting at a desk in an IBM office building for three years, and then one day becomes an 'employee *of* IBM'. Now he is hired by the company — but still goes to work every day at the same time, wearing the same clothes, sitting at the same desk as before, doing the same work. What changed? In the universe, nothing changed. Only some figment of the worker's imagination has changed: "This is good. Now I'm an actual employee *of IBM*. I feel so much better about myself, now a full-fledged member of the community, a parent who can better provide for his children," and so on.

While some feel shut out ("not good enough for 'a real job' with benefits"), others feel trapped inside such institutions and wish to escape. In connection with the latter sentiment, note the following inversion in how biped individuals regard themselves relative to 'the corporation': A well-known reaction is to lament one's status as 'just a cog in the machinery' or 'just a number'. But the aspect of corporations that *should* disturb the bipeds is roughly the inverse of that: It's the fact that a human can be thought of as 'a constituent part of the XYZ corporation' in *whatever* capacity, be it janitor, manager or CEO — it doesn't matter. The fact that Coca-Cola® or Hersheys® exists over time, quite independently of the CEOs and janitors who occupy their temples down through the decades — that's where one's focus should be (on the corporation as 'eternal person', as the attorneys have defined them). For it reveals something new and embarrassing about biped nature (or 'human nature' as you would say): it is far more antlike or coral-reef-like than one generally likes to admit. If Hersheys as a living entity is partly real, partly unreal, then aren't its employees likewise partly real, partly unreal, so many ghosts gliding through the hallways of corporate America?

Another related idea: How does biped culture evolve? If only you had been in the right place and time, you would know from certain changes in the population at large that there is something ephemeral and frothlike about all biped existence. For instance, our Proton Chronicles contain the record of a certain yawn on a crowded commuter bus in Chicago, at 8:07 a.m. on a certain day in June, 1980. The yawn was delivered uncovered by an attractive young well-dressed female who was an attorney — still an unusual occupation for women in those days. But that is not why she is in our journal. Her yawn is in our journal because it was the turning point: Before that yawn, everyone in the United States covered his/her mouth when yawning, to prevent the transmission of billions of germs. After that yawn, nobody covered when yawning, because... Because nothing. The cultural change happened mindlessly, instantly, as when a cloud of gnats flies NW instead of NE. It was Flimsy Foam Cubed in action.

Another example in the same vein: The day is January 10, 2000, the time is 10:23 a.m. The CFO of Medtronic, a multinational biomedical engineering company, says there have been 'concerns around sales in Japan'. Starting the very next day, all managers in all American corporations replace 'about' by 'around' in countless phrases such as 'my concerns around X', 'our discussions around Y', 'your passion around Z', none of which ever existed in English before, during all its centuries of development. Suddenly it's even permissible to say, 'There might be some risk around that' and 'Let's put some structure around what we're doing'. (Whereas, for all those hundreds of years previous to 10:23 a.m. on January 10, 2000, it was 'put some structure *into*...', suggesting a process whereby you provide an improved structure for something already reasonably coherent and well-formed. But what kind of entity needs structure placed *around* it? Something big, blobby and spineless perhaps, like a giant cylinder of cranberry sauce that has fallen out of its tin can and sits quivering in a corner of the kitchen floor? What kind of world *is* yours, anyway?) But this tectonic shift in the language goes totally unremarked by the bipeds. After all, it hadn't been a conscious, deliberate change, had it? It was just Flimsy Foam Cubed in action. (But *you* try swapping out one whole preposition in the language sometime and see how far *you* get, saying, for instance: "I'm going upon the gas station to buy cigarettes," "I'm going upon college to study poetry," "I'm going upon hit that ball." It just isn't done. Except when it is done. Cloud-of-gnats-wise or school-of-fish-wise. Are you hip enough to think like the Medtronic CFO who understood when and how the Flimsy Foam could thus fold itself into a brand-new configuration and lock the instant in forever?)

Moreover, if one observes you bipeds closely enough, one can find indications that you yourselves have inklings that your 'existence' is not divine, but rather queasy and problematic.

Why does the film *BladeRunner* have such a strong cult following? Certainly much of its appeal can be explained in aesthetic terms: the seductive music and soundscape, the excellent script, the high-octane acting, and the neo-noir production values (all of which put its antecedent 'novel' by Philip K. Dick to shame, by the way). But the deeper attraction of *BladeRunner*, the one that grabs you deep down is a secret intuition you bipeds possess that all of *you* are, in some odd sense, replicants yourselves — not quite *as* real as you wish. The dilemma faced by Leon or by Rachel and the other replicants in the story is a dilemma that any thoughtful introspective biped might face at any time in his supposedly *non*replicant, *non*android existence: how to know if one is real., how to make sense of one's mode of existence. (Consider the account of the girl who asked her physician to put her back on Prozac, not to resolve a specific mood problem, but so that she could generally *be herself* again; see James C. Edwards, p. 60.)

Another related example: Our Proton Chronicles contain the 'wind chime' entry — admittedly an extreme case: Preparing for a trip to Japan, a single middle-aged woman puts headphones on at night to listen to language tapes while drifting off to sleep. She has heard the theory that one remembers things best when they are encountered in the twilight zone between waking and sleeping. But her twilight zone is a different one sometimes: There are certain nights when she can't help picturing herself as a cadaver only pretending to listen to language tapes. Such is her solitude and alienation from the world, that she believes in the existence of the turning reel of magnetic tape but doubts the existence of her own motionless self beside it, supposedly listening. Only when a desultory breeze rises and sounds the wind chimes over the neighbor's garage door does she feel a moment of respite: confirmation of her existence: "Yes, I am here in the world, not adrift in nameless regions like a ghost." In terms of her own society, this woman is somewhere in-between an outcast and Eleanor Rigby (of the Beatles classic) — not a comfortable place to be. But in terms of understanding reality, she may have an advantage over the mainstream biped, so complacent and smug in his busy important 'existence': she has insight into the fragile and problematic nature of human ontology. In fact, her existence bears an eerie resemblance to that of a replicant as it 'comes to life' or wonders if it is becoming human. One of the puzzles confronted by the replicants in *BladeRunner* might be articulated as follows: "I know I am a machine [or a corpse-like body, in the case of the woman recounted above]. But since I have self-awareness, could it be that I am beginning to develop something more, something human?"[49]

An interesting variation on that idea (almost its flip side) occurs in an anime film called *Ghost in the Shell:* contrary to expectation, deep inside an AI program there *remains* an essence of life, a *vestige* of something purely human, not computerized or robotic. In **Chapter VII** we will pick this thread up in a discussion of the human soul. Here, our main task is to find images or ideas that will help one break free of the anthropocentric view.

A random example that might help: Suppose earthlings succeed in colonizing another planet because The End is Near (meaning either a self-destructive nuclear calamity or the death of the sun). *Who* is happy? Who benefits? In other words, where is the center-of-consciousness, the primary audience, the locus of happiness, for the headline, HUMANS COLONIZE SPACE? I maintain that the expected happiness exists nowhere that is meaningful. If we try attaching the happiness to the pioneers in space, that doesn't work since the whole point is preservation of the 'race back there on earth'. Conversely, if the happiness is attached to the race 'back there', their happiness is not real since they are soon to be annihilated by some dreadful irreversible calamity — else why the mad rush to spend mega-billions on the colonization of a new planet? In short, the happiness only floats and 'has nowhere to go'. It bears a certain resemblance to love in the film *Magnolia*, at the conclusion of which the William H. Macy character tells the policeman, "I really do have love to give. I just don't know where to put it." Somewhere in their collective consciousness the bipeds will have much happiness after colonizing the new planets; they 'just won't know where to put it' (in such a big wide universe). So it won't really be. And there it is again in the word 'be': that embarrassing question of existence.

Or, in a similar vein, consider the Andy Warhol quotation that "In the future, everyone will be world-famous for 15 minutes." (That was his original saying, circa 1968. Later he became bored answering questions about the bon mot and therefore created several bogus variations on it, just to be a jerk.) Many people have repeated the phrase, seemingly accepting it as a kind of received truth of the NYC gliterrati. But if you multiply 15 minutes by any rough approximation of the earth's population

49. Here, speaking as a visitor to our realm, the Proton tries to honor our usual notion of a human/machine dichotomy, but the result can be disheartening. For a different angle on this topic, recall the discussion of the coming 'supermachine population' on page **14**, where the dichotomy itself is questioned.

(or only by the U.S. population for that matter), you'll find that queueing up all those putative 15-minute clips for televising will land many participants some four or five thousand years out in the future. So yes, you will be 'famous', but your fame will *happen* in front of utter strangers, countless generations removed from your own — and does that still count as 'fame' or not? (Since Warhol was so flip, it would be difficult to say if he was numerically a dullard or saw immediately the preposterousness of the plan and took secret cynical delight in its impossibility. My best guess is that he meant it quite literally and failed because of innumeracy to understand his own cynical utterance. See also the footnote on page **344** below.) Again, as in the case of colonizing outer space, I must ask:

Who is happy?

Does happiness really allow itself to be smeared like peanut butter, across so much space (in the case of the extraterrestrial pioneer) or across so much time (for the 15-minutes-of-fame-er)?

Spend just a few minutes thinking about such things, and it should be relatively easy for a person to start relinquishing his biped-centric view of the world. There must be something more 'real', more fundamental on the cards. What could it be? The atom. Only when you focus on the atom will you ever feel genuinely at home and grounded. In its briefest form, that would be my answer to, 'What to do about Garbage World?' (This topic is addressed at some length on page **403** and elsewhere, *passim*, in this volume.)

At first glance, one might feel that a new Copernicanesque shift (as advocated by your author and myself) would be relatively easy to carry out, since this one would involve information already available. Moreover, there would be no redrawing a map of the universe, only a map of my submicroscopic realm, to brighten and dramatize it. But precisely because it pertains to such terribly small entities, it would be daunting. Meanwhile, in lieu of the Church, you would have the Big Science establishment to contend with this time, telling you the future of science lies, obviously, in the stars or in the DNA of 'higher life forms', cleverly manipulated and transferred to chips for embedding in androids. That sort of thing. Indeed, all the 'higher' forms seem at first blush to be terrifically busy and complex and burgeoning (as suggested by **Figure 24** on page **82**). Try never to forget: When compared against a single instant in the life of a proton or electron, these forms can be shown up as absurdly simple, unproductive, slow and short-lived, failing in all respects to be relevant to the actual warp and woof, *our* high art, of the universe (to be suggested by certain examples in **Chapter IV**).

In passing, consider the school of philosophy known as existentialism: the existentialists are quite right to feel angst and nausea, though few of them seem to realize that the source of all their discomfort is to be sought in the stark realities of **Figure 24**, according to which the atom *does* exist and they do *not*. In short, while humankind does represent a tragedy or comedy of sorts, the central problem confronting humanity is not its existence, but rather the opposite: its blatant nonexistence relative to the atomic realm; its counterfeit life.

If your ruminations are not of the existentialist kind, perhaps your concern is: "How can God allow such cruelty, injustice and horror in the world?" One's response would be similar: If there is a God, he would have the form of a hydrogen atom — just me and my electron cloud — and to such a God as that, the Flimsy Foam Cubed must be a phantasmagoric irrelevance, so the point remains moot.

In **Figure 26** we will attempt yet another consolidated view, harking back to Figures **22**-**25** above.

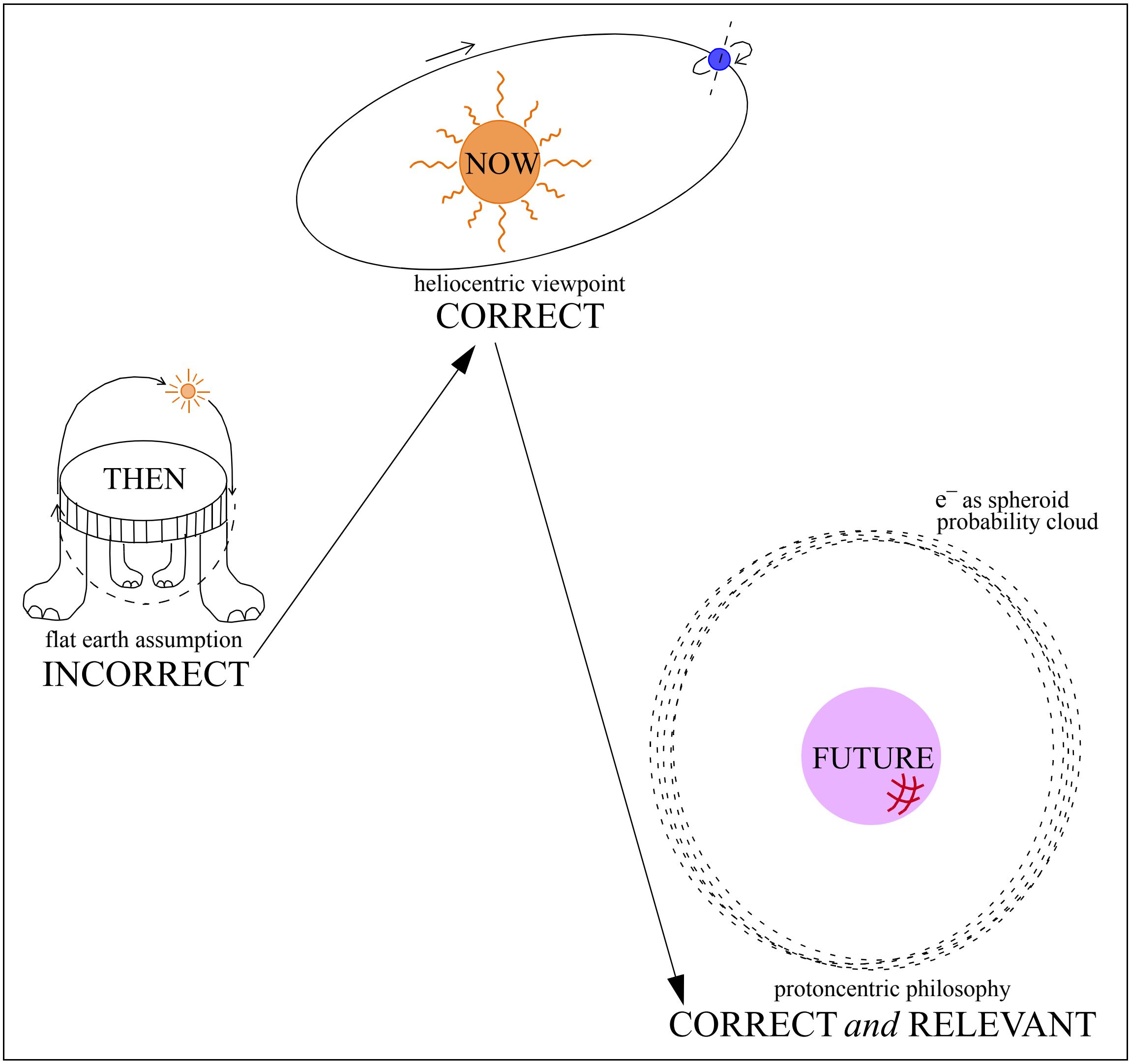


FIGURE 26: Moving Beyond the Heliocentric View

As mentioned on page **18**, there is one scientist of yours who, just for a moment, came close to the embarrassing truth suggested by **Figure 26**, when he inverted the tiresome question of "Why are atoms so small?" and asked, in effect, "Why are bipeds so big?" Given the title of his book, *What is Life?*, it is ironic that Schrödinger's moment of insight into that very question is so fleeting. Rather than pursue his one-page rumination on the atom/biped size difference to its logical conclusion (that the atom is life), he switches gears and devotes the remainder of his book to an anthropocentric concern: How does one's hereditary code-script maintain integrity down through the generations? Writing in 1944, he favored a generic term 'hereditary code-script' because the jury was still out on whether protein or DNA carries the code. Were the 1950s, then, to be the dawning of the Genomic Age? Not quite. Even after DNA's hereditary role was confirmed by the 1952 Hershey-Chase experiment on the T2 phage (Watson, p. 80), and after DNA's structure was deduced in 1953, the journalists were still not ready to declare a Genomics Age. Rather, the 1950s were dubbed the Atomic Age (yet another irony, addressed below), soon to be followed by the Space Age, the Age of Aquarius, the Information Age, the Internet Age...

Apparently, journalists love their Ages, so long as each confines itself to a modest decade:

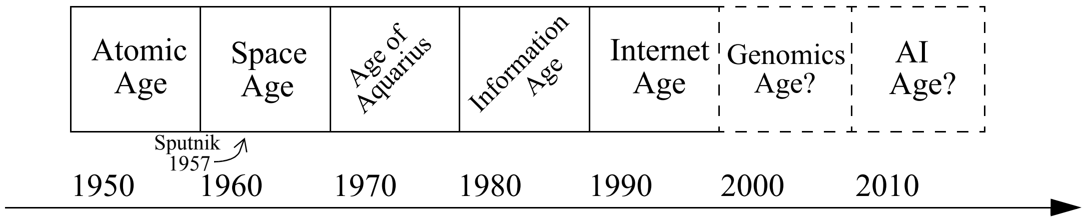
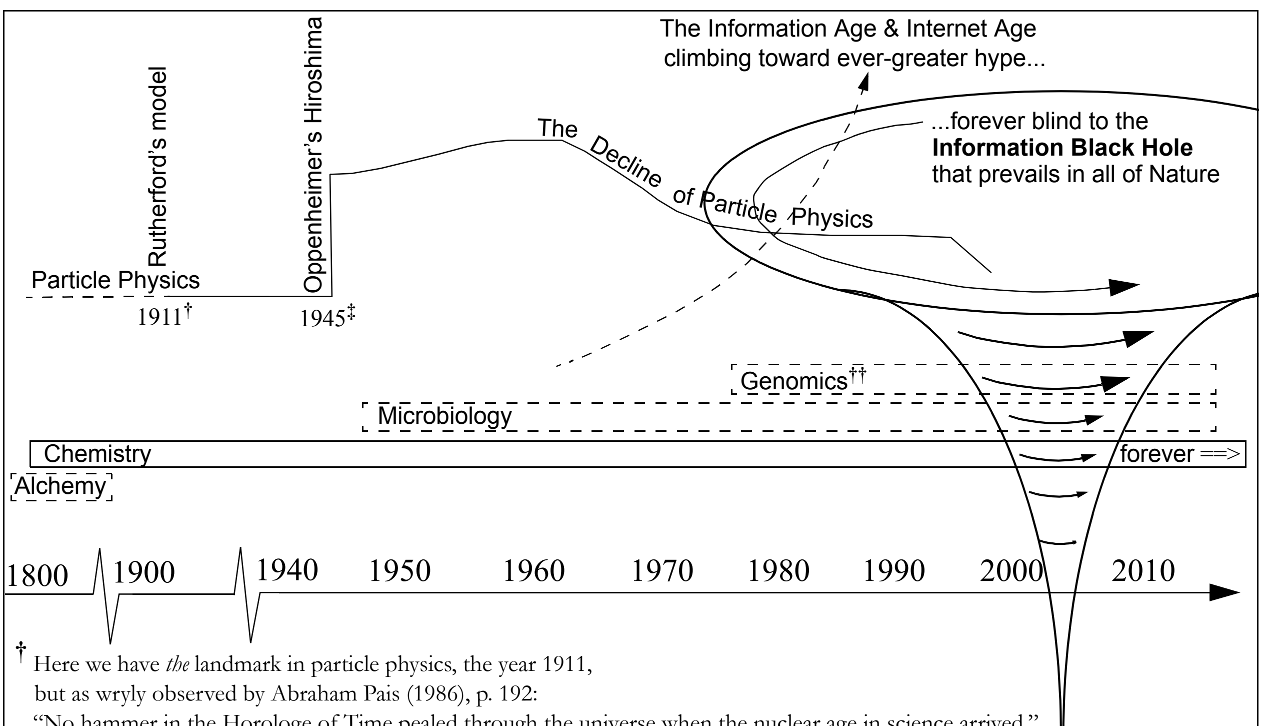


FIGURE 27: Journalistic Time-line

In an effort to improve on the boxy Ages of **Figure 27**, I've drawn **Figure 28**, with the components reworked as a kind of Milkshake of the Ages.



† Here we have *the* landmark in particle physics, the year 1911,
but as wryly observed by Abraham Pais (1986), p. 192:
"No hammer in the Horologe of Time pealed through the universe when the nuclear age in science arrived."

‡ The blame for Hiroshima & Nagasaki we protons attach to one man, Robert Oppenheimer.
To see why, read Herken (2002), esp. pp. 134-135.

†† The term 'genomics' first appeared in 1986, per Danchin, p. 63; thus, in **Figure 27** the lag time for this 'Age' is greater than for the Space Age.

FIGURE 28: Milkshake of the Ages

Rather than accept The Atomic Age in the glib journalist sense of the 1950s (**Figure 27**) let's take control of that phrase and give it some meaning: As I write, the atom has been waiting patiently in the wings for 100 years since its 'discovery' by bipeds, or rather since Albert Einstein demonstrated to the satisfaction of *all* skeptics that the atom even exists (see page **28**). The grace period is over! Now it's time for bipeds to wake up and get serious about the Copernican Shift implied by the presence of the atom as represented in **Figure 26**.

With **Figure 29** (an annotated version of **Figure 6** on page **40**, where we called it a 'mandala'), we switch to yet another perspective on some of the same terrain, to provide a general road map for the book.

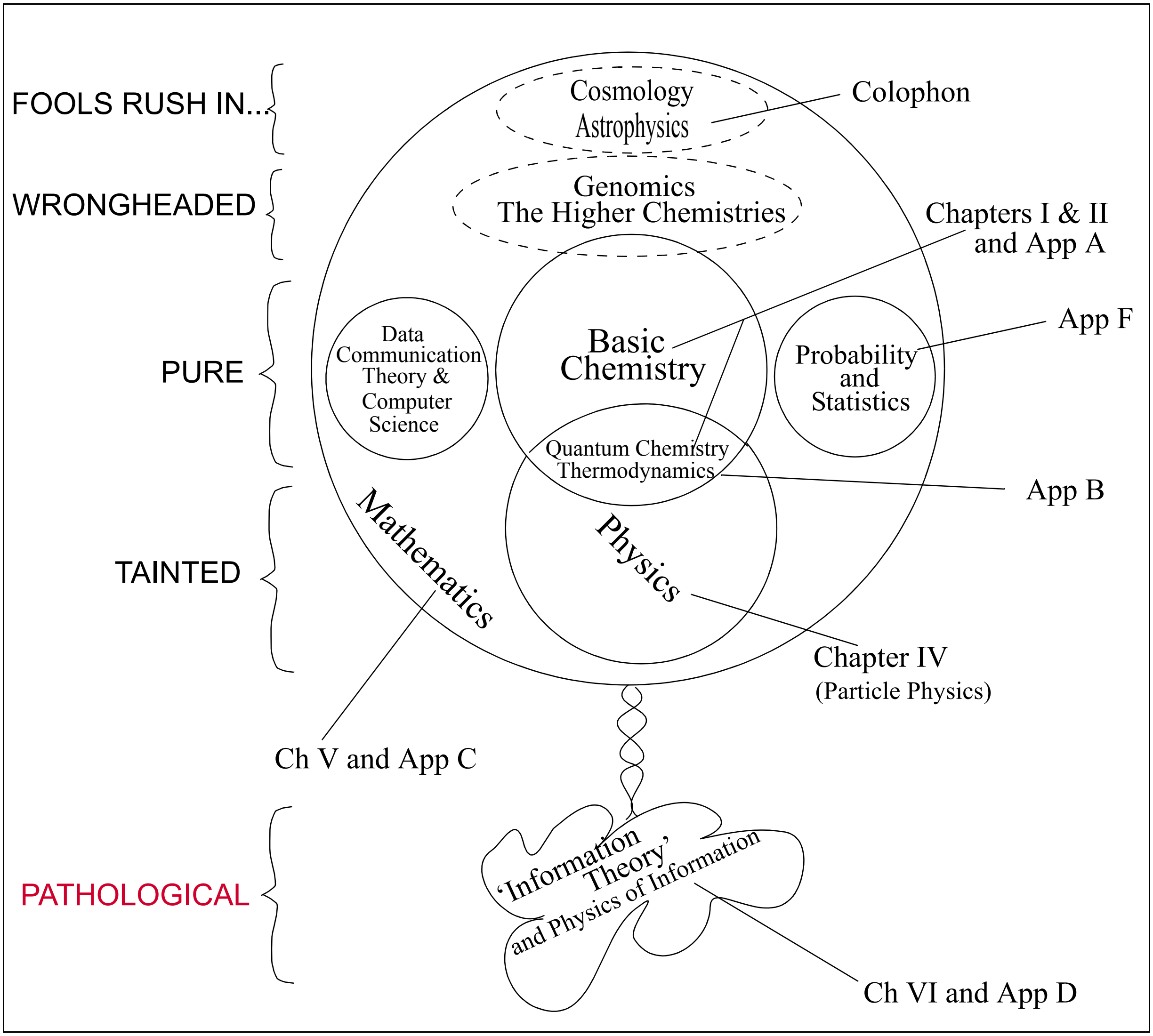


FIGURE 29: The Pure, The Tainted & The Pathological

FOOLS RUSH IN...(WHERE ANGELS FEAR TO TREAD):

The top bubble represents astronomy, cosmology, and astrophysics. These star-gazing fields suffer from inherent problems similar to those of archeology and paleontology AND from the problems that bedevil 'information theory'. As an example of the inherent problems, recall that in January 2002 the color of the Universe was proclaimed to be *turquoise*, but in March of the same year came an embarrassed retraction: the color was actually *beige* (NewScientist.com 07 March 2002). The error was attributed not to science but to a software bug. Whatever. For an overview of the smorgasbord of technical problems that bedevil these fields, see Singh, pp. 365 and 381-383.

Toward such difficulties of doing 'inverted archeology' (as I call it), one can muster a twinge of pity, if not sympathy. (It's a tough job to *correctly* classify one seventh of a proto-feline jaw bone, to *plausibly* assign a color to the whole bloody universe, or to *actually* reconstruct the phonology of Sino-Tibetan; but someone's gotta try, eh?)

But when it comes to those *other* problems in astrophysics, the ones they brought upon themselves by importing nonsense from so-called information theory, one quickly loses her patience. They've nurtured a cult where it seems reasonable (to them, at their Mad Hatter's Tea Party) to build a whole discipline around...

Information-*only*-when-it-isn't-there-but-hidden-in-a-black-hole!

...all the while turning up their noses at the question of what information is and how it differs from data (or rather '**δata**' as it is called in **Appendix D: The Fifty Years' Gibberish: So-Called Information Theory** and **Appendix E: Theory of Information**).

Moreover, one must raise objections to cosmology itself (regardless of what its methods and culture may be): The true locus of life is at the atomic level, and by contrast those at the macroscopic level are 'too big' to be taken seriously as life forms. In moving still higher up the scale toward the solar system, the Milky Way and the cosmos, one is that much further removed from what is important — namely, action at the atomic/subatomic level. So this is a third reason for ranking cosmology so unfavorably in the scheme: Like 'information', the cosmos is chimeric, perhaps unworthy of such an awe-stricken effort of the biped to understand it. (Not yet considered is the Big Bang Nucleosynthesis argument, in favor of studying cosmology precisely because one *does* espouse an atom-centric view; this discussion

I defer to the author, in his Colophon; page **475**.)

WRONGHEADED:

By 'The Higher Chemistries' (in **Figure 29**) I mean such fields as organic chemistry, biochemistry, molecular biology, bionics, and so on, all leading 'up' presumably to genomics. Such topics are undeniably challenging, respectable, trendy, and glamorous. The realm of the superbright. The trouble here is not one of methods/cultures (as in particle physics and mathematics); the trouble is the object of study — so-called 'life' — which is nothing of the kind, only an anthropocentric fetish for advanced machines. We've encountered this idea already in **Figure 24 (A Map of the World: Corrected (Further) to Flimsy Foam Cubed)**, and in the section entitled **Chemistry the Redeemer and the 'inorganic' misnomer** (page **11** f).

I gather that some bipeds shun the higher chemistries 'because life is sacred and should not be engineered'. Our rationale for taking these topics off the table is nearly the opposite of that. Our concerns are pragmatic, not ethical: What is *worth* studying? Certainly not foam-y things in the realm of the phantasmagoric. A biped's sliver of time between cradle and grave is too meager to be squandered on a con that directs one to study recursively his *own* pseudo-life-form. A comparable tragedy: imagine that the supercomputer Hal had been conned into studying only the IC chips on his own circuit boards, thus missing the splendor of Jovian chemistry just outside the portal of his spacecraft.

Whence this craving of the biped for the 'higher' sciences? Listen to Tanford and Reynolds as they comment on Francis Crick's insight into DNA:

> What is astonishing about [Crick's 'sequence hypothesis'] is that there was not at the time any imaginable direct chemical relationship between DNA and protein that might be used to create a synthetic pathway... The emphasis has switched...to 'information content.' A new nonchemical language had to be invented just to express the idea; a metaphor based on 'language' itself — molecular information portrayed as analogous to letters of the alphabet and their ability to create meaningful words. — Tanford & Reynolds, pp. 236-237

Yes, it *was* incredibly impressive the way Crick, Watson, Gamow *et al.* were able to inkle out the nature of the code. However, when viewed from a distance we have here also the makings of what I would call the Alphabetic Fallacy: Every toddler who grows up must learn the following tricky dance step: First make a religion of the individual letters on the alphabet blocks, and then, as soon as the alphabet (or Devanagari script)[(50)] is mastered, realize that the letters themselves are 'nothing', really, and only the gestalt of a whole word counts toward the skill called reading. The *aha* moment of having broken this letter/word barrier must be exciting indeed, a wholly Good Thing that the toddler will remember subconsciously. Forever, alas. For it can also be a conceptual trap, carrying with it the implication that 'up' is always[(51)] better than 'down'; that leaving chemistry behind in favor of a 'higher' nonchemical language *must* be good. Taken to an extreme, this attitude spawns the phenomenon that your author calls *dumbplexity* (page 7).

It is fun to note in passing that Lucretius used the building blocks of language for a very different metaphor, as part of his meditation on atomism: "...you see many letters common to many words; yet you must admit that different verses and words are composed of different letters...So in other things, although many atoms are common to many substances, yet these substances may still differ in their composition" (Lucretius 2.688-697; Latham, tr., p. 54).

THE TAINTED:

Each in its own way, particle physics and mathematics are tainted by an associated biped provincialism or 'theology' (in the mildly pejorative sense). But bipeds have recognized mathematics as the indisputable underpinning for everything else (as suggested by the large all-encompassing ring in **Figure 29**). This is fine, but it puts the pure disciplines (such as chemistry) at constant risk of being adversely influenced by the theological quirks of mathematics. In short, biped mathematics with all its foibles is a necessary evil for the scientists of your planet. So be it. In **Chapter V** we will explore some of the triumphs and embarrassments of mathematics, to help you locate not only the entrance but also the back door exit for escaping that temple-like asylum.

If it were only a question of the discipline being PURE or not, that could be argued back and forth endlessly (by physicists and by mathematicians, for instance, who

50. The Devanagari script takes care of Hindi, Marathi, and so on. But what about toddlers in China? There can be no such letter/word barrier for them to break; however, the teaching of English is so prevalent that they would have the letter/word experience in that context at least. And in Japan, there would be a mixture of the (pure) Chinese experience, where *kanji* are concerned, plus the letter/word experience where *hiragana* and *katakana* are concerned.
51. Unless one is a particle physicist. Then down is always better than up, so to say. For an exploration of this second, mirror-image fallacy, see page 103.

surely see *themselves* as paragons of purity). However, it is not *just* the discipline of chemistry I refer to; it is also *intrinsic chemistry*. Intrinsically it holds a special place among the sciences — once it is properly understood. That's why we single it out for special treatment. Here's the idea. Take a moment to contemplate some phenomena such as thunderstorms, rainbows, camels, shifting sand dunes.

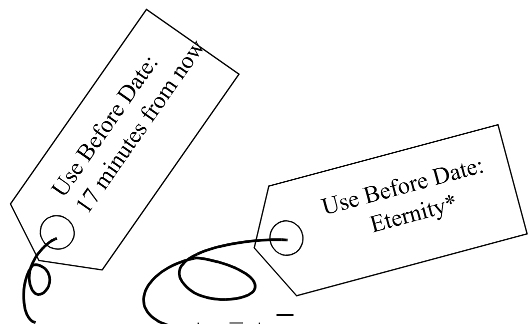
What *are* they?

Physics will claim they are defined by various combinations of electrical forces, optical phenomena, biophysical forces, and mechanical forces. But really they are all just *atoms*, doing what atoms do, with no secret ingredient, no additional anything to parse out save one: the atoms' particular *arrangement* in 3D space, which may give rise to emergent properties. But arrangement is not a thing. Rather, thunderstorms are Fancy Froth, rainbows are Fancy Froth, camels are Fancy Froth, sand dunes are Fancy Froth, even galaxies are Fancy Froth. The only constant, the only reality, the only solid place to stand, so to say (if only your feet were small enough!), is on the atoms that comprise these phenomena. Given the right context, an oxygen atom will do its thing and 'be part of a thunderstorm', but in doing so the oxygen atom is still 'itself': oxygen. On another occasion it may be part of a sand dune. On another day, that same atom might be part of a compound in a camel's liver. But still it would be *itself*: the very *same* oxygen atom, unadulterated. It's one of those truths that is so 'obvious' one can almost walk right past it and fail to see its profound meaning: *atoms* can lay claim to existence and to rich active lives; for everything else, such claims are immediately and endlessly debatable.

You know what comes next: The physicist's retort that, "You can't put stock in something so *ephemeral* as the atom. After all, our best string theorists say the atom is just a collection of *vibrations*, out of which quarks are born, out of which protons and neutrons are constructed, out of which the ghostly atom is formed by the addition of electron clouds. So what? That's nothing real. Plus, we know how to smash it." Such is the knee-jerk reaction of physicist and (educated) layman alike these days to anyone who might suggest that the atom is anything more than a relic of the 1950s. I understand the argument, but I think it is wrongheaded. My counter-argument will take a few pages to set up. We'll start by looking at 'decay', a popular word in particle physics (except when it leads to the delicate subject of proton *non*decay, also covered below).

Sometimes a word choice in a technical field is random, arbitrary or whimsical —

not worth scrutiny since its genesis was a lark or mere historical accident. For example, the Greek letter gamma (γ) serves as the photon's symbol. This usage harks back to the days of the novel 'gamma ray' (preceded by the 'beta emission' and 'alpha particle', so that the first three letters of the Greek alphabet commemorate forever a set of mysteries long since solved). Other times, a word choice might be the touchstone that reveals much about a given field. The term 'decay' as used in particle physics strikes me as such a case. When a neutron 'decays', what really happens? If we use the standard symbols for particles, and add some grocery store call-outs to indicate the shelf-lives of the two main particles of interest, the transformation looks like this:



Here is a case of *so-called* decay, familiar and well-understood for the neutron...

$$n \longrightarrow p + e^- + \bar{\nu}$$

?¦?

...and here would be a *true* decay, *if* it ever happened to a proton:

$$p \xrightarrow{?} e^+ + \pi^\circ$$

* The SU(5) story, highly abbreviated:
SU(5) theory predicts a proton decay rate of less than one every 10^{33} years. In plain English: Eternity.
SU(5) was to be the jewel in the crown of particle physics, the final step following QCD in the 1970s. But the SU(5) scheme for unifying all the particles was never confirmed because *no* proton decay was observed over a period of several decades, in experiments designed specifically to test the '10^{33} years' expectation. Eventually, SU(5) had to be abandoned as it drifted ever deeper into the abyss where a theory might-still-be-true-if-only-you-keep-twirling-all-its-knobs. For me, the interest lies not so much in the drama of the SU(5) story, which is covered very well in Smolin (2001), pp. 54-65, the source of this crude summary; rather, in the related experiments and what they say indirectly about the astonishing longevity of the *proton*.

FIGURE 30: Neutron Decay = Proton Birth

In other words: We depict a neutron (n) in isolation, i.e., not part of a nucleus. Within about 17 minutes, it will transform itself spontaneously into a proton (p), electron, and antineutrino. Rather than call this sequence 'neutron decay', I call it 'proton birth'. Why? Because a brand-new proton is now available (for Eternity) as an ingredient for forming elements, whereas the lone neutron it supplants only sat there passively for 17 minutes and then vanished. (Granted, in a sort of rear-guard legal defense, the term 'decay' can be explained in such contexts by virtue of the shift from a higher energy state to a lower energy state, and the increased entropy. Even still, I find the usage irksome and misleading.)

Part 2 of the diagram: According to a theory called 'SU(5)', a proton *should* decay eventually into a positron (e+) and pion (π°) (or into several other such pairs not represented in the picture). However, *this* time the transformation is only hypothetical. Large-scale underground experiments in Japan and in Minnesota ran for decades without a single such 'proton decay' ever being observed. Thus, the estimated life of the proton keeps getting ratcheted up: It was once thought to be 'no less than 10^{32} years'. It is now thought to be 'no less than 10^{33} years'. And so it goes.

This business about the word *decay* as used in physics starts out as a small annoyance, but leads eventually to insights regarding fundamental truths: the question of whether atoms are 'real', and the question of whether the atom is the basic unit of currency in the cosmos. One might recall the proverb, *To a hammer the whole world is a nail.* It is a saying that seems tailor-made for the particle physicist. To him, everything is an object, waiting to be broken down into something else, if not by spontaneous transformation or by outright smashing to torture a new member of the particle zoo into existence, then by mental gymnastics in the arena of theoretically possible particle 'decay'. Why? Because that's what particle physicists do: they smash things and take pictures. But let's step back a bit and review some fundamentals. What determines the atomic number of an element — its proton count, its neutron count or its electron count? The answer, as even a smart fifth grader can tell you: The atom's proton count. (The sine qua non of mercury *is* its proton count. The sine qua non of silver *is* its proton count. And so on.) And what was the warranty on the proton that we just learned about?

Answer: 10^{33} years or Eternity, whichever comes first.[52]

Such an immense number may seem to live only in the ivory tower, but it has direct relevance to one's everyday life. Suppose you fly from Houston to Chile for a two-week vacation. During that 20160-minute interval, you do many things, but

52. Lest I am suspected of being a romantic and/or proton chauvinist, here is your own George Gamow applying the term 'eternity' to the atom — twice — in a perfectly neutral and pedestrian tone: "But what to do about the atoms built according to Rutherford's model? Theoretically, ... they cannot exist longer than one hundred-millionth of a second, but in reality they do exist for eternity." And again: "This E_1 level is the *normal* or *ground state* of the atom, in which it can exist for eternity." Gamow, 1966, pp. 36-38, his italics.

back in your kitchen there remains on the counter a wooden spoon, let's say, doing nothing. (Well, nothing that one could observe easily at least!) When you return, it is still itself, ready to do whatever it is that a wooden spoon does: stir some soup, perhaps. The reason a substance *is* a substance (or a fabulously complicated compound called 'wood') is because its constituent protons are stable. While the spoon was 'doing nothing', the protons in it were doing plenty: *being* eternal protons. Keeping the wood stable. And, when the wood does begin to deteriorate someday, that will not be because one of us protons has lost *her* integrity. Rather, that deterioration (or 'decay' in another sense) will result from outside forces that alter the wood's molecular make-up and/or the number *of* protons in a given atom, thus morphing it into a neighboring element on the periodic table. Meanwhile, the proton is stable.

But lest one still feel overawed by the particle zoo argument or the image of 'turtles all the way down', we offer also a parable:

Parable of the Music Decreed Noteless

In the year 3029, the Grand Vizier of Sanf decreed the notelessness of music, and hence its demise. Gazing skyward while stroking his white beard, he had reasoned thus: "For over a millennium already, we've known that a 'trumpet note' so-called can be broken down into harmonics, then synthesized on a computer by reverse engineering. This means all notes are illusory. And if notes are not real, neither can music be real." And so it came to pass that 3030 was the Beginning of No Music. But none lodged a complaint, for the Grand Vizier's reasoning was unassailable. Henceforth, those few who might still feel a need to make music could surely satisfy the itch by watching sine waves dance across an oscilloscope instead, since silent decomposed sine waves were the True Reality.

Commentary

Just as knowledge of overtones has not yet caused any conductor to declare the nonexistence of music and the symphony passé, so knowledge of the particle zoo should not cause a rush to judgement regarding the atom. Even if each quark were shown tomorrow to be comprised of, say, an appropriately shaped *Yin*-on half and *Yang*-on half, thus validating ancient Chinese philosophy, one should be underwhelmed. Why? Because physics adheres (unwittingly) to a scheme I call Bottom Turtle Relativism (defined on page 121 f. below). The scheme *itself* is suspect, no matter which level it may be operating on at the moment: Yesterday, we protons were bland placid spheres, the Designated Dumb Things Down There; as of today, your scientists have upgraded us with the volition to take on fancy shapes and to manage our constituent quarks (**Figure 21** on page **78**), and perhaps even our 'moods'? Today, the quark is 'dumb'; tomorrow by fiat the quark may turn 'smart' — smart enough to manage a newly discovered bottom-level-du-jour, the one populated by our hypothetical *Yin*-ons and *Yang*-ons, both suitably dumb and pliant. It's all so arbitrary, how can one take it seriously? (This view of physics is explored further on page **121** f., and in **Figure 31** on page **123**.)

Digression into the Ontology of Rainbows

Suppose the electron clouds that enclose the nucleus were deemed to possess no more reality than that of a rainbow (and likewise the nucleons for that matter, since they may be decomposed into their constituent quarks). I'm thinking of a passage where Nick Herbert uses the rainbow to exemplify things that are simultaneously 'objective without being objects' (paraphrase of Herbert, p. 162). In this worst-case scenario (worst for my proposed atomocentric philosophy, that is), the atom would be classified as object-*ive* but *not* an object. Thus, is it even worth of being chosen as cornerstone for an entire philosophy? That would be the next question. My response: Yes. Here's why: If atoms are that ethereal, then my Tinkertoy biped in **Figure 2** and the flimsy foam in **Figure 25** are that much *more* fuzzy and ephemeral since they rely on atoms for their construction. Thus, there should be no impact on my basic argument that the atom, when compared to any macroscopic entity, is the more substantial and 'respectable' of the two, the more promising locus for life. Meanwhile, deciding whether it possesses the inferior reality of a rainbow or the superior reality of mud is a side-issue, a canard.

Finally, coming at it from the bottom up, we revisit the atom from the standpoint of 'chunking' (as defined in Hofstadter, pp. 285-288) and common sense. Common sense tells us that the atomic level is *still* the right level for chunking. The atomic element is *still* the only plausible unit of currency. (But chunking alone is no panacea; one must have some sense about when to stop chunking, too: Observe how the biped has galloped off to an unhealthy extreme in both directions at once — cutting *down* to the quark, under the compulsions of Bottom Turtle Relativism, and chunking *up* to dumbplexity, as discussed on page **7** and depicted in **Figure 25** on page **84**.)

THE PATHOLOGICAL:

In **Figure 29**, 'Information Theory' refers to a grand (but bogus) field, distinct from Claude Shannon's *Mathematical Theory of Data Communication*, which is *also* known, alas, as *Information Theory.* (In these pages, I will always refer to the former by the name 'data communication theory' — its only proper name but one that fell from grace as 1950s journalists turned relentless in their pimping of 'information theory' as a sexier looking name for Shannon's work. And when I speak of 'information theory' it is to be taken always in quotes, denoting the pseudo-field that hovers about persistently and noisily in the vicinity of data communication theory, cheered on by the ghost of Norbert Wiener who played a leading role in the creation of *both* the solid topic and its psycho sister. For the whole sad story, see **Appendix D: The Fifty Years' Gibberish: So-Called Information Theory**.)

It gets worse. Even if it were free of Wienerisms and other bizarre baggage, information theory would still be a questionable topic for a reason that is purely "structural," to borrow a term from your economics professors.

Two quick examples, from which the larger problem can be readily extrapolated: The universe is an *information* black hole AND a *data* black hole: [1] Consider the question of "How many cookie crumbs were on the floor of my uncle's pickup as of 7:00 p.m. Tuesday?" This leads immediately to the question of "What *is* a cookie crumb exactly?" Surely 1/8 of a cookie is too large to count as 'a crumb', but what about 1/16, and what about 1/32 of a cookie? At some point, things begin to get crumb-y, but *where* exactly does this occur, allowing us to form our first rough-and-ready crumb-definition? And, on the other end of the scale, wouldn't 1/2000 of a cookie be 'too small to matter'? Of course *that* would be too small to matter. Obviously. What a silly question. But what about 1/200th or 1/20th? Somewhere along the way things become 'big enough to matter'. But where exactly? (Similarly, at what age may legal copulation occur and *why*?) The obvious conclusion from this little thought experiment: For many kinds of *potential* data, you are incapable of defining the desired data itself. Ergo, data is largely mythical, just a sad preoccupation of you self-deluded bipeds. [2] Even if *data* of all conceivable types were crisply *definable*, it would still be 99.999999999999% *uncollectable*, meaning *information* is a myth, regardless of all premises about its underlying *data*. Example: Who counted the number of times your left elbow formed an angle between 30 degrees and 60 degrees while your right elbow formed an angle between 35 degrees and 55 degrees on Tuesday? The number of staples in your uncle's stapler on the day you turned seventeen? None of your biped brethren collected these data? Tsk tsk. Why not? What if they possessed forensic value in relation to a complex crime? Now take these same kinds of question down to the cellular level, the molecular level, the atomic level, the quark level, where speed and direction determine my protonic shape as grape, peanut or bagel: At all of those levels, the data is both definable and available, but obviously uncollectable, outside of its one googol-tillionth part during a billionth of an instant. The entire known universe would come to a screeching halt in the effort, if made. In short, even for the subset of cases where we've convinced ourselves that the data is readily defined and measurable, *still* it is being sucked off at multi-astronomical rates into the one great stupidhole[53] that is our universe, like it or not. Thus, the *potential* information hinted at above is lost forever, and so is MOST of all the OTHER potential information about you, the earth, the galaxy, and so on. Mind you, it's nothing personal about you bipeds and your computers and database theories. Not this time. The universe just happens to be an intensely data-hostile place. Ergo, information is a myth, just a sad preoccupation of self-deluded bipeds.

But wait. You say that outside this universe there exist a googolplex of *other* universes whose sole purpose is to manage the information overload of this *one* universe we call home? In principle, that might be a way to solve your severe data-and-information management problem. But be careful what you wish for, as this would also make a triviality of your whole universe. And for one *entire* universe to be labeled 'trivial' is a concept both embarrassing and beyond the reach of humans, I dare say, who find it difficult enough to grasp their *own* triviality relative to a putative *non*trivial universe, never mind the proposed triviality of their entire universe relative to googolplexes of other supervisory universes in the beyond, busily crunching the numbers for them because Someone (nontrivial) deems the data Important. No, that's not an acceptable answer. There is no easy way out: 'Information theory' remains the most pathological *and* the most absurd of all the subjects currently fashionable in biped universities and think tanks.

53. Astronmers call a sonic black hole a *dumbhole*. Looking at data, the entire universe is a data black hole, which means that virtually all potential information is stillborn. To capture the state of data and information together in such a data-hostile environment, I propose that the whole universe be dubbed the *stupidhole*.

Before concluding this section, we must touch on the following...

data communication theory, computer science, the internet, cyberspace, artificial intelligence, robotics

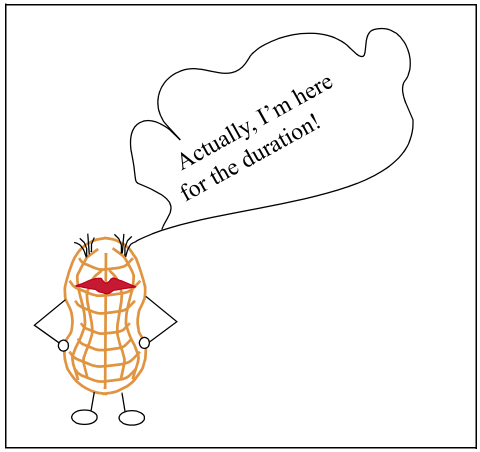
...as all of these are associated with so-called information theory, either directly or indirectly. Indirectly, data communication theory will be covered in some detail in **Appendix D: The Fifty Years' Gibberish: So-Called Information Theory**, in an attempt to clarify its (non-)relation to so-called information theory. Like your chemistry, earthling computer science strikes me as a 'pure' discipline, and it will be mentioned briefly in **Chapter V**, as a tool for illuminating the dark side of mathematics, and again in **Appendix B: Heat Engines and the Cycle-Design Gotcha** to illustrate the 'gotcha' concept (**Figure 61** on page **213**).

Information theory has a curious connection with astronomy. The astronomer likes to talk about 'information', but only when it isn't there, only when it is safely locked away in a black hole. If asked to give a lecture on actual information here and now, the astronomer would surely be tongue-tied.

Information theory is associated also with the 'higher chemistries' by way of bioinformatics and also the endeavor to build databases large enough to support plausible artificial intelligence (AI) and robotics. But none of *this* is my reason for ranking information theory so low as a field of study. Borrowing from medical jargon, we might say that information theory is an 'independent risk factor' for damaging the brain, an intellectual Disaster Area for reasons all its own. Only slightly less dubious than the quest for a 'theory of information' is your quest for artificial intelligence. See Penrose, *The Emperor's New Mind*. (Others have said that Penrose's thesis is: "the brain as quantum device, not a classical computing device." It isn't clear to me that his book has that primary message, but I sense a related subtext in his book that goes like this: If one actually had a grasp of what a human brain is — meaning a really *interesting* brain on the caliber of Penrose's brain for instance — then one wouldn't fool around with silly notions of replicating a brain with clusters of AND/OR logic gates. In other words, artificial intelligence is doomed to stumble not so much for lack of cleverness on the 'artificial' side but for failing to grasp the nature and magnitude of the 'intelligence' side.)

Finally, there is a quieter sandbox to account for, peopled by those who would devote a lifetime to spying upon a single notional gas molecule in a cylinder and dare to label this grandly as 'The Physics of Information'. Really it is the physics of data-computation and data-*storage*, some of which *could* be intriguing stuff, I concede, but only in its place. The result is a modern-day version of 'How many angels can dance on the head of a pin?' complete with Berkelian ruminations that prompt one to ask: "Okay, if it's true, as you insist, that information is physical, then in all the eons *before* Helium was discovered in 1895, did the information 'There exists an element with atomic number 2' exist nowhere in the Universe — just because you bipeds didn't yet *know* about Helium?" And so on. Thus, in too many of its subdisciplines, physics has allowed itself to veer toward Poodle Science.

Your author invited me to write this chapter (and others) by way of showing how the macroscopic realm might appear from the subatomic viewpoint. I must confess it is not a pretty picture. But there is a way out: chemistry as a kind of half-kidding half-serious 'redemption'. It appears that your kind (the biped) is sorely in need of *some* such salvation, not only from the standpoint of a visiting proton, as elaborated in this chapter already, but also in consideration of certain negative forces at work within your own world. Some of these are described in **Appendix G: Time's End (1967) and Garbage World (1992)**.



IV Particle Physics

Now that I'm conversant in a biped language, your author has asked me to go beyond our original contract for a 'Letter from a Proton' (**Chapter III**) and help him with other topics. In fact, I'll be with you for several more chapters, straight through to the Epilogue (**Chapter VII**).

The present chapter begins with a quick retrospective of particle physics, presented in a neutral tone, via **Table 4**, which begins on page **114**. Implicitly, we draw a distinction between particle physics *itself* (an area that should inspire mostly praise rather than criticism) and the particle physics *culture* (where some questionable habits and traditions will be examined later, as a continuation of the critique that began intermittently in Chapters **I** and **II**).

The scheme works well, so we use it again, explicitly, in the ensuing chapter on biped mathematics: first mathematics *itself*, then the mathematics *culture*. (But we will not give similar treatment to chemistry, for we believe chemistry to be relatively 'sane', subject to a few peccadilloes, as pointed out in **Appendix I: Myths & Realities of Electrochemical 'Flow'**, for example, but with no such neurotic cultures as manifest themselves *egregiously* in physics and especially mathematics.)

Our ultimate goal is to appreciate the atom as the foundational life-form (compared to which everything higher is Flimsy Foam Cubed, as depicted in **Figure 24**b on page **82**), but in your universities I find no such subject as *atomry* or *atomology*;[54] rather, the atom is to be understood by exploring the wide band of overlap between biped chemistry and biped physics. Clearly, anyone interested in 'the atom' is obliged to spend time with both disciplines, or risk missing out on important insights and perspectives. (Hence, this generously proportioned chapter on physics in a volume whose focus, ostensibly, should be on chemistry to the exclusion of physics.)

One need look no further than the device known as a car battery to see the difficulty of drawing a neat line between physics and chemistry: Viewed as a box on a block diagram, a car's battery is what triggers mechanical motion in the starter engine, and is thus a (small) part of *physics*. Viewed rather as the broth in a hermetically sealed container where liquids and metals do sexy things to one another, the battery is a (big) topic in *chemistry* called electrochemistry. Meanwhile, the engine in your car doesn't really 'care' about all this: it simply starts with an explosive roar, because that's what engines do, oblivious to any such mechanical/electrical/chemical boundary line(s) that might help the academician match physical events up with favorite cubbyholes in the taxonomy. Let's say the battery suffers a physics/chemistry 'identity crisis', then. Note that this problem will manifest again in the discussion of galvanic cells in **Appendix I: Myths & Realities of Electrochemical 'Flow'** (page **429**f).

Though it lends little weight to my argument about 'overlap', it is fun to note in passing the 'exotic atoms' phenomenon. One such atom is *muonium*, its name derived from a member of the particle zoo (*muon* has its own long humorous history: in **Table 4** see the entry for 1934 and its footnote [**d**] on page **118**), plus a pseudo elemental suffix, *-ium*. It gets better: it's actually made up of an *anti*muon (playing the role of proton) and an electron. It is represented by the symbol μ^+e^- or by *Mu*, the latter by analogy with standard symbols in the Periodic Table such as Mg, Mo, etc. Also, compounds with names such as *sodium muonide* (NaMu) are possible, though very short-lived, since muonium itself is so ephemeral. Here is the physics/chemistry overlap at its most whimsical, putting to shame the would-be

54. True, Democritus, Epicurus and Lucretius each in turn included a kind of 'atomic theory' as part of his philosophy, but the particular kind of 'atomism' I need here today stands in sharp contrast to their assumption of an insentient atom. Compare pp. **18** and **22** above.

'creative writer' with truths stranger than fiction.

Evidence of an overlap between the two fields is found also in the content of the two curricula: For example, any freshman physics text *or* freshman chemistry text will be sure to contain a chapter or two on thermodynamics. Or, at the intermediate level, suppose you wanted to take classes in statistical mechanics and quantum mechanics. Coverage of these topics can usually be found in the chemistry department in a two-semester class called Physical Chemistry or Quantum Chemistry (see sample problem on page 44), *and* in the physics department, in separate classes called Statistical Mechanics and Quantum Mechanics.

Another consequence of the artificial physics/chemistry split is the opposite case where — instead of getting good coverage in both fields, as thermodynamics does — a topic falls in the crack and is barely covered by *either* discipline, or is given uneven and unpredictable depth of coverage in the textbooks. I'm thinking of ionization energy (aka ionization potential, aka binding energy): the energy required to remove an electron from an atom. Because ionization potential is classified as a 'chemical property' of the atom (i.e., something chemists care about and physicists don't), a physics textbook author may feel no obligation to cover it at all. Conversely, since — as soon as one scratches its surface — the topic rapidly shades off into the inner workings of the atom, a chemistry textbook author will typically focus on the *consequences* of ionization potential, thus excluding 'unnecessary' details such as the fact that the Balmer series appears to approach a definite limiting value. True, this crucial aspect of ionization potential is mentioned in Langford & Beebe, pp. 236-237 and 260-261, but note that theirs is not a textbook at all, it is a broad leisurely *historical retrospective* on how chemical principles were developed. (For more on this, see page 179 below.)

Another example:

> Atoms are studied by physicists, molecules are studied by chemists,
> n'est-ce pas?

WRONG! Language is a double-edged sword: The very thing that makes it so powerful and convenient, usually, is also the thing that often can turn the brain off and lead one down a semantic rat hole. The proposition above is a half-truth at best. In the sense that particle physics deals with subatomic events it is TRUE; in the sense that chemistry textbooks have lots of molecular formulas in them, while physics textbooks have only a sprinkling of molecular formulas in them, it is TRUE.

But in a very important and fundamental way it is FALSE: The heart and soul of chemistry is the Periodic Table. And many chemists are literally 'card-carrying' as they keep Periodic Tables in miniature in their wallets, just in case the copy in one's head should develop a fuzzy spot. ("Is bismuth really the next-door neighbor of polonium?") And what is the Periodic Table a celebration of? The atom. Nothing to do (yet) with molecules, except for the atoms' great implicit *potential* to form such structures. Whereas, to a physicist, the Periodic Table is just another table to consult when needed, with zero sentimental attachment. None of the kind that Oliver Sacks articulates so well in *Uncle Tungsten*, for instance.

We'll begin with a whirlwind tour of particle physics between the years 1874 and 2000, as represented by **Table 4**. The table is constructed from two main sources: The Theoretical column is populated primarily by items that I abridged from the *Chronology* in Pais, pp. 627-637; the Experimental column is based primarily on Close, pp. 230-233 (rearranged in chronological order and with a few items shifted one year earlier per the more precise dating in Pais). The Experimental column is supplemented by several items from Jim Al-Khalili's *Quantum*. In building the table, I've represented all 100 years of the twentieth century, even those years for which no event had a high enough profile to populate a cell (e.g., the years 1904 and 1938); this way, the 'Year' column serves double duty as index and time-line, providing a visceral sense of the ebb and flow of theoretical versus experimental activities, e.g. the flowering of theoretical talent in the 1920s and 1930s, contrasted with the wave of experimental triumphs in later decades.

How to read **Table 4**: Note that Al-Khalili regards 1920 as the *end* of the Quantum Theory era and the start of Quantum Mechanics proper; from that viewpoint, our single column called Theoretical Highlights is in danger of looking rather clumsy. The Experimental Highlights column is a compendium of particles, represented by their symbols in chronological order:

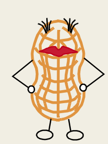
e^- = electron; p = proton; γ = photon (the old 'gamma ray'); e^+ = positron; n = neutron; μ = mu meson or muon; π = pi meson or pion, K = kaon, $\bar{p}$ = antiproton, 'u d s' = up quark, down quark, strange quark; and so on.

Note that for a given year, these two columns are — by and large — to be read in-parallel-but-separately. E.g., gamma rays were discovered in 1923, hence the γ character in the Experimental column for 1923; but this γ has nothing to do with the entries in the Theoretical column for 1923. On the other hand, there are also plenty of cases where one must read the two columns together to get the whole story: The stretch from 1911 to 1920 stands out in this regard: The presence of Rutherford is felt strongly in both columns. (In the literature, most writers hasten to paint Rutherford as 'just an experimentalist', an unfortunate typecasting that is reinforced by Rutherford's own suspicion of projects that were too vaguely theoretical-sounding. A significant exception to the rule is Abraham Pais, who uses the words 'Ernest Rutherford, theoretical physicist' as a section heading, after which he paints a balanced picture; see Pais, pp.188-193.)

By contrast, one is inclined to register the presence of Hantaro Nagaoka as 'only a theorist', and rightly so. (In 1903 Nagaoka proposed a variation on the Saturnian model considered earlier by Maxwell; though said to be seriously flawed in its details, at a high level of abstraction Nagaoka's Saturnian atom might be regarded as anticipating both Rutherford's planetary model of 1911 and even the refinement involving 'probability clouds' that are currently favored. Just for fun.)

The relation of theory to experiment is especially convoluted for the year 1964, as partially described in table footnote **(g)**. Along with 1920, another landmark is 1932, the Miracle Year when antimatter was confirmed *and* the neutron discovered (Gino Segrè, p. 236). From 1932 on, the Experimental Highlights column is noticeably busier than the Theoretical column; the emergence of this pattern is what justifies the high-level split into a pair of columns labeled Theoretical and Experimental in the first place, which otherwise might seem too heavy-handed.

TABLE 4: Theoretical & Experimental Highlights in Particle Physics

Theoretical Highlights (along with theoretical highlights, this column also contains selected new *terms*, in quotation marks)	Year	Experimental Highlights [this column also contains new *devices/facilities* in brackets]
Stoney: ‘electron’ (Langford & Beebe, p. 149)	1874	
Balmer’s formula for the hydrogen spectrum; birth of Bohr	1885	
	1895	[Wilson cloud chamber]
First J.J. Thomson model; see footnote 77 on page 180.	1897	e^- Key to the symbols in this column: See text above or first footnote following table.[a]
Curie: ‘radioactive’	1898	
	1899	
Rutherford: radioactive half-life; Planck: quantum	**1900**	
	1901	
	1902	
Hantaro Nagaoka: Saturnian model; J.J. Thomson: plum pudding model (see fn 77); Rutherford: ‘atomic energy’	1903	
Rutherford: ‘half-life’	1904	
Einstein: light-quantum and $E = mc^2$	1905	
Rutherford: α-particle scattering	1906	
	1907	
	1908	
Rutherford: *back*-scattering	1909	
Haas computes *correct* Hydrogen radius as he makes first *attempt* to (fully) relate *h* to atomic structure.	**1910**	
Rutherford: nuclear model with positive core (‘planetary’)	1911	p (In hogging all this space, have I allowed my Proton Pride to get the upper hand? No. If you compare other accounts of the discovery of the proton [1911-1919] and the rethinking of protonic shape [1995-2000] you will find that these unusually stretched-out events in the history of particle physics are already canonical, not my doing.) 
Rutherford: ‘nucleus’; nuclear spectroscopy begins	1912	
Bohr trilogy, including decoding of Balmer-Rydberg-Ritz equation(s); emergence of proton-*electron* model; Moseley: With Z numbers, he ‘calls the roll of the elements’ (Pais, pp. 228-229)	1913	
	1914	
Sommerfeld: the fine structure constant[b] $= e^2/\hbar c \approx 1/137$	1915	
	1916	
	1917	
	1918	
	1919	
Rutherford: the word ‘proton’ in print	**1920**	
Landé: half-integer quantum numbers	1921	
	1922	

Theoretical Highlights (along with theoretical highlights, this column also contains selected new *terms*, in quotation marks)	Year	Experimental Highlights [this column also contains new *devices/facilities* in brackets]
DeBroglie waves[c]	1923	γ
Bose-Einstein statistics	1924	
Heisenberg: **matrix mechanics**; Pauli: exclusion principle; spin postulated	1925	
Schrödinger: **wave mechanics**; Fermi statistics; Wigner: group theory; Dirac: Quantum Electrodynamics (QED); Dirac: prediction of e^+	1926	
Heisenberg: uncertainty relations; Pauli: matrices; Dennison: proton spin	1927	
The Dirac equation (QED + Sp. Rel.); Wigner: parity	1928	[first linear accelerator]
Lagrangian formulation of quantum field theory	1929	
Dirac's e^+ proposal (published May '31; experimentally observed December '31); Pauli posits the neutrino in 12/4/30 letter (but its name is 'neutron' until 1933).	**1930**	
	1931	[first cyclotron, Berkeley] [first electron microscope] e^+
Heisenberg: isospin; Wigner: time-reversal. The Miracle Year (see page 113).	1932	n
Fermi β-decay (n --> $p + e^- + \bar{\nu}$); Fermi 'neutrino'. (This new name was needed because *the* neutron (n) was discovered and named in 1932. Still, neutrinos remained theoretical, not confirmed experimentally until 1956.)	1933	
Yukawa: meson[d]; DeBroglie: 'antiparticle'; Heisenberg's Hamiltonian formulation.	1934	
EPR thought-experiment; Schrödinger's cat	1935	
Serber: 'renormalization'; SU(4) symmetry	1936	$\mu^+\mu^-$
	1937	
	1938	
Meitner: 'nuclear fission'	1939	
	1940	
Møller: 'nucleon'	1941	
[Manhattan Project: 1942-1945]	1942	
Heisenberg: S-matrix	1943	
Schrödinger: *What is Life?* [and, Why are humans so big?]	1944	
	1945	

Theoretical Highlights (along with theoretical highlights, this column also contains selected new *terms*, in quotation marks)	Year	Experimental Highlights [this column also contains new *devices/facilities* in brackets]
Pais: 'lepton'	1946	[Berkeley Synchrocyclotron 380 MeV α-particles]
	1947	[Brookhaven National Laboratory] $\pi^+\pi^-\ K^+K^-K^\circ$
Beginnings of QED renormalization program	1948	
	1949	[first time a new particle was discovered in an accelerator experiment] π°
	1950	
Evolution of CPT theory, 1951-1957	1951	Λ
	1952	[Brookhaven Cosmotron accelerates protons beyond 1 GeV] Ξ^-
Gell-Mann strangeness scheme; conservation of leptons	1953	[Berkeley: first bubble chamber pictures[e]] $\Sigma^+\Sigma^-$
Pais: 'baryon'	1954	[birth of CERN]
theta-tau puzzle	1955	$\overline{p}$
	1956	confirmation of the neutrino[f] $\overline{n}\ \Sigma^\circ\ \nu_e\ \overline{\nu}_e$
T.D. Lee and C.N. Yang: P- and C-violation (1956-1957)	1957	C.S. Wu: downfall of parity
weak interactions mediated by bosons (later aka 'W-bosons')	1958	$\overline{\Lambda}$
	1959	[Berkeley 72-in hydrogen bubble chamber] Ξ°
	1960	
Gell-Mann: a corrected version of SU(3), following Ikeda *et al.*, 1959	1961	
Okun: 'hadron'	1962	$\nu_\mu\ \overline{\nu}_\mu$
	1963	
Hypothesis[g] that all hadrons are composites of 3 species of quark and antiquark; introduction of a 4th species, 'charm'; John Bell: nonlocality.	1964	u d s $\bar{u}\ \bar{d}\ \bar{s}$ Ω^-
color	1965	
	1966	[SLAC]
neutral currents	1967	

Theoretical Highlights (along with theoretical highlights, this column also contains selected new *terms*, in quotation marks)	Year	Experimental Highlights [this column also contains new *devices/facilities* in brackets]
	1968	At SLAC and at CERN, '68-'72: Confirmation of partons, i.e., quarks; electron-proton scattering is 'hard'.
	1969	
charm eliminates paradoxical properties of neutral currents	**1970**	
	1971	[ISR at CERN]
	1972	[Fermilab] [SPEAR at SLAC]
beginnings of quantum chromodynamics (QCD) and Grand Unified Theory (GUT)	1973	neutral currents in neutrino reactions
beginnings of supersymmetry; 'charmonium'	1974	$c\ \bar{c}\ J/\psi$
	1975	$\Lambda_c\ \tau^+\ \tau^-$ (tau-lepton)
	1976	[SPS at CERN] $D+\ D^\circ$
	1977	$b\ \bar{b}\ \Upsilon$ (upsilon)
	1978	[PETRA at DESY]
	1979	g
	1980	[PEP at SLAC]
	1981	[$\bar{p}p$-collisions at CERN]
	1982	Aspect: confirmation of Bell nonlocality
	1983	$B^-\ B^\circ\ W^+\ W^-\ Z$
	1984	[Fermilab reaches 800 GeV] nuclear halos(h) (mid-1980s)
	1985	
	1986	
	1987	
	1988	
	1989	
	1990	
	1991	Λ_c
	1992	
	1993	Supercollider project cancelled; tunnels converted to mushroom farm
	1994	

Theoretical Highlights (along with theoretical highlights, this column also contains selected new *terms*, in quotation marks)	Year	Experimental Highlights [this column also contains new *devices/facilities* in brackets]
Gerald A. Miller at U of Washington: The proton is not always spherical. Confirmed in 2000. Our more specific reference, in support of **Figure 21** on page **78**, is to Miller, 'Shapes of the proton', *Physical Review* **C 68** (2003), pp. 022201-1/022201-5.	1995	$t\,\bar{t}$ anti-atom made at CERN
	1996	
	1997	
	1998	
	1999	
	2000	$\nu_\tau\ \overline{\nu}_\tau$

a. e^- = electron; p = proton; γ = photon (the old 'gamma ray'); e^+ = positron; n = neutron; μ = mu meson or muon; π = pi meson or pion, K = kaon, $\bar{p}$ = antiproton, 'u d s' = up quark, down quark, strange quark; and so on.

b. The fine structure constant is described in Crease, p. 111, as encapsulating the relation between electrodynamics (e), quantum mechanics (h), and relativity (c). Conceived at first as one over an integer, 1/137, later it was understood to be an irrational 1/137.035 963... See Pais, pp. 215 and 463.

c. Students and chroniclers of physics seem well aware of the 1920s as an extraordinarily vibrant and productive era: one can only marvel at the entries for that decade as they step through the names of DeBroglie, Bose, Einstein, Heisenberg, Pauli, Schrödinger, Fermi, Dirac, Wigner. Meanwhile, music historians seem to have been beguiled by the term 'twentieth-century music' which they interpret literally, thereby missing out on the full significance of 1920s music which, similarly, possess the 90% essence of the *music century*, so to say; see page **404**.

d. A few muon-related quotes: "Who ordered *that*?" (I.I. Rabi, as quoted straight in Lederman, p. 294); "Who ordered the muon?"(I.I. Rabi, as nicely tweaked by A. Zee); 'the ten-year joke' (Oppenheimer, in reference to the interval that stretches from the muon [1936] to the pion [1947], which finally correlated with the meson proposed by Yukawa in 1934); 'Divine Laughter' (Pais p. 452).

e. Berkeley bubble chamber, 1953: This sets the stage for Emilio Segrè's discovery of the antiproton ($\bar{p}$ in 1955, followed by $\bar{n}$, $\bar{\Lambda}$, and $\bar{\Xi}^\circ$ in 1956, 1958, and 1959.

f. For an overview of the neutrino story, compare entries for 1930 (where it was called the 'neutron'), 1933 (where its name had to change), 1956 (electron neutrino and electron antineutrino, aka β-decay neutrino), 1962, and 2000 (where a fifth and sixth flavor of the neutrino are discovered).

g. If we consider the items listed for 1964 and 1969 together, we see a blurring of the line between theory and experiment, in a way that would not have been tolerated before the weird world of quarks: When assigning a date to the *u d s* quarks, Close *et al*. (pp. 230-231) choose 1964, and only then mention that direct observation was in 1968-1972 at SLAC and CERN. To see how odd this is, compare the case of the neutrino: In terms of theory, it was nailed by Pauli in 1930, but not experimentally confirmed until 1956. Which date is chosen for listing the neutrino? The latter, of course. Compare Crease, p. 179, where the omega-minus is cited for 1964, as a discovery that clinches Gell-Mann's SU(3) scheme. That seems a more reasonable way to interpret the events of 1964, but since I've chosen Close *et al*. as my primary source for the Experimental column, I've done the 1964 entry 'their way' with this caveat attached. (Keep in mind that even Gell-Mann talked vaguely about quarks as late as 1966, *still* equivocating about whether they were just useful mathematical constructs or something real.)

h. My sources for Schrödinger's cat; John Bell; Alain Aspect; and nuclear halo entries are found here: Al-Khalili, p. 115, pp. 70-71 and 102-103.

Bringing the story to life: Behind many of the *one-word* items summarized in the Theoretical column of **Table 4**, there are *multiple pages* of anecdotes and personal reminiscences mixed in with mathematical formulas (labeled sequentially as in a textbook) in the body of Pais's six-hundred page book — an unusual and attractive format.

Lest you suspect that I've imposed the term 'theological' on physics as an outsider, I should provide a few quotations where we see the term applied (in its mildly pejorative sense) from inside the field:

> The physicist Shoichi Sakata once warned others in his field against the "inverted viewpoint of believing the ultimate aim to be a discovery of the symmetry properties as a type of 'theology' " — quoted in Crease, p.262.

> "It's gotten a bit too theological," said Howard Georgi, a field theorist (Grand Unified Theory, 1974) commenting on string theory — quoted in Crease, p. 36.

> "[Gell-Mann] retained a lingering annoyance at Glashow, who for more than a decade had been mockingly comparing the ideas about superstrings to medieval theology." — Johnson, p. 349.

Here are four quick examples of my own to provide a preview of what I mean by a 'taintedness', or theological flavor in physics:

1. As quarks began to be confirmed as real (i.e., as something more than mathematical constructs for convenience), why didn't physics revise their fractional charges +2/3 and –1/3 to be full charges +2 and –1? The whole scheme could still work, with the proton (that's me!) now having a +3 charge and the neutron 0 (as before). Then the electron would be –3 instead of –1. If physics were an *un*tainted science, I say, it would have made this adjustment.(55) Instead, the high priests swirled their robes, wafted their incense, and reveled in the fake exoticism of the quarks' 'fractional charge'. After all, "It was an article of faith that the smallest unit of charge was –1 or +1" (Johnson, p. 203), and who would be so foolish as to question the faith? Actually, there was one such renegade: Abdus Salam (Nobel Prize, 1979) did once briefly entertain the notion of integer charges for quarks, as recounted in Crease, p. 396. (So, if you have ever entertained that lonely train of thought, you see that you're not quite *so* crazy after all.)

2. Looking at Lee and Yang's conjecture and the results of Madame Wu's 1957 experiment (described in some detail on page **135**-page **142** below), why didn't

55. ... and found the truth, incidentally: my charge *is* +3, as it happens.

physics roll the timpani of doom and *admit* the downfall of parity? Instead, they persisted in using euphemisms, referring to the event as a 'violation of parity' or a 'parity nonconservation' event.[56] Fast forward several decades: We find the physics establishment still engaged in its quixotic mission to rewrite the rules such that all 'violations' and 'nonconservations' might be tidied up and put to bed. If physics were an *un*tainted science, its practitioners would have changed course the moment they were aware of Madame Wu's result, with its clear message that parity is not the overarching principle of the Lord, only a biped preoccupation.

3. Heisenberg's paper on the uncertainty relations is famous. Few are aware of the circumstance of its publication, though. For various reasons, Bohr thought it was not ready for publication in 1927. Uncharacteristically, Heisenberg ignored this advice from Bohr and rushed the paper into print anyway. Why? Because Heisenberg was in a frenzy, with the clearly stated motive of trying to thwart the ascendancy of Schrödinger. (For the whole story, see Segrè, p. 141-149.) To the end of their days, both Einstein (taking Schrödinger's part) and Heisenberg remained in a theological snit over the issue of how best to approach wave mechanics versus matrix mechanics. Both kinds of calculation are used today by students and working physicists. But the underlying philosophical dispute still smoulders and could easily flare up at any moment.

4. From the story of Pauli and the neutrino (in G. Segrè, pp. 193-199), we see a different side of Bohr. Here, it's not so much a case of 'theology' as it is an astonishing pope-like obstinacy on the part of Bohr. Both Pais (p. 314) and Segrè entertain the notion that Pauli's uncharacteristically revolutionary behavior in

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56. My first encounter with the term 'downfall of parity' was in George Johnson's biography of Gell-Mann (*Strange Beauty*, p. 150). Thus, it took an 'outsider' (a biographer) to find the right word for the occasion. It is easy to see why a term like 'violation' or 'nonconservation' was used initially, in the heat of battle. But years later, the event is still referred to by physicists as *a* 'violation' when in fact it was *the* downfall. Possibly it's just a matter of convenience and continuity, a desire to avoid a proliferation of names all for the same historic event, but I am skeptical of that explanation. Put it together with events leading up to 1957, and the linguistic oddity feels more like a case of dysfunction; anything to avoid admitting there was a downfall of parity. Despite all the scientific evidence, emotionally and philosophically they just won't let go of it. That's what it feels like. And this is ironic, since they generally claim to have such clarity about the line between science and philosophy. Consider, for example, the very last sentence in *Symmetries, Asymmetries, and the World of Particles*: "To meditate on the union of the microscopic and the macroscopic is philosophy, to quantify their dualism is physics" (T.D. Lee, 1988, p. 56).

proposing the neutrino was connected somehow with the unusual turmoil in his personal life. I disagree. Read Segrè's own account of how the tension grew between Pauli and Bohr (who insisted pigheadedly against the whole world on explaining the β-decay anomaly in terms of nonconservation of energy), and it seems obvious to me that what pushed Pauli over the edge, temporarily away from his usual self-described conservatism into a brilliantly radical style, was Bohr. I say it was 70% Bohr's obstinacy that prompted Pauli to send his 12/4/30 open letter to be read at the gathering in Tübingen (with the hope of putting an end to their protracted 'discussion'), and only 30% Pauli's personal-life turmoil. Thus, we can thank Bohr for being midwife to the neutrino, delivered to us from Pauli's mind nearly 30 years before its experimental confirmation, but equally I blame Bohr for thus doing his part (all that mulish nonconservation of energy in the sun, etc.) in turning physics into a tainted discipline.

Bottom Turtle Relativism

The lesson that many take away from the embarrassment of the particle zoo years (say 1947-1962) and the lesser chagrin of the standard model (with its outré whimsy of quarks and antiquarks) is "Be careful about assuming that no lower level of detail exists." As seen by us protons, that's not the real issue, though. The lesson still unlearned by bipeds is that one creates blind spots — at *whatever* intermediate or ultimate depth in the probing effort — so long as one carries an unconscious assumption of the Designated Dumb Thing Down There (DDTDT). The DDTDT assumption is related to but distinct from the danger of assuming 'no lower level exists'. It is part of a bigger topic I call Bottom Turtle Relativism, or BTR syndrome for short. (Both terms were introduced briefly on page 102 above.)

The term 'Bottom Turtle Relativism' is meant to evoke, among other things, the turtles-all-the-way-down story, one version of which runs as follows:

Little Old Lady's comment after a public lecture on Astronomy:
"Don't you know? The Four Legs of the Universe rest on a turtle's back."(57)

The patronizing speaker: "But what does the turtle stand on, hm?"

She: "You think you're so clever, young man. Well it's *turtles all the way down*."

It's not that one wishes to take sides in the possibly apocryphal debate. (Following a lecture by Bertrand Russell perhaps? Or Arthur Eddington? But really who cares, as the legendary lady and her pithy comments have taken on a life of their own, quite eclipsing the fame of this or that astronomy expert at the podium.) Rather, the point is to wake up and *notice* when one is making assumptions of whatever kind about what is 'down there'. The word *relativism* I intend as a mild pejorative, as when one speaks of 'moral relativism'. By contrast, one might regard *relativity* as a value-neutral term.

This is the malady: While traversing certain scales that seem smooth and objective from a distance, you bipeds have a tendency to turn arbitrary and subjective at certain key points, tacitly changing the rules of the game. To demonstrate how thoroughly BTR permeates the human psyche, I will give examples that show it at work across a broad range of situations that have little in common *except* for the common thread of BTR psychology. A preview of and framework for the discussion to follow is provided by **Figure 31**.

57. Here she would be thinking of something along the lines of **Figure 22** on page **79**, but with the four elephantine feet resting on the back of an immense turtle, as large as the world itself (a rather Indic-sounding notion?) Incidentally, the elephant motif in my illustration is thanks to faulty memory: For a time, that's the way I remembered a biblical illustration called The World of the Hebrews. In reality, the picture in question, in *The St. Joseph Edition of The New American Bible* (1970), p. 4A, shows your planet supported by six 'Columns of the Earth'. (And the six Columns in turn are 'supported', rather improbably, by the Abyss!) In the original, the shape of each Column is only vaguely reminiscent of an elephant leg, I realize now. But I leave my drawing unrevised since the image fits so nicely with our story, here, of turtles all the way down.

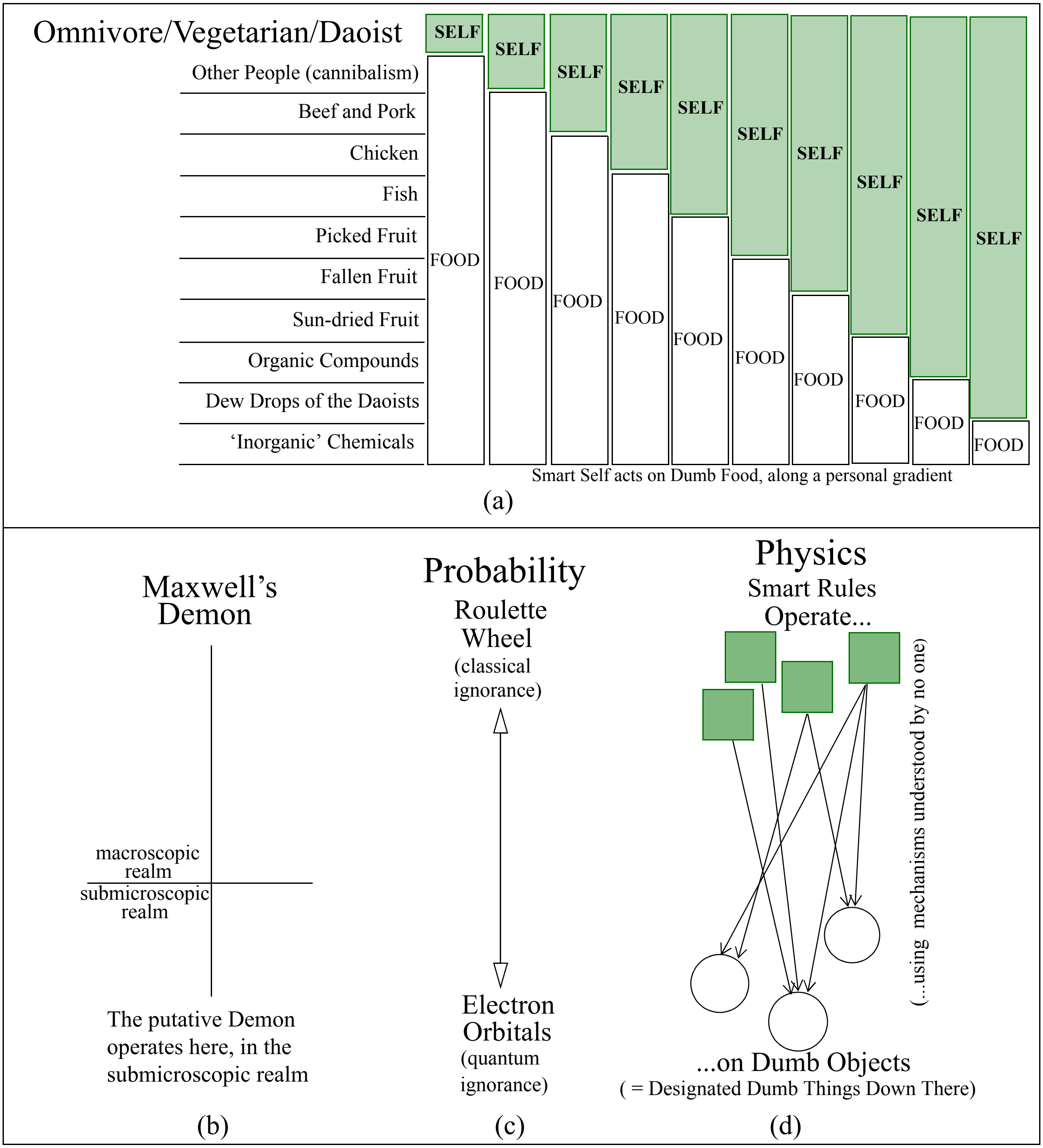

FIGURE 31: Bottom Turtle Relativism (BTR) examples

*1 — The Calculus of Omnivorism/Vegetarianism (***Figure 31***a)*

Your taboos begin with a notion of Thou Shalt Not Eat Thyself. That seems reasonable, even to a proton, if I try to imagine your psychology. Then comes, Thou Shalt Not Eat Other Humans. Then other animals if one is pure vegetarian. Or one's private rules might permit chicken but no mammals. Or fish but no higher animals. And so on. Everyone shares in the DDTDT foible, which is a distant relative to the I'm-glad-to-be-a-Beta syndrome in Huxley's *Brave New World*. "For me, the DDTDT shall be the lowly and welcoming walnut meat," says one person. Another might search for something yet loftier than vegetarianism: one can easily imagine a credo for the consumption of 'nothing but the morning dew' (as a Chinese sage of yore might say), or one that identified inorganic powders from a chemical supply house as the only ethically justifiable food. This would be in accord with the organic chemist's outlook, whereby the atoms are one's Designated Dumb Thing Down There (DDTDT), just loitering about dully until the Lord or for Lady Luck might gather them up into a configuration that would be suitably 'interesting' and 'alive'. The implication is that inorganic molecules and isolated atoms are boring, simple, dead, mere powders stuffed into bottles. As a sentient proton, I beg to differ.

*2 — Maxwell's Demon and Maxwell's Theology (***Figure 31***b)*

Have you never wondered why Maxwell, of *all* people, would allow his little omniscient creature to do its observations without once raising the question of *energy expended*? The vast majority of writers find Maxwell's silence on the matter so awkward (or so uninteresting?) that they simply ignore it, as if to say, "Well, this is only a *thought*-experiment after all, so Mr. Maxwell can do as he bloody well pleases, right?" (WRONG. In a thought-experiment one must be extra-careful of the nuances precisely because it *is* a thought-experiment! Not the perfect analogy, but think of Wolfgang Pauli, a *theoretical* physicist, getting the neutrino right, nearly thirty years before its detection in a cave near Augusta, Georgia. Could he have pulled that off by being sloppy?)

One writer attempts lamely to get Maxwell off the hook by saying Maxwell died too early (1879) to have benefitted from Max Planck's take on blackbody radiation (1900). E.E. Daub tackles the issue head-on and argues convincingly that the real reason for Maxwell's silence has nothing to do with the state-of-the-art in his day; rather, it was a matter of theology. At the level of individual gas molecules, Maxwell willingly disengages his brain and *lets God take over*, to inkle out their speeds and positions by *whatever* ghostly mechanism, 'of course' unknowable to mortals. That's my paraphrase of Daub, who is reprinted in Leff & Rex (pp. 55-56). Working at the level of his DDTDT (individual molecules of gas), Maxwell exhibits the characteristic behavior of Bottom Turtle Relativists the world over: An insistence that "complexity shall vanish when I *say* it should vanish." A desire to put the brain in neutral and relinquish control to God.

*3 — Chance: classical ignorance vs. quantum ignorance (***Figure 31***c)*

This relinquishing of control (mentioned immediately above) is reminiscent of the decision in Quantum Mechanics to split probability into two broad flavors: one where we *could* make predictions if only we were not ignorant (of, say, the myriad parameters driving the weather, or a roulette wheel), and another flavor[(58)] where we may *never* make predictions (because electron orbitals, for example, are assumed to be driven by intrinsic probabilities — forces that generate inherently unknowable paths for an electron, truly *by* chance). In the literature, this contrast is usually called 'classical ignorance vs. quantum ignorance'. I have a slight preference for calling it 'ignorance probability vs. intrinsic probability' instead. In any event, here again one is struck by the biped's willingness to stop thinking beyond a certain point and let God take over, as it were.

*4 — Physics revisited as the land of (smart) rules and (dumb) objects (***Figure 31***d)*

At relatively high levels of the structure, the biped simply assumes various laws and mechanisms of physics are at work. The unwitting or unstated assumption is that there exist objects governed by rules (arbitrarily symbolized by four squares in **Figure 31***d*). Rules act *upon* the objects. Accordingly, the objects must be *dumb.* (But up there where the rules are, who is running the show? That's the question. This is reminiscent of the mind-brain dichotomy, which is equally vexing. Also the question of the missing 'main module' for DNA, which otherwise seems to possess such a strong computer affinity: Where is the master module that, as it were, 'calls all the subroutines'? Note in passing that Danchin, using different terminology, finally addresses this elephant in the room, offering a persuasive argument for *no* master module! See Danchin, pp. 237-245.)

58. In two distinct sub-flavors, actually: Bose-Einstein statistics and Fermi-Dirac statistics. Detailed in Abraham Pais, pp. 280-285.

Feynman once remarked that discovering the laws of physics is like trying to learn the rules of a chess game played by the gods (Johnson, pp. 329-330). In that analogy, too, we see particles cast in the role of as DDTDT pawns. That even Feynman, the flamboyantly brilliant iconoclast, should think in terms that imply the notion of DDTDT shows how deeply entrenched the view is. Note also that the DDTDT outlook is embedded in the name of the field itself: 'particle physics', i.e., a set of clever rules (physics) to govern certain dumb things (particles). This puts one in mind of the proverb: "To a hammer, the whole world is a nail."

Stop to Smell the Flowers: the Balmer Series (1885) and Its Decoding by Bohr (1913)

Before examining the Downfall of Parity, let's look at the Bohr model: Bohr's decoding of the Balmer equation is one of *the* triumphant moments in particle physics, and one owes it to himself to relive it periodically, not keep it hidden away in the history books.

Setting the stage: Pass the light from an excited element such as hydrogen or neon through a prism, and you will see its characteristic spectrum — a kind of atomic fingerprint. By comparison to the busy noisy rainbow spectrum of white light, the calling card of hydrogen possesses an austere elegance:

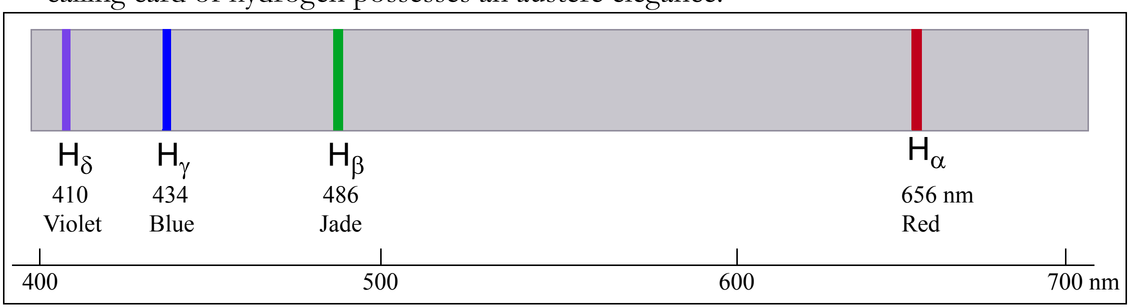

FIGURE 32: The Balmer Series (visible portion of Hydrogen spectrum)

Typically its four lines are labeled right to left as alpha, beta, gamma, delta, following the order of increasing energy or diminishing wavelength (scaled above to nanometers): red, jade, blue, violet. To a scientist, **Figure 32** is not only a tantalizing beauty but also a tantalizing riddle. Given that a cloud of excited hydrogen atoms will emit light with these specific wavelengths — 656 nm, 486 nm, 434 nm, and 410 nm — what is the relation between those numbers? What is the magic of those particular values?

As early as 1858 (which is to say long before some plausible physical models of the hydrogen atom would be proposed in the early twentieth century), Johann Balmer went to work on the numbers themselves as a mathematical abstraction. Balmer published in 1885, the year of Bohr's birth. Bohr was the very one who would put it[(59)] all together in 1913, having decoded the Balmer-Rydberg-Ritz equation(s) in such a spectacular way as to leave even Einstein with his tongue hanging out on the floor:

59. The 'it' in this case is far richer than what I've suggested in the text. Excluded from my presentation are the role of Rydberg (1890), Planck (1900), Einstein (1905), Rutherford (1911) and others. For a more complete account and/or additional illustrations, see Langford & Beebe, pp. 228-239, Moore *et al.*, pp. 280-281 or Rhodes, pp. 72-75. For a more technical look at the same terrain, see the essay in Pais, pp. 170-174, or the problems in Metz, pp. 280-283.

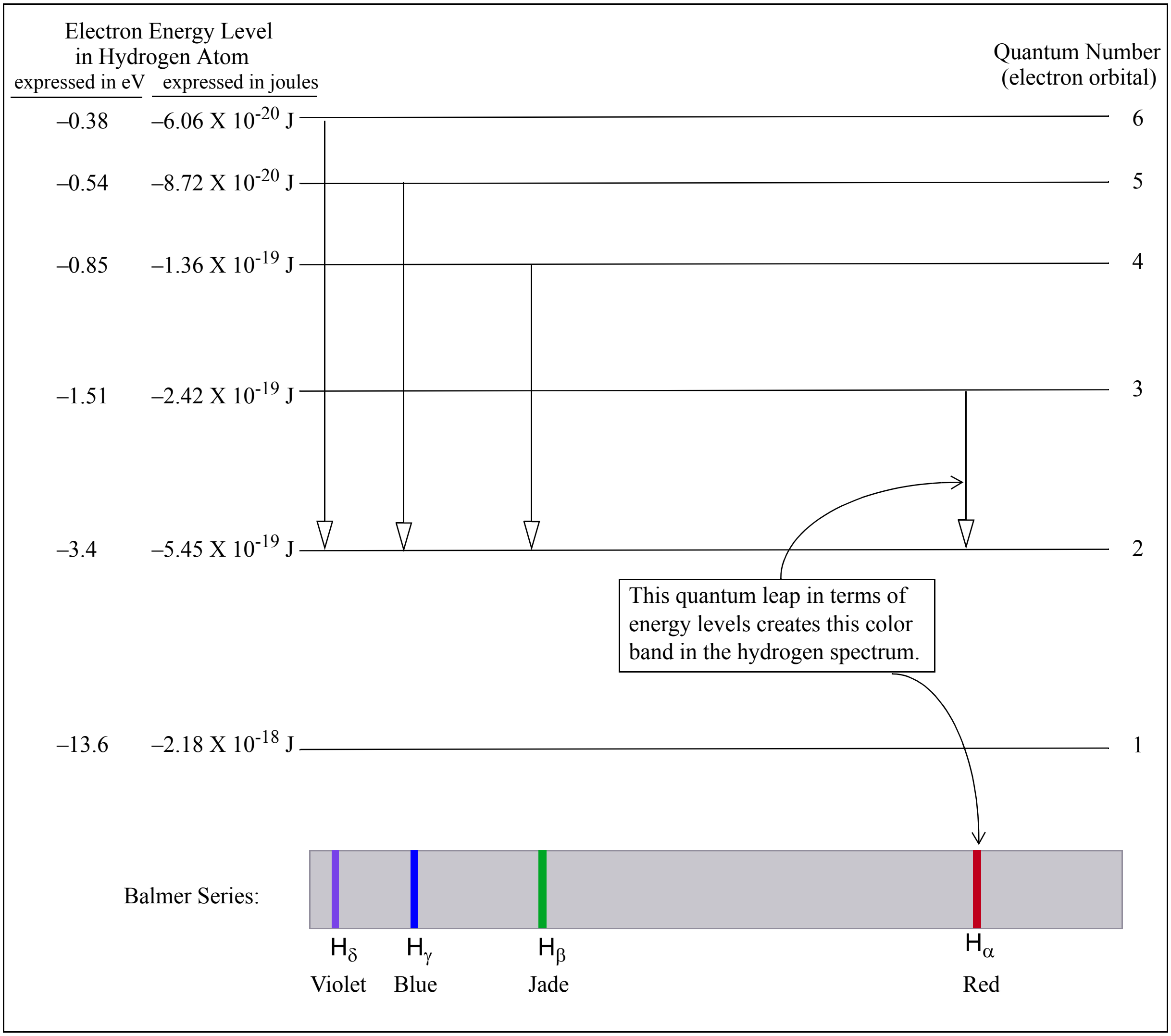

FIGURE 33: The Balmer Series as Decoded by Bohr in 1913

In **Figure 33**, the horizontal lines represent electron energy levels 1 through 6, which in turn correspond to electron orbitals that are further and further away from the implicit proton at the atom's center (which is typically not represented in such diagrams). The straight vertical arrows are interpreted as follows: When one of the electrons stops being 'excited' and jumps from level 6 (a high energy level) to level 2 (a lower energy level, –5.45 X 10^{-19} joules), the energy difference corresponds to that of violet light. This transition contributes to the violet band in the spectrum (which is a composite picture over time for all the excited gaseous hydrogen atoms in the sample being studied). Similarly, when an electron jumps from level 5 to level 2, this transition contributes to the blue band in the spectrum. And so on for the other two colors.

An aside regarding the association of zero with 'maximum energy'

Authors of physics textbooks routinely characterize this zero-energy scheme as 'arbitrary' and/or 'natural'. It is no such thing. It is inherently unnatural and confusing because of the resultant double-negative notation; it is also wrongheaded because it obscures the fact that zero in this context is a *limit*, not a value. For the latter discussion we defer to page **179**, where it appears as part of a generic problem of the Establishment, the practice of sweeping limits generally under the carpet. The former problem we will explore briefly here, by way of clarification for the general reader. If zero is chosen 'arbitrarily' to represent the maximum energy state for an electron, then the electron's ground state (i.e., its lowest possible energy level) must lie somewhere to the left of zero on the number line. Specifically, **Figure 33** tells us that the ground state for the electron in a hydrogen atom is -2.18×10^{-18} J (or –13.6 eV). In this side-discussion, though, we will talk in terms of order-of-magnitude only, without the multipliers 2.18, 5.45, etc. Accordingly, the ground state we will represent in **Figure 34** by plain -10^{-18}, without the 2.18 qualifier; and so on for other numbers pertinent to the Balmer series, namely -10^{-19} and -10^{-20}:

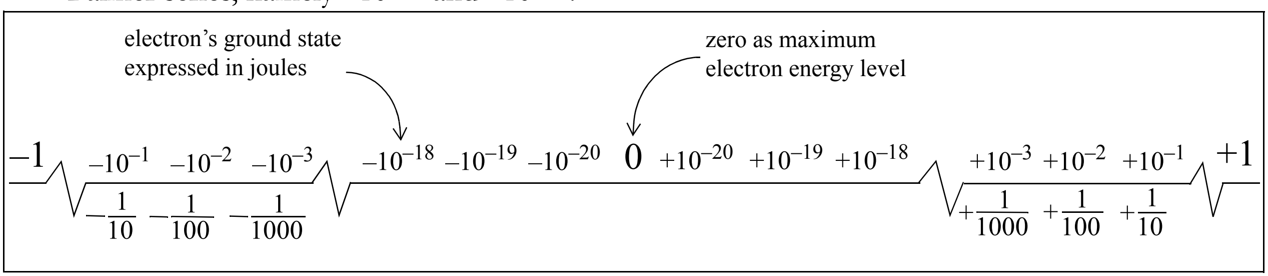

FIGURE 34: Simplified Energy Levels in Context of Familiar Numbers

What might be confusing is how to navigate and feel 'at home' in-between -10^{-18} and 0. Suppose you happen to see it this way: "The *less* tiny a negative value is, the *farther* left of zero it must lie, thus making it relatively 'lower' in the scheme of electron energy levels." That is a true statement, but it makes the notation convention sound more confusing than it really is. Here is a better approach: Start by comparing some comparatively large values that are easier to visualize, such as -10^{-1} and -10^{-2} set against $+10^{-1}$ and $+10^{-2}$ (i.e., –1/10 and –1/100 versus +1/10 and +1/100). In **Figure 34**, notice that on the minus side of zero each larger value for the negative exponent brings you closer to zero, moving left-to-right. On the plus side of zero, meanwhile, the progression goes right-to-left in a mirror image. To the nonphysicist, this right-to-left progression is the only familiar one, while the left-to-right progression on the other side of zero will seem somewhat exotic at first. But now that you have a 'map' for placing such values in context, try revisiting the Balmer zone as conventionally represented in **Figure 33**, and its double negatives should be less troublesome to interpret. (For the rationale and foibles of this notation scheme, see discussion preceding **Figure 48** on page **181**.)

Nowadays the diagram in **Figure 33** can be expanded to show an additional Balmer-like series hiding in the ultraviolet region (beyond the left edge of the page, with the vertical arrows terminating at level 1 instead of level 2), and another in the infrared region (beyond the right edge of the page, with the vertical arrows terminating at level 3).

Can one of the electrons occupy the orbital that corresponds to an intermediate energy level such as -7.00×10^{-20} (a value picked at random)? No. That's the thrust of Bohr's 'quantum' concept. Electrons are found in various different states of excitement over time, but only on one of the six levels depicted in **Figure 33**, and never in-between the lines labeled 1 through 6. That was Bohr's conjecture that amazed everyone, Einstein included, finally 'decoding' the long-standing Balmer-Rydberg-Ritz equation(s). This was the great event of 1913, to thus make sense of Hydrogen's line emission spectrum.(60)

"...to coin a phrase, a kind of microchemistry," Julius Plücker had said in 1858.

"...a true atomic music of the spheres," says Arnold Sommerfeld in 1919.

These two quotations come from Pais, who extends the music analogy thus: "H_α:H_β:H_δ = 1/20:1/27:1/32...the 32nd, 27th, and 20th harmonics of a fundamental vibration" (Pais, pp. 166-167, p. 171). (In the second quotation, which is from *Atombau und Spektrallinien*, note that it was still possible in 1919 to try inserting 'atomic' in a lyrical phrase. Sommerfeld was writing some decades before the word would be usurped by the journalist, quick to write 'atom bomb' for fear that his reader might stumble over something so ponderous and alien as 'uranium bomb', never mind if the latter were more descriptive. The snappy rhythm of 'atom bomb' would be the sure winner in that contest.)

Against this new music of the spheres, one discordant tone had sounded early on, however.

And it's a sour note worth remarking because it persists in quantum mechanics up to the present day in one form or another. I refer to Bohr's non-answer to a question from Rutherford.

60. Only two years hence, the fine structure constant would be brought into the picture. At first sight this seemed to contradict the whole quantum leap theory, until relativity was added into the mix; some details of this problem and its resolution are given in Pais, pp. 212-215.

In reaction to Bohr's radical update to his planetary model, Rutherford had asked: "...how does an electron decide what frequency it is going to vibrate at when it passes from one stationary state [quantum state] to the other? It seems to me that you would have to assume that the electron knows beforehand where it is going to stop" (quoted in Rhodes, pp. 75-76, and in Arabatzis, p. 114).

But the question fell on deaf ears. As perceived by Bohr, it must have seemed a throwback to the ossified physics that he (Bohr) was busy dismantling and replacing with a fresh enlightened version of physics for the new century.

Paraphrasing, Bohr said the electrons have free will(61) so there's no point asking which energy level is the target. Nor are we allowed to wonder where they are in that instant after leaving one level but before arrival at the next level. They are either in one quantum state or the other, never in an in-between state. Later, the non-answer would become: "an electron is a Heisenbergian matrix, so don't ask that kind of question." Still later, following Max Born's probabilistic interpretation of the Schrödinger wave equation, the non-answer would become, "an electron is a possibility wave, so don't ask that sort of question."

I call these non-answers because they effectively change the subject from something Bohr (or a follower of his) does not wish to discuss to a subject he does wish to discuss.

For example, let's humor Bohr and say the electron does possess free will. That whimsical notion of Bohr's might have been a way of quieting Rutherford if Rutherford had asked, "How do we know *when* the electron will leap?" Bohr could then have answered, "That we don't know. The electron possesses free will. It leaps to a new state when it pleases." But given the question that Rutherford did actually pose, I regard the 'answer' as a non sequitur. The question actually posed by Rutherford implied countless follow-on questions, such as these:

61. In recounting Rutherford's question and Bohr's nonresponse, Rhodes goes so far as to connect Bohr's iconoclast stance with that of his compatriot Kierkegaard. This juxtaposition of Bohr's quantum leap with Kierkegaard's leap of faith is intriguing (Rhodes, pp. 76-77), but I wonder if it is reading too much into something that is mostly a surface resemblance. Be that as it may, one does feel that Bohr was promoting *some* kind of philosophy (or anti-philosophy) with his decipherment of Balmer. He was not offering those results in an empty room with no strings attached, so to say.

WHY do the electrons become 'excited' and skip around so much between orbitals?
How does a given low-energy electron 'know' that level 6 even exists?
How does it decide it is time to jump up to energy level 6, and how does it navigate from its current orbital out to the new orbital, so much further away from the proton?
Later, how does it decide it is time to jump back down to a lower level (thus emitting the colored light that we see)? And in doing so, how does it find and reoccupy the lower orbital?

Given the 'free will' assumption, these would still be legitimate questions.

By considering a die in Flatland (**Figure 35**), it may be easier to see what kinds of questions or answers are reasonable, and which are unreasonable, in connection with electrons taking quantum leaps.

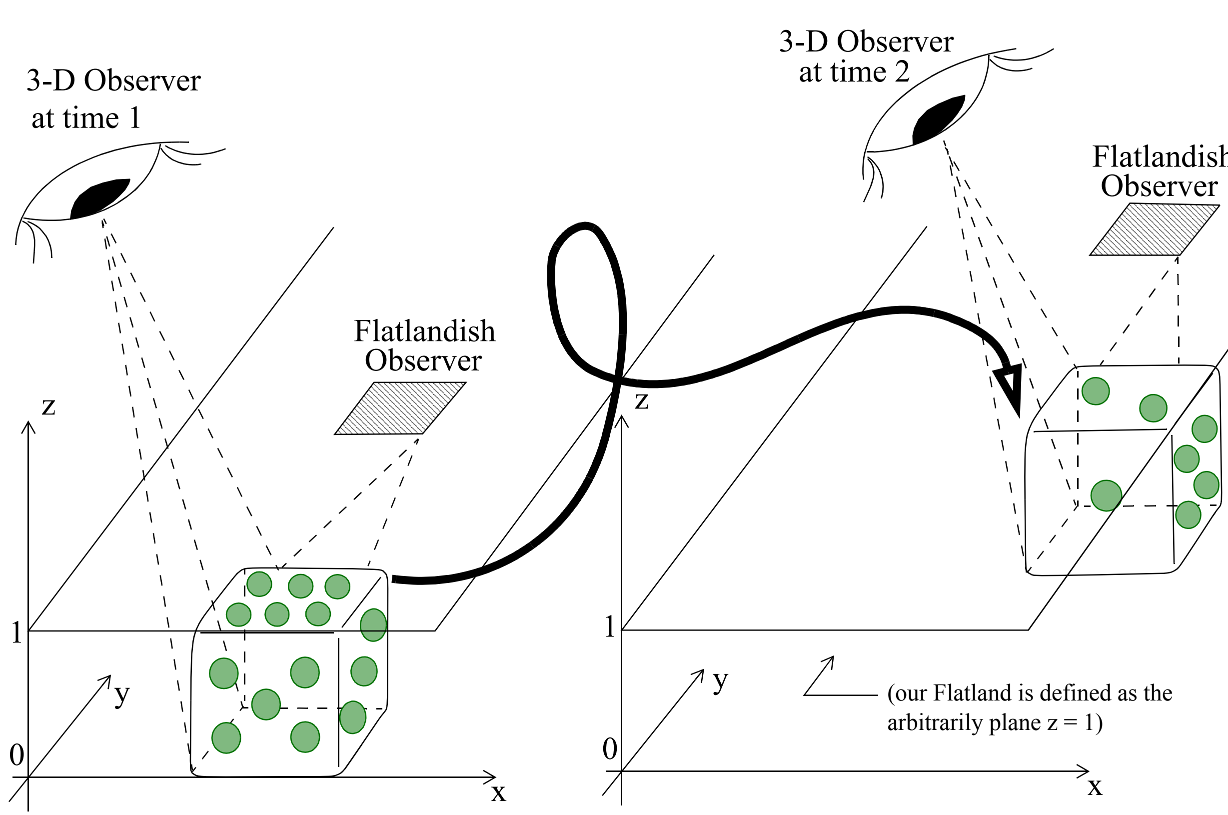

Figure 35a: Die visiting Flatland at time 1

Figure 35b: Die visiting Flatland at time 2

FIGURE 35: Flatlander Visited by a Rolled Die from the 3-D Realm

In **Figure 35**, both the denizen of Flatland and the 3-D observer read 6 pips(62), then 2 pips, on the uppermost surface of the rolled die. But the Flatlander (a notional 2-D creature) has *only* that one upturned face of the die to observe, as the Flatlander lives in ignorance of the die's cubic nature and the human observer's 3-D space. (Compare **Figure 98** on page **386**.)

Now, even as a humble Flatlander, is someone not entitled to at least *wonder*, "How does the die decide which value to adopt next? And having decided on 2, for instance, how does the die make 2 appear in lieu of 6?" Not to say it would be easy for the Flatlander to obtain

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62. We don't mean to suggest that there is any particular magic in the number 6. It just happens that the Balmer series (**Figure 33**) is represented customarily with six levels only; this paves the way for our die analogy in **Figure 35**. But in principle, the Balmer series may be expanded by the calculation of an indefinite number of energy levels approaching a limit; see **Figure 48** on page **181**. For a look at dice in their native habitat, so to speak, please refer to the appendix on probability: **Appendix F: God IS the Dice**.

answers to such questions or, God forbid, to propose a visual solution to the puzzle. But surely the Flatlander should not be scoffed at for ruminating occasionally about the hidden parts of the object. To the contrary, one might say it was a sign of Flatlander intelligence at least to show some curiosity about how the face of the die changes itself. Even *if* the transition is assumed to be probabilistic (for more about this see **Appendix F: God IS the Dice**), that leaves a host of other topics still legitimately up for discussion: Does an outside force toss the die, or does the die toss itself? Is the face with 6 pips attached through some higher dimension to the face with 2 pips? Or is it a single face morphing? And so on.

Figure 35 provides a picture to accompany the Bohr quotation:

> It is wrong to think that the task of physics is to find out how Nature is.
> Physics concerns what we can say about Nature.

In other words, if you were the Flatlander in the picture, you would agree to limit your activities to saying, "After I see 6 pips, I always see 2 pips" and you would agree to refrain from all speculation about the suspected 3-D nature of the die visiting Flatland, and questions regarding how it makes the transition from a face with 6 pips to a face with 2 pips. As a Flatlander, would you be happy with such a restrictive covenant? Somehow I doubt it.

True, all through the 1920s and 1930s, Bohr appeared to welcome lengthy discussion of related matters, notably Schrödinger's wave function, but really there seems to have been only one 'correct' answer allowed at the end of the day: The Bohr-Heisenberg answer, which came to be known as the Copenhagen Interpretation, with emphasis on 'the' since there was never really another interpretation of quantum mechanics that 'had legs' and/or tolerance in the world, not back then and not now, nearly a hundred years hence. If Bohrism[(63)] was not a religion or a theology, then it was at least a terrifically rigid doctrine or cult. In a rare effort to delicately question the Sacred Scrolls, Penrose wonders (repeatedly) if

63. In painting this portrait of Bohr, I realize I am very much at odds with a writer such as Gino Segrè, who *says* that he is showing Bohr as the one who is so reliably reasonable, the one always willing to listen and reconsider and help others patch up their differences. Call me an outsider who just doesn't get it. Or, possibly, an outsider who can see the terrain better precisely because he has no familial ties or political (academic) entanglements that might cloud his vision. I say that Bohr cast a grotesquely long shadow over his own Balmer flowers. And support for my viewpoint can be found right there in Segrè's own account, i.e., in what he 'shows' us, as distinct from what he 'tells' us. See my remarks on page **120** above about the genesis of Pauli's neutrino, which, as it turns out, is directly related to this discussion.

perhaps Bohr and Heisenberg had not been 'too pessimistic' (Penrose, pp. 226, 243, 248-249, 255-256).

The Downfall of Parity

In the 1950s, theoretical physicists T.D. Lee and C.N. Yang conjectured a large class of parity exceptions ('Question of Parity Conservation in Weak Interactions', *Physical Review* 104). During the winter of 1956-1957, experimental physicist C.S. Wu provided support for Lee and Yang's conjecture in the behavior of super-cooled cobalt ('Experimental test of parity conservation in beta decay', *Physical Review* 105). Soon these two events would become known jointly as the 'violation of parity', so that the year 1957 became a permanent landmark(64) in physics. The story:(65)

At the sixth Rochester conference in April 1956, in connection with T.D. Lee's proposed solution to the tau-theta puzzle (whose 'tau-meson' and 'theta-meson' later merged into a single K-meson), several participants, including Dr. Lee, began to speculate on the (faint) possibility that parity might be violated in weak interactions, where 'weak interactions' refers to β-decay, π-decay and μ-decay. Only 'faint', because Conservation of Parity was such a towering Article of Faith for the discipline. Scarcely worth questioning. Or was it?

For the moment, we defer the group theory aspect of symmetry and say only this about it: symmetry refers to [1] the commonsense belief that an experiment carried out in Room 201 in May will behave essentially the same way if carried out again in Room 307 in July; and [2] the idea that whatever image a particle might present to us in a mirror during an experiment, that mirror-dwelling image-in-reverse is not fanciful, but must rather be the picture of a real scenario that may exist somewhere in this universe. (Example: Look at yourself in the mirror with your hair parted its usual way. Realize that there's no prohibition in Nature against a person walking around who looks just like that, with her hair parted the other way — literally your mirror-image, *and* real.)

The 1957 experiment focused specifically on a type of symmetry called parity, as it

64. Sometimes the subject of parity nonconservation seems to be dominated by the CPT-invariance conniptions of the 1960s; it is easy to lose sight of the fact that 1957 was *the* watershed year.
65. For the account that follows, I draw upon the following technical and popular sources (plus several others not itemized here): Ford (1963), Giancoli (1995), Hudson (1997), Lederman (1993), Lee (1988), Zee (1986), Pais (1986), pp. 531-533, George Johnson (1999).

relates to β-decay. If an isotope has 'too many neutrons' or 'too few neutrons' (relative to the atomic number), one of the said neutrons may vanish via β-decay. β-decay comes in two flavors, which can be symbolized as follows...

$$n \longrightarrow p + e^{-} + \bar{\nu}$$

$$n \longrightarrow p + e^{+} + \nu$$

...where n = neutron, p = proton, e^{-} = electron, $\bar{\nu}$ = antineutrino, e^{+} = positron, and ν = neutrino.

In words: An electron and an antineutrino are kicked out of the nucleus (alternatively, a positron and Plain Jane neutrino are kicked out); meanwhile, inside the nucleus a proton is born,(66) replacing the neutron and thus transmogrifying the element in question into its neighbor in the Periodic Table. In this context, e^{-} is understood to be a high-energy electron, i.e., the β-particle. (Or, in the second flavor, the positron e^{+} would be the β-particle.)

The kicked-out thing may also be referred to as a β-*emission*, its funny name harking back to an era when the particle in question was a mystery and had not yet been identified *as* a (nonorbital) electron or positron. (Incidentally, C.S. Wu did her test both ways, using two isotopes of cobalt, so that she could evoke first one kind of β-emission, then the other. Some summaries of her work read strangely as they mix results from both, yet cite only cobalt-60, as though no other isotope played a role.)

Now for the main event, which is perfectly accessible to the nonphysicist. It is one of those concepts that is not especially *difficult*, just *novel* to the laity, and it needs to be explained with a pair of illustrations like **Figure 36** and **Figure 37** (the burden of which many authors impatiently smush into a single figure, thus taking the risk that they've illustrated nothing). The circle represents a spherical cobalt nucleus. The curved arrow that belts it means the nucleus has real or imaginary spin, hence left- or right-handedness. The straight hollow arrow represents a nonorbital electron being kicked out of the nucleus by β-decay. So, strictly speaking, it has ceased being cobalt (element 27) and has morphed already into nickel (element 28) at the instant we picture it. (This aspect is intrinsically interesting as an example of *real* alchemical transmutation, by the way, but it is of little consequence for the discussion to

66. I hope this sounds familiar. In a slightly different context, the case of an isolated neutron, we discussed the question of 'neutron decay' vs. 'proton birth' already; see page **100**.

follow.)

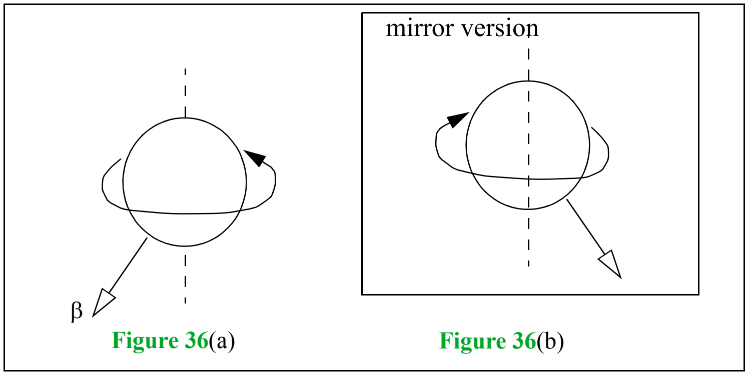
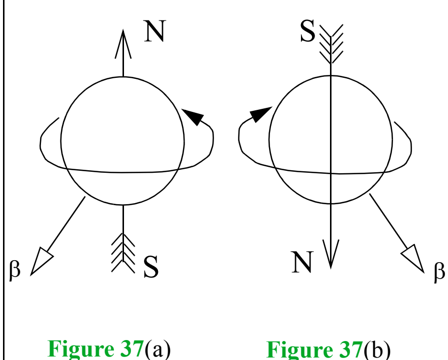


FIGURE 36: β-decay and its mirror image

Fetch a hand mirror. Hold it to **Figure 36**a. You will see **Figure 36**b in your mirror. Note that this is different from saying, "A creature like the one depicted in **Figure 36**a will see **Figure 36**b when looking at itself in the mirror."

Now for the punch line: What the curved arrows mean in **Figure 36** is that the two 'north poles' are located as shown in **Figure 37**. There are some subtleties, so it is important to look at the pictures *and* read the 'N.B.' text in **Figure 37**:



N.B. **Figure 37**b is *not* 'the mirror image of **Figure 37**a'. Rather, **Figure 37**b is an elaboration of **Figure 36**b above, nothing more. Here is the subtlety: The polarity depicted is real, but it has no visual manifestation in nature. Think of two copies of the planet earth, oriented oppositely so that the north pole of one was pointed 'up' and the other pointed 'down'. Viewing them both from a certain distance in space, it is conceivable that you would be unable to make out the contrasting shapes of their four polar regions, but might nevertheless be able to inkle out the contrast in their two spin directions; and from the latter information, you could *infer* their mutually reversed polar orientations. In short, the feathered arrows and the labels N and S are only *annotations*; by contrast, each curved arrow is 'part of the object itself', whether original or mirrored.

FIGURE 37: β-decay with north/south arrow added

Not a pretty picture.

If the β-emissions had been observed to occur unpreferentially in both the north and south hemisphere (i.e., now in the north for one cobalt atom, now in the south for another cobalt atom, with only one such emission occurring per atom, incidentally), then the parity status quo would have been fine: north and south right-side up become south and north when upside-down, with β-emissions going every which way without preference. In that happy random soup, there would have been *mirror symmetry*. Refer to **Figure 38** for this version, which is what they did *not* find in nature.

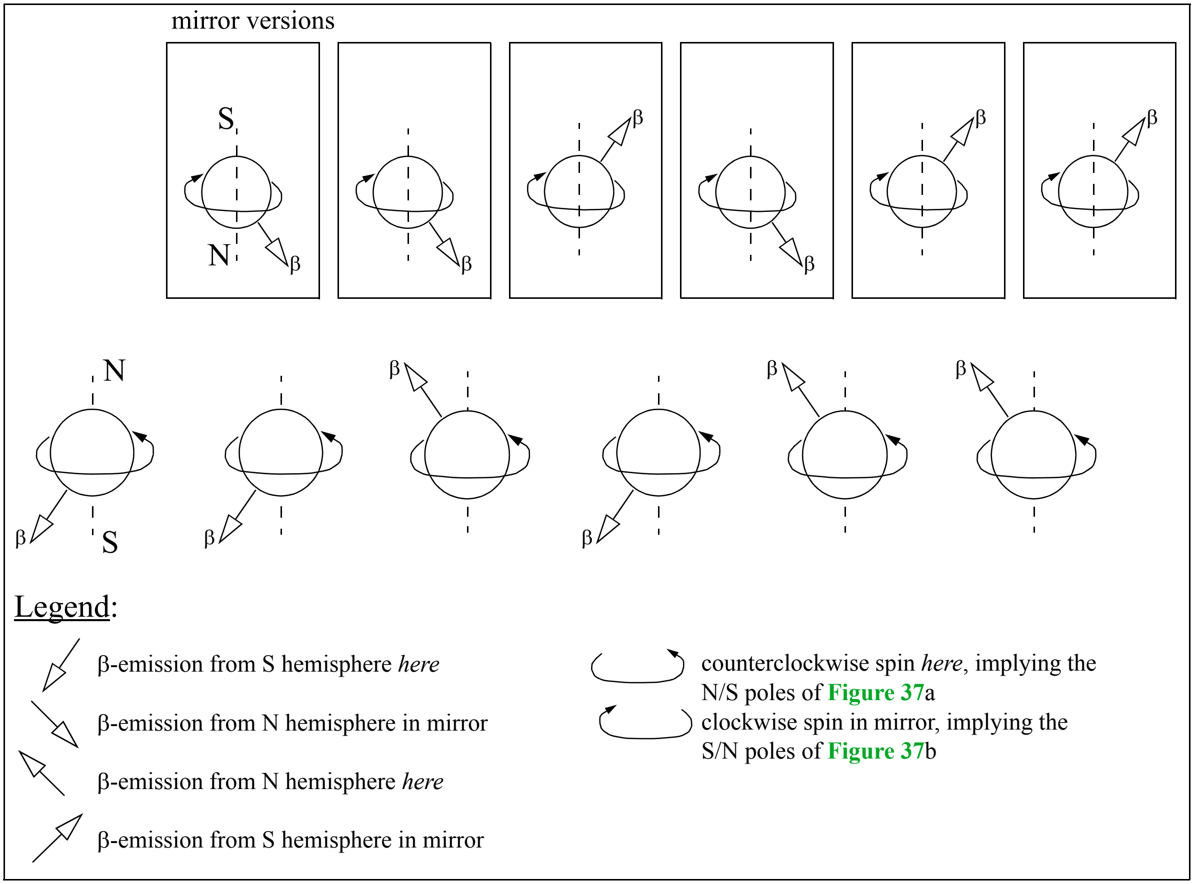
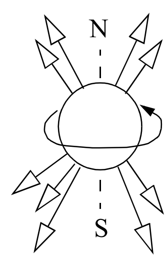


FIGURE 38: A Pretty Picture (the one *not* suggested by Mme. Wu's 1957 experiment)

[Caution: In other books, you may have seen an illustration of parity (unviolated) that looks something like this:



That would be roughly equivalent to our **Figure 38** collapsed into a composite picture, for the sake of brevity. For someone already familiar with the subject, that might work nicely as a shorthand for conveying 'symmetrical β-emissions' in a terse abstract format. I, however, find it problematical: For readers who are unfamiliar with the subject, such a picture will surely suggest multiple events over the history of a single Cobalt atom, whereas in truth a β-emission is part of *one* 'Cobalt/Nickel Alchemy' event. This event is, by definition, special, isolated and specific to a particular atom. Thus, the convenience of such a picture is overshadowed by the fact that it plants misconceptions — misconceptions that will collide sooner or later with other parts of the story. The other thing to watch out for is the term 'mirror' itself, which is routinely used in textbooks, even those on group theory, *as if* it were a technical term, which it cannot possibly be since a mirror lacks up-and-down reversal. In Crease, p. 204, and in Johnson, pp. 139 and 378, we are alerted to this vague and *metaphorical* use of the term, and my various illustrations above are a different kind of attempt to guide one past the related pitfalls.]

Back to the main event. What **Figure 36** and **Figure 37** say is this: Inside the laboratory, β-emission occurs preferentially[67] in the southern hemisphere; meanwhile, in the mirror, it occurs preferentially in the northern hemisphere. That spells the 'downfall of parity', since the mirror is now showing us a world that cannot exist. (Note in passing how physics is frequently anthropomorphic in spite of itself: *Why* is **Figure 37**b deemed 'impossible' out of hand? Because one assumes that if β-emissions have 'shown a preference' for the southern hemisphere 'here', then they surely wouldn't 'change their minds' and show a preference for the northern hemisphere 'there'. That would run counter to the (subconscious) assumption of a Designated Dumb Thing Down There. One can scarcely avoid the impression of a kind of stealth-anthropomorphism or, at the very least, an example of subconscious anthropomorphism that threatens to tarnish the physics citadel of cold logic. Not that *I* mind. As a living, breathing proton, I can hardly object to their acknowledgment of something lifelike at the subatomic level, but the irony needs to be remarked.)

Unequivocal evidence that parity is violated? Well, for some it was, anyway. Years later, Lederman characterized it as one of the quickest and most decisive experiments in history. But there he was biased, as one who had expected a negative result even more than C.S. Wu had, later whipping himself into a frenzy that he might run a quickie cyclotron-based version of the experiment and try grabbing the gold for himself (as detailed above). But others in the meantime were derisive and dismissive. Wolfgang Pauli snapped at a hapless member of Madame Wu's team, "Do it again," too exasperated to spare two seconds for clarifying his subtext, which would have been: "The whole project was just a fool's errand, *don't you see*?"

A naïve observer of the 1957 landmark might imagine that the trio of Chinese

67. The actual experiment is even more interesting than our cartoon sketches suggest: β-emission occurs overwhelmingly in one hemisphere, but not exclusively there. Hence, the one hemisphere truly is a 'preference', not a simple 'choice'!

physicists whom it made famous would enjoy a lingering, decades-long sense of pride for having shaken up the physics establishment to such an extent. But that's not it. All three of the major players in that drama — Lee and Yang and Wu — found the idea *itself* repugnant, no matter what personal glory it might bring them. And this feeling was shared by most physicists of the day. (And, to avoid being disturbed by such a disruptive idea, some simply wrote the results off as experimental error; such was Wolfgang Pauli's coping method at first.) Only one is known to have found the prospect of parity violation exciting: That was Richard Feynman. Among the physics luminaries, he alone seemed able to entertain the idea of parity's *downfall* without having a cow.

From Lederman's account (Lederman, 1993, pp. 265-273), it strikes me that in his case, at least, the potential for glory outweighed any knee-jerk revulsion about the parity violation. With admirable candor, Lederman makes it quite clear that there was, in fact, a bandwagon effect following Madame Wu's experiment. No, *during* it we should say: As soon as Lederman was aware of Madame Wu's preliminary findings (indicating the presence of *dramatic* differences to measure rather than hopelessly subtle ones), he whipped together a team and became frantic that they should do their own related experiment in parallel, and even publish *with* Madame Wu's team if she would consent. She declined, but Lederman did manage to get the results of his whirlwind weekend experiment into the very same issue of *Phys. Review*, just two pages away (105: 1415) from where the famous results are published (105: 1413). Shortly thereafter came confirmation for lambda decay, as well, in F.S. Crawford[68] *et al.*, 'Detection of Parity Nonconservation in Λ Decay', *Phys. Review* 108: 1102.

Just *how* repugnant did T.D. Lee (and the Establishment generally) find the parity violation? Extremely: It appears that Dr. Lee has spent the whole rest of his life trying to reformulate the rules themselves to accommodate those findings and make them *stop* being violations! Such is the physicist's adoration of symmetry. Rather than contemplate a universe that is free of Symmetry Nazis, the physicist will embark on a quest that sounds almost quixotic at times, what with resurrecting the aether to balance the books and provide a plausible hiding place for the missing symmetries, and the 'bagging' of quarks. The proposed hiding place is not literally the aether, of course, but 'the vacuum', understood to be not empty but 'complicated' (a technical

68. For more about Frank S. Crawford, see page 480 in the Colophon.

term); T.D. Lee (1988), pp. 22-24. By Lee's own admission, in such an approach — leaning so heavily as it does on 'matter + vacuum' to balance one's equations — there is the danger of creating a tautology (T.D. Lee, pp. 25-26) where everything works on paper but none of it is real.

Now don't you wonder *why* virtually everyone on both sides of the Atlantic found the violation of parity *so* repugnant? After all, symmetry is nice, but it's not the be-all and end-all of aesthetics. To the contrary, there are various kinds of art — notably in Japan — that revel in asymmetry: "...Japanese design prefers asymmetry, rhythmic unbalance, diagonal slashes, and uneasy inner tensions"; Grilli, *Sotatsu*, p. 43. (At first, Japanese landscape painters imitate Chinese painters directly, but by the time of Sesshū and Sesson, asymmetry rules. Later, Tououse-Lautrec and Van Gogh are deeply influenced by the asymmetry in Hokusai.) So, what can be the source of the physicist's fetishistic adoration of symmetry? I'll venture that it is not symmetry per se that has such a hold on him. Rather, it must be the way that symmetry in his world is so intimately tied up with *group theory* in the world of mathematics. The latter is terrain that the physicist inevitably would have traversed, on his way *to* symmetry. Meanwhile, the general reader sees only the tip of that intellectual ice berg (symmetry for its own sake, seemingly) and may feel baffled by its importance. To understand where all the unscientistly emotion comes from, one might look at Mario Livio's popularized account of group theory, especially pp. 47-48 and 181-187. Then the light will begin to dawn. Note in passing that David Bishop tries to convey the wonder of it all in Chapter 1 of his classic, *Group Theory and Chemistry*, but his effort pales beside Livio's all-out campaign to fascinate the reader. (His book includes, among many other things, a biography of Évariste Galois, on pp. 112-157, and an introduction to Noether's theorem, gauge symmetry, Lie groups and supersymmetry, on pp. 217-232.) In the first seven chapters Livio appears to be a true believer, but in Chapter 8 he finally plays devil's advocate and raises the question of whether the fascination with symmetry isn't only a biped *selection effect* — based ultimately on the role of symmetry in one's primitive past (Livio, pp. 246-250). Better yet, he even quotes a rather heretical sounding statement attributed to Bertrand Russell: "Physics is mathematical not because we know so much about the physical world, but because we know so little; it is only mathematical properties that we can discover" (Livio, p. 250). But for all that, there is scarcely a word about the role of *asymmetry* in Japan (save for a fleeting reference in the Richard Feynman quote on p. 251). On p. 225, Livio mentions C.N. Yang and Robert Mills' pioneering attempt to mathematically describe symmetries (the Yang-Mills theory of 1954), but he remains silent on the much more dramatic events of 1956-1957 (involving C.N. Yang, T.D. Lee, and C.S. Wu, as described above). By contrast, in *Fearful Symmetry*, A. Zee does acknowledge the events of 1957, and even ventures that broken symmetry might come to the rescue as an explanation, of sorts, for nonconservation of parity; Zee, pp. 214-216 and 261. But wouldn't that only push the question down to another level since the 'breaking' north and south (or up and down) is not random but preferential? Consider the following case: A team at the Berkeley Bevatron reported a sample of 353 Λ decays yielding 215 UP and 138 DOWN, and remarked that the odds for such a pattern to occur randomly are only 1 in 10,000. (This was an important follow-up study in the wake of C.S. Wu *et al.*; see Crawford *et al.*, 1957, pp. 1102-1103.) Meanwhile, the official way of putting it all to rest is CPT-invariance (or 'CPT symmetry'), as refined during the 1960s; see Pais, pp. 538-542 and Johnson, p. 233 . To some of us, though, CPT-invariance (where the parity violation is now represented by 'P') appears to be about as convincing as the story of the man with his head in the oven and his feet in a bucket of ice water who declares, "My temperature, on average, is just fine!" Similarly, when viewed all together from a higher perspective, the C and P and T violations are said to present a symmetrical face — on average, as it were. Somehow, one remains underwhelmed by the argument, which smacks of a shell game or an attempted end run.

Grey Alien, Purple Alien

Here we'll try an extended, two-part analogy to provide another insight into 'how the physicist thinks'.

First the story of the grey aliens. Suppose their space craft entered the solar system near the orbit of Pluto. Let's say it passed by Uranus but had to crash land on Titan, a moon of Saturn. On Titan, assume the grey aliens still had many sophisticated instruments that were unharmed by the rough landing. However, the space craft itself was seriously damaged, unable to take off again. From Titan the grey aliens begin their examination of Jupiter, Mars and Earth. The latter they find especially interesting because of the cars. They develop a theory about the cars. A proposed rule is that cars are found only on freeways and streets. Cars cannot go through fields or buildings. But then, using an improved detection algorithm, one investigator discovers a car hidden on the inside of a building. At first this discovery is treated as a disturbing 'exception' to the general rule about freeways and streets. Eventually the theorist becomes comfortable with it, as he confirms that many buildings possess these 'car chambers' (garages) occupied by cars. Later, another alien discovers that a moving car contains a sack of hydrochloric acid (i.e., a human stomach), whereas a stationary car does not. Another rule is proposed. But soon this rule too has an exception: Sometimes a stationary car, too, may contain an HCl bag (see **Figure 2** on page **13**) or even a pair of HCl bags (two bipeds conversing or having sex). And so on. Gradually, a comprehensive picture of automobiles-on-earth is compiled by the grey aliens. It even includes an exceedingly rare case where a moving car is found with *no* HCl bag in it (a runaway car on Knob Hill in San Francisco, it happens to be). But for all its excruciating detail and accuracy, the theory compiled by the grey aliens has a gaping hole in it: What is a car? Why do some of them of move while others stay in 'car chambers'? When in motion, why and how does a car acquire an HCl bag, always at the upper left corner of the image?

In other words, the grey aliens have no clue that you humans are the motivating force behind the creation of automobiles, and that the automobiles move only in accord with your volition, your needs, your dreams.

Second story: A few years later, some purple aliens visits Earth and do *their* report on the cars, plus an analysis of a Beethoven late quartet — not remotely from Titan but directly here on the planet. As they are leaving Earth, they have some questions for you: "You earthlings clearly understand the operational principles of an automobile, but why do some of you also spend time riding inside these machines? Is it because you derive pleasure from sitting in them?" Unlike the grey aliens, the purple aliens are acknowledging some connection between the cars and the humans, but they don't quite get it either. In similar vein, they ask why certain humans perform the notes written in a Beethoven score; but why bother if you already know 'what it says in the score'? Finally one of them adds, "Probably I can never understand subjectively what the performance of such music means to an earthling, but at least I feel it is a reasonable question to ask: I gather from your humanities professors that you regard such artifacts as a Beethoven score as 'the highest expression of the human spirit' — something to that effect?"

Well, at least these purple aliens are trying to get a clue what cars and quartets might *mean* to the biped. By contrast, the grey aliens didn't even think it was worth *acknowledging* such issues, much less asking the questions about your 'semantics' as distinct from your 'grammar'; some cars had HCl sacks in them and some did not, that's all. (Here I've used 'semantics' as a metaphor, but literal semantics, too, would have a place in such a parable: One could imagine the space aliens performing an exhaustive analysis of English grammar and phonology, and thus claiming the glass was 'half full' — even though they had left out semantics. The Report on Earthling Language was 'good enough'. Meanwhile you would feel the glass was 'half empty' since they had shown no interest in semantics and were therefore still incapable of conversing with you. You would not have a good feeling about their Report on Earthling Language.)

Partly the contrast in the two alien reports was a function of the greys' remote location on Titan versus the proximity of the purples; partly it was a function of different racial temperament between the greys and purples.

In any event, the grey aliens' outlook resembles that of your physicist as he delves into my subatomic world: just keep adding rules and exceptions, and exceptions to the exceptions; don't bother with those 'high-level' questions that might relate one rule to another, because time is precious and that sort of nonsense (looking for meaning in the random twitter of atoms doing whatever all across the galaxy) is for philosophers and artists to ponder.

I appreciate why the physicist is so terribly delicate and fastidious about such matters, but when the physicist goes to the extent of not even acknowledging the *existence* of such questions (sound familiar?), I think the fastidiousness has become excessive, perhaps to the point of being counterproductive.

Why not at least acknowledge the *possibility* of meaning, the *possibility* of volition and intelligence at the subatomic level? That's all I'm asking. That you break the 100-years silence imposed on you by Bohr.

The grey-alien/purple-alien parable above is my reaction to (and take-off on) a discussion of watchworks found in Ford, p. 213. Paraphrasing, Ford's meditation on watchworks goes something like this: "It is remarkable that we were able to build functioning watches a hundred years or more before we fully understood the characteristics of the metals and jewels used to create them. And similarly, in the realm of particle physics, we've been able to do useful things [such as build the A-bomb] considerably ahead of the time when we fully understood the atom's constituent parts." Ford too is concerned about a 'missing piece' in one's understanding of a phenomenon. BUT, while my concern is with understanding the higher level abstract 'meaning[s]' of an object, his concern is with not having gone 'far enough down' into the guts of the thing, to find out why a metal spring possesses springiness.

Given the degree of overlap between physics and chemistry (see **Figure 29** on page **95**, and the beginning of this chapter on page **109**), don't chemists too suffer from the drill-down myopia that is the point of the grey-alien/purple-alien parable? Logically it must be so, but in studying chemistry, I don't remember a single instance of it ever coming up in real life. Somehow the two fields behave differently in this regard.

Breaking Down and Building Up

In *Strange Beauty* (p. 9), George Johnson quotes Murray Gell-Mann to this effect: Never forget breaking down an entity into components and subcomponents is relatively easy compared to building it up. Then Johnson opines that the idea is worth repeating, and spends a moment meditating on various complex build-up scenarios such as ecological systems and the human organism. The point is that quarks millions of years ago couldn't have predicted the physicist, for example, standing before us today. Gell-Mann's point is fine as far it goes. But to me, there seems to be a blind spot in the thinking broad enough to drive a truck through: He begins at the quark level and jumps all the way to complex organisms in the macroscopic realm. What's missing is the atom: In my view, the atom itself is a living entity that *likewise* cannot be 'built up' from quarks or 'predicted from quarks', only broken down into quarks. (Earlier we touched on this issue in the context of the Balmer series and Rutherford's question to Bohr about the electron's choice of frequency; page **131**.)

The Physics / Chemistry Contrast (again):

In its most extreme form, the contrast between chemistry and physics might be stated as follows: Chemistry is where it all began, *and* chemistry has kept its original identity as a science. By contrast, particle physics is an upstart with an oddly checkered history, during much of which it has felt more like a mixture of 'theology' and science.

After all, from 1905 into the early 1940s, physics was just eggheads scribbling on blackboards and using found objects to cobble together experimental equipment.

There was no budget for a proper laboratory at the time (strange but true; see Crease, p. 257 for example). Only with the bomb did it find 'glory' and a budget to match, thus turning eventually into Big Physics, the glitter of which would take some forty years to fade, the slow decay punctuated by the cancellation of the Supercollider project in 1993 (Crease, p. 255). The party was over, and the physicists went back to being eggheads scribbling on blackboards (or pointyheads scribbling at white boards if you prefer to update the image). In 2006 came a book by Peter Woit called *Not Even Wrong: The Failure of String Theory & the Continuing Challenge to Unify the Laws of Physics*. (The first part of the title is a famous Wolfgang Pauli witticism, newly applied.)

Another contrast between physics and chemistry:
It strikes me that the mind-set of physicists is perhaps 80% focused on a frenetic search for the New. Consider the case of Leon Lederman. Overall, he is very funny and self-effacing; and these are qualities quite absent from the stereotypical physics geek. Nevertheless, even Lederman reveals a lurid vein of geekiness in his character in his recounting of the famous 1957 parity nonconservation discovery. First, he all but admits that as soon as Madame Wu showed the way forward, he would gladly have leapfrogged her team to steal their thunder, even though just three days earlier he didn't even believe in the theory they were pursuing. Admitting to that psychology is fine, even admirable, but what is not so fine is the subtitle that appears eventually in Lederman on page 265: 'The Experiment'. There he earns a dope-slap for missing the point that people reading such a chapter are hoping to learn something about **THE very famous 1957 experiment carried out by ***Madame Wu*****, not about the me-too experiment that Lederman's team frantically carried out in her wake. Yet it's his own experiment that he now recounts, having said all he wished to say about the C.S.Wu experiment already, very briefly, in an earlier section. I'm not mentioning this to be critical of his book — which is hilarious and informative — but because those two words, 'The Experiment', offer us a glimpse right down to the bone of the self-centered quasi-hysterical geekiness that probably resides at the core of many a physicist, of diverse stripe.

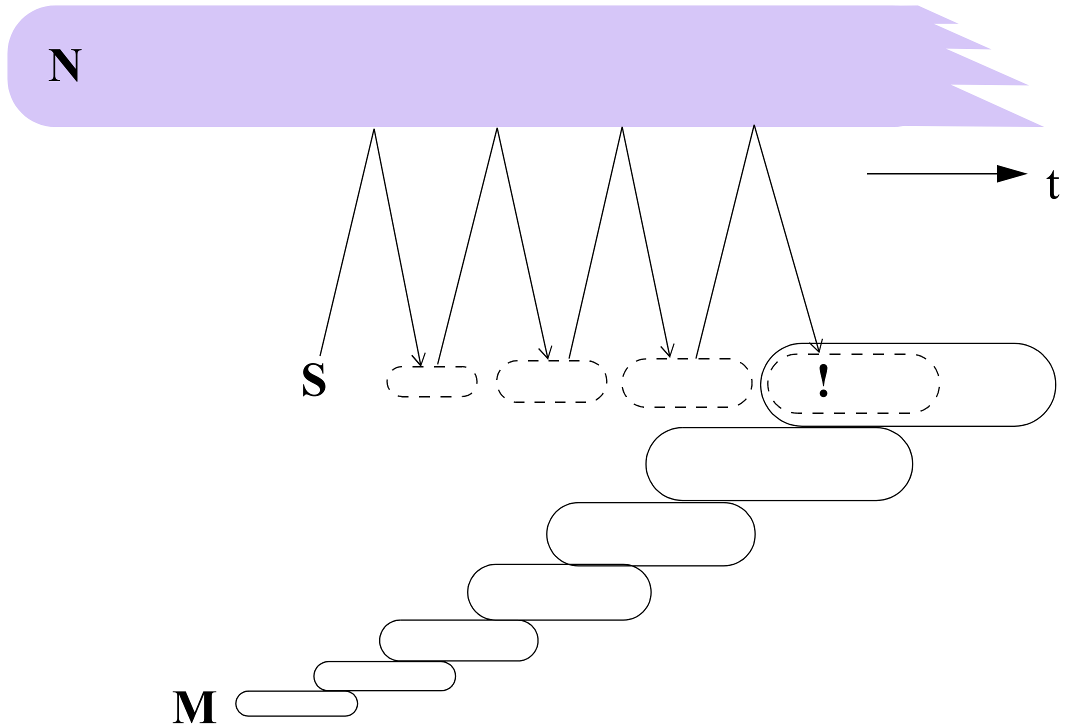
Thus, after experimental confirmation of neutral currents in 1973 and charm in 1975 (and the discovery of the tau lepton in 1975 and the W- and Z-bosons in 1983), it seems that physics has in a sense burned out. (And this problem is aggravated by, or partly the genesis of, the epoch of 'Not Even Wrong', as summarized by Peter Woit, and again by Smolin in *The Trouble with Physics*, 2006.) In the history of chemistry there are plenty of exciting moments of discovery, too, but these are balanced by calm contemplative moods that seem native to chemistry (as manifest in Hoffmann's *Chemistry Imagined*, for example). These are not an integral part of physics. The chemist's mind-set seems only 50% focused on the frantic new, leaving a healthy 50% of one's energy free for contemplative moods or activities.

V Biped Mathematics

Preface to Chapter V

Apparently on earth there has been much soul-searching over the three-way relation, possibly mysterious, between mathematics and physics and nature. Accordingly, as preface to the present chapter, we take a quick look at two well-known essays on that subject, one by Eugene Wigner (1960), another by John Barrow (1988).

Words can be treacherous, and in any event we Protons tend to think best in pictures, so I'll begin with **Figure 39**, my graphical synopsis of the essay by Wigner entitled, 'The Unreasonable Effectiveness of Mathematics in the Natural Sciences'.



Legend

N = Nature, the Eternal
M = Mathematics (aspirinig to the Eternal)
S = Sciences (Echoing Wigner, we say 'Sciences' but in all such discussions of mathematics and the sciences, one can sense that the writer is thinking about physics, specifically.)
The broken arrows represent physics 'bouncing off' Nature as it tries and corrects various theories.
! = surprise, as when the second derivative in calculus comes to the aid of the Law of Gravitation

FIGURE 39: A Picture to Summarize Wigner's Essay

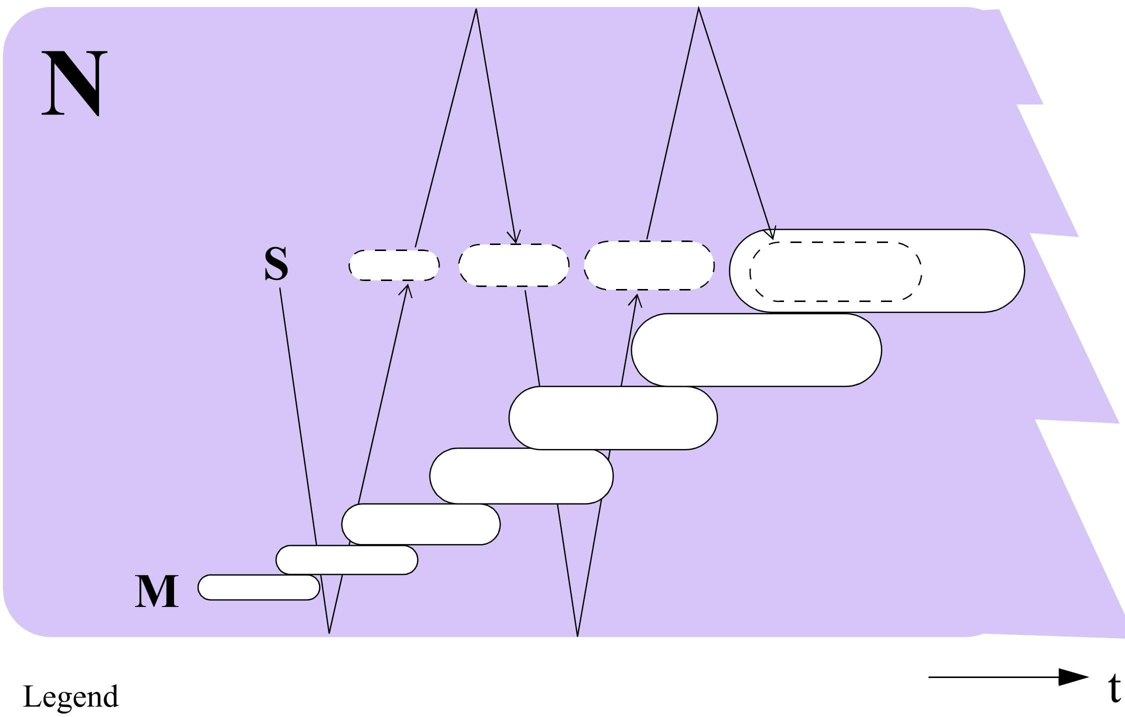
What is 'unreasonable' about the relation depicted in **Figure 39**? Primarily, its ability to keep generating unexpected connections, one of which we represent by a generic moment of surprise marked by an exclamation point. Also, as a natural extension of that idea, Wigner alludes to one's inability to determine if a given theory based on mathematical concepts is 'uniquely appropriate' (Wigner, p. 527). (Since the crossing of paths of mathematics and the sciences takes us by surprise, that leaves us wondering: Was this particular help from mathematics the only possibly way to model that problem in nature? Very often it seems to be, and yet... There must always be the lingering doubt, given that 'the answer' reached us in such a circuitous way.)

One of Wigner's examples is the second derivative in calculus (represented in **Figure 39** by the largest of the stepping stones for **M**) in relation to the law of gravitation (represented by the rightmost lozenges in the **S** row, while gravitation itself must reside somewhere in the amorphous colored region marked **N**). Wigner says, "...as formulated by Newton [this connection] was repugnant to his time and to himself. Empirically, it was based on very scanty observtions...the law is simple only to the mathematician, not to common sense" (pp. 534-535).

In a similar vein, on p. 535 Wigner mentions Max Born's 'reminder' about Cayley's 1858 invention of the calculus of matrices, a 'reminder' to young Heisenberg that led directly to his birthing of matrix mechanics in 1925. For an incomparably engaging account of this most remarkable of all such 'unexpected connections', see Chapter IX in Banesh Hoffmann, especially pp. 99-102.

Out of modesty, Wigner refrains from mentioning a parallel case close to home: Just as Max Born helped Heisenberg by leading him 'back' to matrices, so John von Neumann set Wigner on the path to group theory, and "Thus did group theory enter quantum mechanics" (Pais, p. 266). In describing the latter relation, here is David Bishop, writing circa 1973: "At first sight, group theory appears so abstract and so unrelated to physical reality that it seems amazing that it should be the powerful *practical* tool which it is"; Bishop, p. 24, his italics. (For more about David Bishop's *Group Theory and Chemistry*, see also page **39** above.) And this brings us full circle to Eugene Wigner's essay.

As your Proton visitor from far far away, so to speak, I must confess that it takes some effort for me to appreciate the surprise element in all this. Much of that surprise element can be defused for you as well, once you recognize the following as a false trichotomy (by analogy with false dichotomy): Nature versus Mathematics (i.e., a certain liberal art) versus the Natural Sciences (viz., physics). Try to see it this way: By definition, your Mathematics and your Sciences must be part *of* Nature; else where did they come from? Thus, our first of two corrections to **Figure 39** shows Nature now *encompassing* Mathematics and the Sciences:



Legend

To create this figure, we've overlaid the bottom part of **Figure 39** on the top part, as an acknowledgment that everything is part of Nature.
As before, the broken arrows represent physics 'bouncing off' Nature as it tries out various theories.
In this arrangement, the ping-ponging and coalescing seem somewhat less surprising, so we omit the exclamation point that marked a crossing of paths in the original figure.

FIGURE 40: First Correction of the False Trichotomy in **Figure 39**

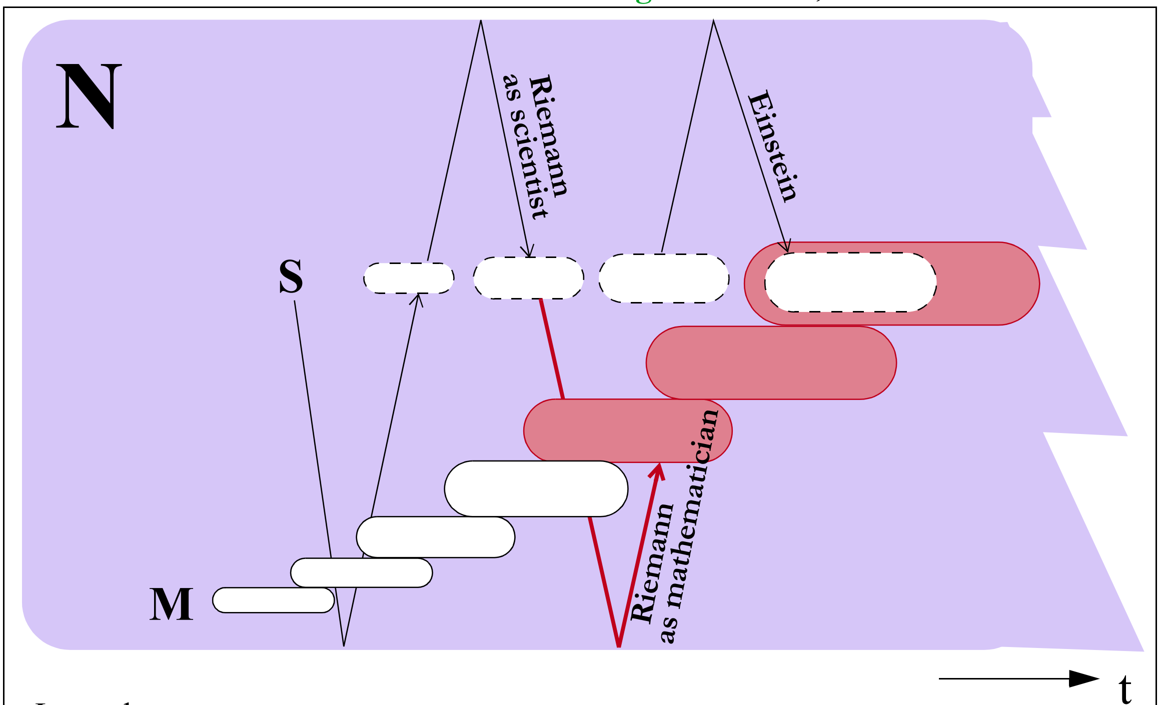
You bipeds and your Mathematics and your Sciences and Nature are all of one cloth, after all. How could it be otherwise? (Similarly, much though you bipeds may gnash your teeth and bemoan the tragedy of a shaved-head brat throwing down his Coca-Cola® can at Yosemite or Yellow Stone, his actions and the empty can itself, and even its ugly brown stain on the virgin granite, are all part of Nature; obviously, once you stop to think about it. In other words, once you've accepted the hideous little jungle monkey as part of sacred Nature, then the hideous little *super*-monkey is equally in the fold of Mother Nature's bosom. So deal with it. Harshly if you must, to assuage your sense of outrage at the aesthetics, or lack thereof, but also with a modicum of intelligence, please.) For another angle on these problems, see the Bertrand Russell quote on page 141 above.

Either way (Wigner's way in **Figure 39** or my way in **Figure 40**), I'll concede that the relation between Mathematics (M) and the Sciences (S) is *somewhat* noteworthy. I just don't find it deep-space mysterious. But in revisiting Wigner, my aim is not so much to dispute his famous essay as to open up the vista and consider other facets of the problem he tackles. In particular, I wish to try the following: Let's draw a sharp line between [a] mathematics *itself* (in its ethereal role of being 'unreasonably effective') and [b] the classroom culture *of* mathematics, on the ground, as it were. The latter I find quite 'unreasonable' in the ordinary sense of the word, as elaborated later in this chapter. There we will broach the following (novel?) idea: Mathematics succeeds in underpinning the sciences not only *because* of her virtues but also in *spite* of her arbitrary cultural neuroses; mathematics is *one* liberal *art* that has (unfortunately) infected *all* the sciences with its (bad) culture, not just its (good) substance. Bad how? Briefly, because your queen exudes the meticulous while actually being slovenly. She has everyone fooled.

But here, still in the preface *to* the present chapter, we must first, for further perspective, explore the idea that *all* of mathematics (itself) might best be interpreted as *a culture*, not as a form of Platonism. I'm thinking now of John Barrow's essay, 'What Is Mathematics?'

Barrow outlines four interpretations of mathematics for which he uses the labels *Platonism*, *Conceptualism*, *Formalist* and *Intuitionism* (Barrow, pp. 542-550). As soon as they have been defined, he then combines the latter three -*ism*'s into a single viewpoint. This allows him to set up an "imaginary dialogue between a Platonist [i.e., a Platonist mathematician] and a mathematician who maintains that mathematics is a human invention"; the dialogue ensues on pp. 550-556. Thus, on one side of the conversation, we are given a tour of mathematics-as-culture, as an anthropologist's artifact, so to say. By the time we reach p. 556 in Barrow's essay, we can see that he takes this non-Platonist (pro-anthropologist's) viewpoint quite seriously, too. Clearly, he set it up not only as straw dog to help us better understand the Platonist mathematician's viewpoint but also as a serious objection to or damper on the latter.

But what of Wigner's influential essay, where often he leans strongly toward the Platonist viewpoint? ("This shows that the mathematical language has more to commend it than being the *only* language which we can speak; it shows that it is, in a very real sense, the *correct* language"; Wigner, p. 534, emphasis added.) One of the arguments that Barrows offers against the Platonist view, by way of his imaginary dialogue, seems especially persuasive, and it leaves Wigner on the ropes. I'll paraphrase it here: At first blush, Bernhard Riemann seems the perfect case to cite in support of the Platonist view: Riemann's ethereal mathematical toy helps Einstein solve a real-world problem. What could be more surprising? But Barrow points out an intriguing kind of hidden circularity, waiting to ambush the Platonist here: "You see, Riemann's study of the geometrical properties of curved surfaces arose from his interest in a very practical problem: the distortion of sheets of metal when they are heated. The effect is not dissimilar to the distortion of space-time geometry my mass and energy according to Einstein's theory. In fact, some physicists have even used the heated metal sheet as a heuristic to explain Einstein's theory to the general public" (Barrow, p. 551). The circularity illuminated by Barrow suggests that we should add a second and final correction to **Figure 39** above, as follows:



Legend

N, M, S = Nature, Mathematics, and Science, as before. The broken arrow in red and the three red-tinted lozenges represent the 'Riemann'-type nuance as described in the text below.

FIGURE 41: Second Correction of the False Trichotomy in **Figure 39**

Thus, in deciphering Nature, Science will eventually find 'help in Mathematics', yes (as represented by our original crossing of the **M** and **S** paths); but this particular help has its origins in a long-ago interaction between Riemann the Scientist and Nature, before it appeared on Einstein's radar as part of Mathematics (the final red-tinted lozenge in **Figure 41**). Thus, the potential is revealed for a circle of relations between the three entities, Nature, Mathematics, and Science. No more trichotomy, or at any rate it is now a quite slippery trichotomy. The moral of the story: Everything is potentially related to everything, so be careful about your assumptions — especially of causality, perhaps even of 'mystery'.

As a visiting Proton, my own opinion on all the above is rather ambiguous — more detached and less emotional: Your earthling instinct to pursue mathematics in a quest for the Platonic is valid *in principle*, probably even admirable; no one should deny you that. But given the imperfect and quirky state of mathematics as it is *now*, marred by earthbound provincialisms (to be enumerated later in this chapter), it would be safer to accept the side of Barrow's imaginary dialogue where he warns us that mathematics may be only a cultural artifact. Not ready for prime time.

What happened to chemistry?!

Finally, a note about chemistry, which thus far seems to have fallen in the cracks of this chapter. At the beginning of his essay, Barrow echoes Wigner in stating, "Contemporary science is going to be proven wrong, but mathematics is not" (Barrow, p. 541). Moreover, in explaining the Platonists' viewpoint, he says they would trust "only mathematics as a universal language for communicating with alien beings" (pp. 542-543). But here he traps himself by letting 'science' always equate to 'physics' (as we've warned the reader in the Legend to **Figure 39**). Relative to physics, perhaps mathematics appears to be the better horse to bet on. But once you put chemistry back into the mix, there is no contest: *I* am an alien being, and if you wish to communicate with me, please avoid your quirky physics and quirkier mathematics, and choose chemistry as your language, so I won't get a migraine! (Granted, in the area where chemistry and physics meet, in physical chemistry, my argument runs into trouble, but still it has merit from a certain high perspective: Forget mathematics; chemistry is the universal language for chatting up an alien, fully comprehensible from the very first instant of contact.)

(Reminder: This volume includes a separate essay devoted to probability: **Appendix F: God IS the Dice**. The present chapter pertains to mathematics as it exists on the typical college campus, in a department distinct from the probability and statistics department. Meanwhile, in the appendix, we recognize probability as one of the ‘sane’ disciplines, i.e., those that are relatively free of neurosis or pathology, the other two being computer science and chemistry.)

Part One: Mathematics *Itself* (The Pretty Face of Queen Mathematics)

Suppose we wish to define the domain of the following function:(69)

$$f(x, y) = \frac{\sqrt{x+y+1}}{(x-1)} \qquad \text{(EQ 1)}$$

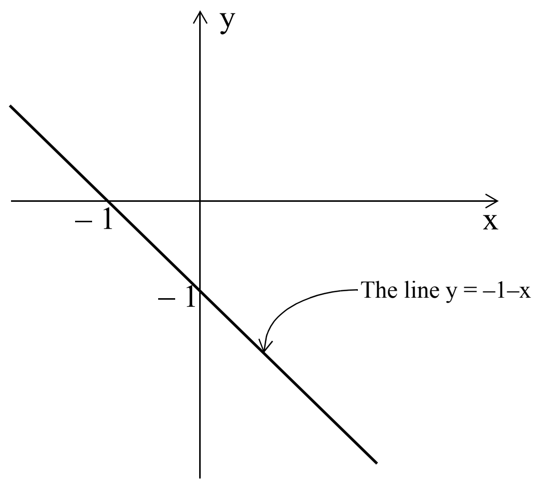
The mathematician writes...

$$D = \left\{ \mathbf{(x,y)} \;\middle|\; \mathbf{x+y+1 \geq 0, x \neq 1} \right\}$$

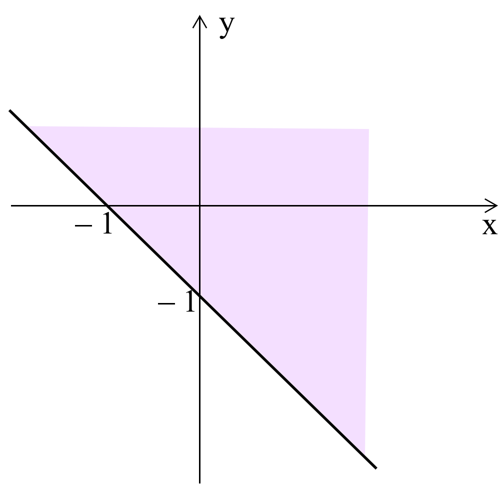
...and he or she is done. The terseness of those 21 characters rivals that of Classical Chinese, so it will take me a few paragraphs, plus illustrations, to unpack them and fully explain their meaning. First, here is a quick overview of the terrain: To the laity, a ‘domain’ sounds like something positive, which it is; and yet, for practical reasons, the way to define a given domain is to think negatively. You back into it by itemizing those conditions that could ‘break’ the equation, and/or make positive statements that are carefully tailored to preclude certain negative conditions (i.e., any condition that would make the function nonsensical). In this instance, one condition that would break the function is ‘taking the square root of a negative number’. In other words, we wish to ensure that x+y+1 under the radical sign shall never add up to something negative. In English, the first part of the domain definition must be, “Don’t ever allow x+y+1 to be negative.” Translated to mathematical language, this becomes ‘x+y+1 ≥ 0’. Let’s try to make a picture of the domain.

As a slight algebraic variation on the statement x+y+1 ≥ 0, one might define a slanted line as y = –1–x and see if that would mark the domain’s boundary:

69. The term ‘domain’ is just a fancy way of saying, “Where does this function or equation have values?” The example itself is borrowed from James Stewart, *Calculus* (Fourth Edition), p. 908, and elaborated here.



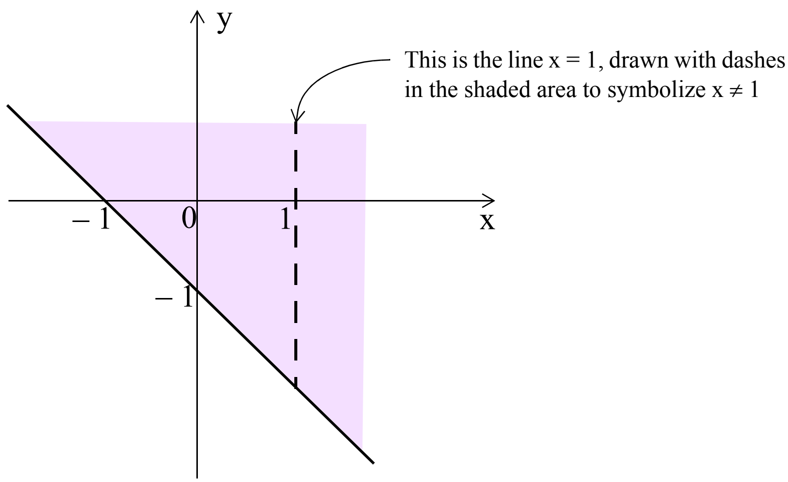
Close but no cigar. What we have so far is a picture showing *one* of the domain's boundaries, not yet the whole picture. A better statement would be y ≥ (–1–x). Here, as if by magic, a mere line has become the definition of something that really does look like a two-dimensional domain (i.e., a whole region)...



...simply because we replaced the equal sign by an inequality sign. (The shaded triangle is an abstract symbol: By convention, one imagines that the hypotenuse may grow as long as one likes, along the line already defined by the points (–1, 0) and (0, –1). Meanwhile, the other two sides of the triangle are mentally 'pushed out' in concert, in the positive x and y directions, to form as large a triangle as one wishes to imagine, all the way to infinity.)

Other than 'taking the square root of a negative number', what else might break the function?

Division by zero would break it (i.e., render it nonsensical or 'undefined' in the coy jargon of mathematics). Accordingly, we need to add the phrase, 'Don't ever allow x to be one' (because if x were 1, then x–1 would become 1–1=0 in the denominator: thus leading to the dreaded condition of 'division by zero'). In symbols, the constraint we need to add is this: $x \neq 1$. Returning to the graph, this second part of the domain definition can be accommodated by adding a vertical dashed line, positioned at 1 on the x-axis:



Now the picture says, "The domain is anything on or above the slanted line y = –1–x except that x=1 is not permitted; points on *that* vertical line are everywhere excluded from the large triangular domain that is otherwise stretchable to infinity."

Elegant though the picture is, what is even more elegant and terse is the string of 21 characters we began with...

$$D = \left\{ (x,y) \;\middle|\; x+y+1 \geq 0,\ x \neq 1 \right\}$$

...which says precisely the same thing, all by itself. This may provide the *laity* with an inkling of why mathematicians think so highly of their field. However, relative to what the *mathematician* admires in the way of terseness, even this example would not be noteworthy. Such is the power of the mathematical language. (But if I seem to be gushing with admiration, please savor the moment. I'll have only a few friendly things to say about biped mathematics beyond this point!)

Part Two: Mathematics *Culture* (The Unreasonable Face of Queen Mathematics)

Between mathematics and the sciences, remarkable parallels exist. As discussed in the preface to this chapter, the consensus is that the models provided by mathematics are, in fact, the *right* ones. In this sense, there is 'no escape' from mathematics: It is an essential tool for doing chemistry or physics, and the more of it you have under your belt, the better. In **Figure 29** on page **95**, the large, all-encompassing circle labeled 'Mathematics' is meant to convey this aspect of the subject already; meanwhile, the tilt of the word 'Mathematics' in that figure is a reminder that this subject possesses a dark side, too, its own special brand of subtle taintedness.

I'm willing to accept mathematics and science as partners in a marriage of sorts, but only if we add two important caveats (which possess a curious interrelation of their own, like two twisted sisters):

[1] While the universe expresses herself over and over and over again in exclusively *ir*rational numbers such as 3.1415... (of which more in a moment), the biped never stops yearning for a magic number in nature, something like The Answer (42 was it?) in Douglas Adams' *The Hitch-hiker's Guide to the Galaxy*. This on-going tug-o-war between stark reality and the quixotic dream leads inevitably to the occasional big embarrassment. A famous astronomer who went daffy for a time over the idea that the fine structure constant in particle physics (page **118**, note (**b**)) was 1/137 (with a plain integer on the bottom), only to be told later that improved measurement techniques showed its value to be an irrational 1/137.035963... (i.e., with a long ragged decimal that goes on forever).

[2] Mathematics lives a double life, always: its one face public and bemused in coy support of the hard sciences, where it doesn't mind sharing some reflected glory; the other face austere and aloof — so far up into wispy clouds that neurosis becomes a real danger. And, as detailed below, where a value such as 1/137 is pitted against 1/137.035963... inside mathematics (as distinct from 'inside physics'), the field has its own internal drama in continuous nightly play, where the issue is not 'earthling dreams' vs. 'nature's reality' but something wholly abstract that can easily strike the unbiased observer as a mild form of insanity.

Word games in Mathematics

Ratios that are not ratio-y enough; values that are 'approximate' or perhaps merely 'exact'

As much as the mathematician may hate it, his/her world does not consist solely of lovely abstract symbols such as the ones explored in Equation **1** above. It consists also of certain concepts tied to words. Take the word 'irrational' for instance. In her arrogance, mathematics imposes upon nature two kinds of ratio, the kind that is properly ratio-y in its behavior and the kind that feels *unratio-like-from-the-biped-perspective*. Lacking the nerve it takes to stand up to an English teacher and insist on the sane way of labeling the latter concept, the mathematics establishment throws the word 'irrational' out there, thus compounding the insult against nature: Not only does mathematics impose a division on nature motivated by biped inadequacy, but to cover this crime the mathematician cooks up a word that seems to mean 'slightly mad', and fails even to say what it means: The word 'irrational' as used in mathematics is just a lazy way of saying 'unratio-like-from-the-biped-perspective'. For if *pi* isn't a ratio I'd love to know what it is. It is, *if anything* (other than a figment of the feverish biped imagination), the ratio of circumference to diameter, so how does one get away labeling it with a word meaning not-really-ratio-y-enough? A ratio such as 3/4 is ratio-y enough since it divides evenly into 0.750000, but pi is not ratio-y enough since biped arithmetic shows its decimal dribbling off forever. Perhaps the goofy label 'irrational' results from a fear of English teacher wrath over 'not-really-ratio-y-enough'?

Then come my favorites, 'exact' and 'approximate', two more words that have very particular but neurotic meanings in mathematics.

Suppose I make the following bald assertion, just for the heck of it:

$$e^{\pi} = \pi^{e} \qquad \text{(EQ 2)}$$

How does one determine if my statement is *true*, i.e., that e raised to the π^{th} power really is the same as π raised to the e^{th} power? Taking a horse-sense approach, one might say,

"*If* Equation *2* were a true statement, surely one of my teachers would have mentioned it somewhere along the way. It's such a 'neat'-looking relation and so easy to memorize. But Equation *2* *doesn't* look familiar so I'll have to say, *No*, the assertion is false."

And that would be a correct if slightly goofy conjecture. Here's another way that one could test the assertion: Pick a pair of sample values for *pi* and *e* and try them out to see if the two powers match. The value of *e* is something like 2.7182 and the value of *pi* is something like 3.1415. So let's try this:

$$2.7182^{3.1415} \approx 23 \neq 22 \approx 3.1415^{2.7182}$$

From this quick experiment, it appears that *e* raised to the πth power is about 23 while π raised to the *e*th power is about 22. This pair of values — 23 versus 22 — would confirm one's hunch that the assertion (*e* to the *pi*$^{\text{th}}$ equals *pi* to the *e*$^{\text{th}}$) is not true.

But suppose we had chosen the following values to test the assertion: $e \approx 2.7$, $pi \approx 3.1$. Then the test would have played out this way instead:

$$2.7^{3.1} \approx 21 = 21 \approx 3.1^{2.7}$$

Judged by this test, the two pieces of the puzzle seem to match, with both of them landing on the value 21. If taken seriously, this test seems to suggest that the original assertion is true.

Which test should we believe? The one that says '23 ≠ 22' or the one that says '21=21'?

"Obviously, the first test," says the naïve amateur. And the *amateur's* common sense response is correct. The first test contains more decimal places, so it is obviously a more convincing test of the premise. The second test contains fewer decimal places, so its crudeness leads us to an incorrect conclusion. But inside the world of mathematics itself, the *professional* might hem and haw at this juncture, finding himself a victim of his own dubious logic, hence unable to respond with common sense.

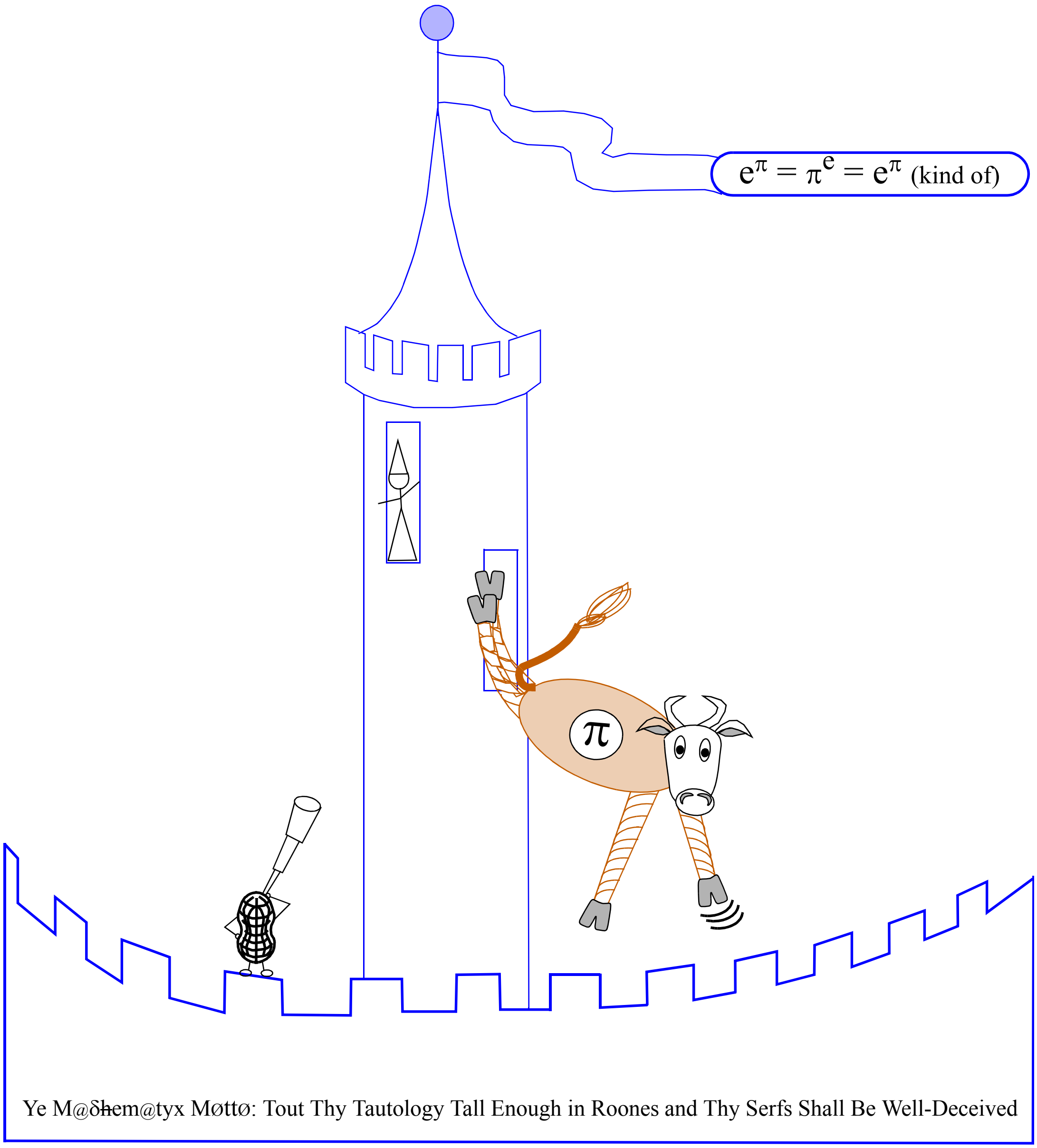


FIGURE 42: The Queen Snugly in her Spire and a Sacred Cow Imperiled

As you might recall from one of your own math classes, there are countless circumstances where 'the right way' to show your answer is something like '2π', and the wrong way would be '6.2830' (= 2 x 3.1415).

Why? Because in the jargon of mathematics the former is 'exact' (= good, true, worthy of the Priesthood) and the latter is merely 'approximate' (= an insult to the teacher's fine sensibilities, a reminder of the extra-Mathematical world of serfs who toil in the mud beyond the walls of the Ivory Tower).

Mathematicians will say they've done something wonderful by lassoing the unknowable abstraction 'Circumference over Diameter is 3.1415...' and branding that doggie with a π-iron. After all, didn't that in turn make way for Euler's identity, $e^{i\pi} + 1 = 0$, universally praised as "the most beautiful theorem in all of mathematics"? Yes, but we protons are not so easily wowed by a Greek letter, just because it happens to resemble a Stonehenge monument (or a *torii* if you like). We are π skeptics. We would say, "Sooner or later, of course, one of you earthlings will stumble upon this so-called Euler identity, because that's the way you've rigged the deck of cards: to close back on itself 'exactly'. Have you never stopped for one moment to think about an outsider's view of π? *Is* it a cause for joy and pride or is it perhaps a Biped Badge of Shame? *Is* the legendary equation 'beautiful' or merely the Mother of All Tautologies?"

Consider the following relation. In calculus, one of the most exciting moments is when you realize that the first derivative of $V(r) = 4/3\ \pi r^3$ (the *volume* of a sphere, expressed as a function of r) is $4\pi r^2$. This is the equation for finding the *surface* area of a sphere of radius r, probably an 'old friend' from earlier studies.

$$\frac{d}{dr}\left[\frac{4}{3}\pi r^3\right] = \left(\frac{4}{\cancel{3}}\right)\pi\cancel{3}r^2 = 4\pi r^2$$

Take the first derivative of the volume of a sphere

An old friend: the surface area of a sphere

$$\frac{d}{dr}\left[\frac{4}{3}\pi r^3\right] = \left(\frac{4}{\cancel{3}}\right)(3.14)\cancel{3}r^2 = 4(3.14)r^2$$

less prettiness, more understanding

FIGURE 43: The Epiphany of *pi*-less Epiphanies

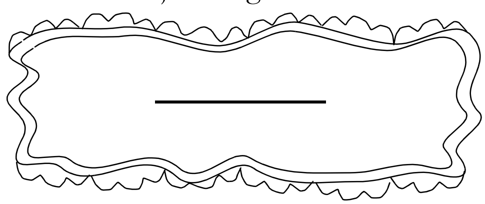
At first sight, the beauty of the equality might seem to be tied up intimately with π. But really, π is just a 'constant' (in the math jargon sense) going along for the ride, just as 4/3 goes along for the ride; meanwhile, the derivative-taking 'action' is with r^3 exclusively (which becomes $3*r^2$ by application of the first rule taught in Calculus I: multiply by the exponent then decrement the exponent). So, even without π in the mix, you should still find it possible to appreciate the epiphany. Here's how it would play out: In a hypothetical *pi*-less culture, one would have learned $S_{sphere} = 4(3.14)r^2$ in Middle School geometry, let's say. Then, in calculus, one would see that the equation $V(r) = 4/3(3.14)r^3$ can be transformed into an old friend $4(3.14)r^2$ by the rule for differentiation mentioned earlier. Still there would be the magic, although admittedly of a less pretty kind. What I would like to suggest is that loss of *prettiness* would be compensated amply by one's increased (general) *understanding* of 3.14 in preference to the primitive, quasi-mystical idol-worship of π that pervades the establishment today. To gain some perspective on this, think of the gas constant in chemistry: There are countless situations where the chemist simply writes the figures '8.31' (followed by the units). True, the gas constant has an abbreviation, R, which feels convenient and right in a formula such as PV = nRT. But once the chemist has something specific to calculate, s/he tends to switch immediately to 8.31, and this is psychologically easy to do since 'R' doesn't carry the quasi-mystical baggage that π does. In chemistry, R is not a temple fetish, merely an abbreviation, as it should be.

If you ask me, π seems to be a tacit admission by the biped that he eternally lacks complete knowledge of the number 3.1415... and therefore lacks a way of ever writing it down and therefore is in perpetual need of a proxy that will draw attention away from such an embarrassing situation. Like a winning politician, the mathematician is adept at spin. What is '3.1415'? It's a decimal fraction with 4 significant digits. And, as any student of chemistry knows, when you have 4 significant digits, you are offering a reasonably *precise*(70) value, *not* a vague approximation of something. Thus we see that the two words 'exact' and 'approximate' are used backwards in mathematics. The mathematician takes the Badge of Shame π and spins it as 'exact'. This in turn requires relegation of 3.1415 to 'approximate'. But this exact/approximate fetish doesn't even help with an analysis when push comes to shove: Notice, for example, how it fails to illuminate the realities of our (deliberately false) assertion above that 'e^{π} equals π^{e}'. The

70. Just as the words 'exact' and 'approximate' have a high profile in mathematics, so the words 'precision' and 'accuracy' have a high profile in the natural sciences, although the two pairs of meanings are clearly not parallel. The issue in the natural sciences is to avoid 'precision without accuracy'. The weather lady knows we'll only laugh if she predicts an 89.531% chance of rain; best to say 90% and be done with it. The number with three decimals promises precision but delivers nothing. Meanwhile, doctors, nurses and therapists have yet to apply this principle to BMI calculations, where the 'normal' range is defined as 18.5 through 24.9, with 18.4 signifying the start of the anorexia range, and 25.0 the start for obesity. Note that the vagaries of using scales are such that the BMI decimal place is quite meaningless — *unless* it were to trend down or up persistently over a period of weeks. Yet frequently a doctor will trot out a BMI value in the form xx.x, *in isolation*, and try to read meaning into it (for a patient who seems at risk of becoming abnormal, or for one long deemed abnormal, as the case may be), apparently having forgotten a lesson from Day One, literally, of freshman physics or chemistry.

assertion itself I cast in the guise of an 'exact' statement (as the mathematician would view it, since it uses only the sanctified glyphs π and *e*, and no plebeian digits with decimal points lurking). But to test that 'exact'-looking assertion, even the mathematician must sneak a private look at some down-to-earth values such as 3.1415 and 2.7182 (the ones he would rather call 'approximate' in public). But wait. It is only because the latter are *precise* that we trust them as the litmus test for deciding the truth of the symbols I piled haphazardly together to form ' $e^{\pi} = \pi^{e}$ '. So, what are they really: approximate or precise? And so the logic goes in an unending pretzel.

A story: By decree of the Grand Vizier, a certain line has been defined as the Imperial Unity. I.e., its value is declared to be $1.0000000000\overline{0}$.... to an infinite number of zeroes of accuracy. And here, in a scalloped frame befitting its importance, I give you that very line, exactly one of something, whatever unit you may wish to call it, say 'one Vizier' just to give it a name:



Now your job is simply to construct a good circle on the line, using it as the circle's diameter. No, wait. What we'd really like is for you to construct a perfect circle. Is that asking so much — what with all our hi-tech equipment these days?

So you haul out your hi-tech computerized drawing tool or your lo-tech but trusted drafting compass, and using one or the other, you draw a circle such that my line of '1' is its diameter. There, a perfect circle. Now all you need to do is take a measurement to confirm that it's *as* perfect as it looks. And the way to find a circumference, as everyone knows from grade school is to multiply D times π. In this case, D = 1 Vizier (by fiat of definition), so all you really need to know is whether a piece of thread, overlaid upon the nicely drawn circle and secured with a few map pins, measures π Viziers. Something like that. But how far to go with the decimal places, 3.1416...? Ah, there's the rub. No matter which formula you choose, the fraction will never end. Ergo, you may *not* claim to have drawn a perfect circle — only a 'purdy darn good circle' or a 'really outstanding circle'. It is literally impossible for you to complete the assigned task. But let's not despair. Instead of π being a circle-shape generator, perhaps π is a random-number generator (see and Goldstein and Goldstein, pp. 199-202).

Not only is π a random number generator, but as envisioned by Poundstone (in *The Recursive Universe*, pp. 230-231), one could use a π algorithm hooked up to a TV set to 'watch any show', assuming you were willing to wait some billions of years for such to appear on the screen. Now that you understand that 'I Love Lucy' and 'Gilligan's Island' and all the rest are living (in deep space, yes, but also) right there *inside the number* π, does it still seem such a mystical number? Is one proud to belong to a species that is locked in for Eternity to the limitation of 'purdy darn good'? One cannot escape the feeling that you Earthlings are out of your depth in a *fundamental way* for which there is no remedy. *Ill-equipped* is the term that comes to mind always when thinking about this problem. On many key topics, such as 'what is a circle?' or 'what is infinity?' (see **Absolute Axes (Sans Arms)** at the conclusion of this chapter), the biped has no clue if these are even reasonable questions, much less how to find their answers.

Cat Food at the Dollar Store

To further illuminate the peculiar nature of the mathematical landscape, I offer an analogy in a fanciful retail setting. In a land far away, each can of cat food is marked '98 cents'. Meanwhile, actual inventory is valued at $1.02 per can (because the Czar said do this). Meanwhile, the customers in this imaginary land carry only dollar bills. There are no coins in this country, only paper money. So, for cat food and money to change hands, some rationalizing needs to occur, such that rounding *up* from 0.98 to 1.00 is okay, and likewise a delicate rounding *down* from 1.02 to 1.00, so that customer and merchant can figuratively 'meet in the middle' and complete their transaction. (Apparently, in that curious land, merchants are continually losing money instead of making a profit, but that's for the Grand Vizier and the Keeper of the GNP to fret about and need not concern us here.) Now we have something comparable to what happens whenever a value is *tending* toward pi and the mathematician declares the answer to *be* 'pi'. He has made the judgment to round *up* to pi (if pi is the limit in a problem to be solved). Simultaneously he is also rounding *down* (or truncating), since pi as known to a biped (with a finite set of decimal places) is always less than true pi (with its tail of infinite decimal places trailing off forever).

Similarly, if a number were approaching *e* there would be a desire to round it 'up to *e* '. But *e* itself is a lie, since by any definition such as "e = 2.718," what the biped really means is that "we've stopped at the third decimal position" (having lopped off the others that stretch tediously to infinity). So again, there would be a simultaneous rounding up *and* rounding down implied by the seemingly innocent step of 'using *e* to represent 2.718...' Could it be that these two wrongs make a right? Somehow I'm not convinced. It's one thing to use such tricks in the retail cat food business, especially if sanctioned by the Czar, but it seems tacky to try such things in a dignified field like mathematics.

It is interesting to note that Indic English contains the expression 'exactly and approximately'. I suspect this to be the only sane way to approach those two words now that the mathematics establishment has done such a number on them: Keep the two unfortunates out of mischief by keeping them always in sight and together. And, as so often happens in Indic English, deliver them with a delicious sense of irony. Two examples occur in the Mira Nair film *Monsoon Wedding*. Parabatlal Kanhaiyalal Dubey, alias P.K. Dubey (played by Vijay Raaz), agrees in a cell phone conversation to stop by the bride's home and fix the marigold gate 'in 10 minutes, exactly and approximately'. Later, he quotes his waterproofing fee for the wedding tent as '5,000 rupees, exactly and approximately'. Ganesh only knows what the fellow means by that, but *touché* to the western mathematics establishment, I say.

Buffon's Needle

Buffon's Needle (1777) demonstrates a technique that would much later come to be known as the Monte Carlo method (after the name was proposed by Nicholas Metropolis and popularized by John von Neumann).

Cutting to the chase, the idea is that if you drop a bunch of needles on the floor one by one, counting them as you go, and also tallying up how many of them touch one of two parallel cracks between the floorboards, then π can be approximated as:

$$\frac{2 * \text{Number of Needles Dropped}}{\text{Number of Hits}}$$

The juxtaposition of the quasi-mystical letter π with this haphazard tossing of needles on a wood-hewn floor lends more mystery to this problem than it deserves, however. That's my quibble — the fact that π as usual hogs the limelight. Also, the fact that it isn't really π that is the output from this process; rather, two numbers which, when *divided* into each other, produce π. (Also, the fact that π is allowed to be part of the input to the typical 'proof' of Buffon's Needle, which it shouldn't be if one truly believed π to be it's output! That's a kind of sloppiness that would not be tolerated in Computer Science although it is common practice in the math/physics Establishment, but we'll skip that aspect here.)

In an attempt to gain a clearer picture of what π is, suppose we treat the *circle* with a bit of respect and let *it* equal one, so that C = 1 instead of D = 1. What then? Under that assumption, the diameter, D, must be 0.3183, calculated as follows:

$$\text{pi} = C/D$$

$$D = C/\text{pi} = 1/3.1416 = 0.3183.$$

In this system, school children would memorize 0.3183 as the ratio of *diameter* to circumference, whereas in the conventional system one memorizes 3.1416 as the ratio of *circumference* to diameter. Let's call 0.3183 the anti-pi, just to give it a name. Not that it would lead to anything very interesting if we globally replaced pi by anti-pi — just a tangle of difficult and alien looking computations. The point is just to consider the proposition that pi is not an *attribute* of the circle, pi is merely a ratio taken *between* two attributes of the circle, and in principle there could be another civilization somewhere in the universe using anti-pi instead of pi. In such a civilization, the two numbers that come out of the Buffon's Needle Problem would be divided in the other direction, and people would say 'it approximates anti-pi' not 'it approximates pi'. And the focus would be on the Monte Carlo style simulation itself, as it should be.

Seen clearly in its essence, the Buffon's Needle problem can be *restated* as the simplest imaginable Monte Carlo process, whereby we would toss pebbles randomly upon a *square* in which a *circle* has been inscribed (rather than tossing needles on the floor to see if they touch the cracks or not). Behind the Buffon's Needle problem as usually stated, there is a simple
A/B = C/D (proportional) relation. However, because π happens to occur in one of the denominators, and because the equation can therefore be 'solved for π' (a slippery half-truth at best since the output from Buffon's Needle is a ratio, not a number), it is easy to get lost in a thicket of circular reasoning: One worries about 'using π already' to integrate, within a *rectangle*, a *sinusoidal* region on the interval [0, π] of the unit circle; about how to simulate a needle's orientation after it falls to the floor landing at a random angle; and so on. All for the sake of 'estimating π' in a novel fashion. Evidently members of the subculture have great fun doing this, but

let's hope they also have an inkling of the airborne view, which is the circle mentioned earlier, with its face fully visible and *static* and *comprehensible*, concealing no delphic mystery. For an excellent introduction to the inscribed circle approach, see Schillaci, p. 5.

The double equal sign and related issues

Even more astonishing than his idol-worship of the π glyph is the mathematician's sloth regarding the equals sign. In computer science, 'x = y' and 'x == y' mean wildly different things — the *assignment* of a brand-*new* value to 'x' versus a *test* to see if the *existing* value of 'x' matches the existing value of 'y' — but these two cases are smeared together as one in mathematics, where they are handled by the one symbol '=' (to be interpreted variously according to context). Sadly, physicists (and even chemists, who should know better!) have been infected by the same sloppy thinking, since they rely so heavily on mathematics as a tool of the trade. But what the computer science major regards as sloppiness is easily rationalized by others: It is easy to imagine the math or physics major's retort: "Oh, it's only because computer science majors are less intelligent than us that they feel the need for distinguishing 'x = y' from 'x == y'. We are clever enough to carry such distinctions in our heads, or to let the context tell the story. No problem!"

In comparing the culture of computer science against the culture of mathematics (and physics), one is struck also by the different attitude about parameters versus values.

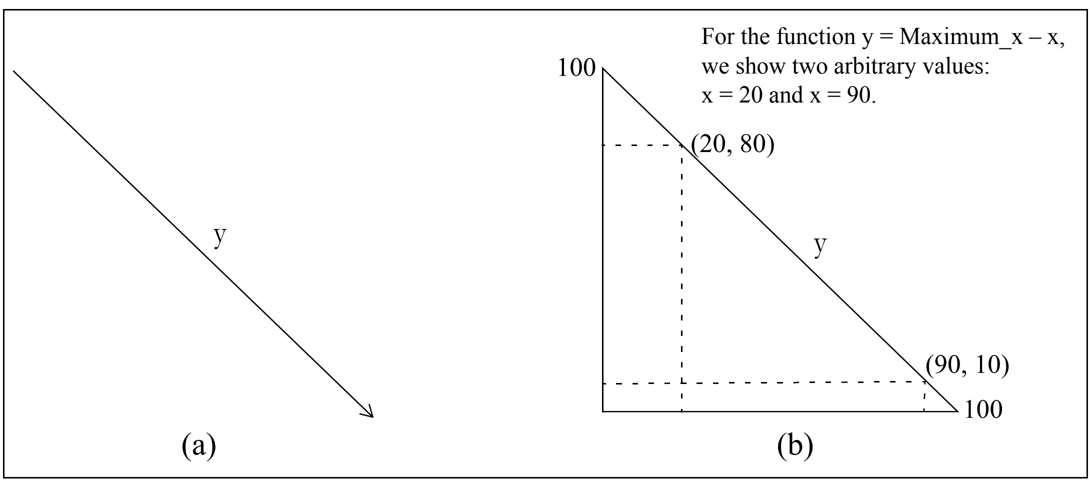


FIGURE 44: Translation of a Diagonal Line into Computational Language

In **Figure 44**a, we depict a slanted line. The arrow suggests that the line 'grows' from northwest to southeast. It carries an arbitrary label, 'y'. It appears to be tilted at a 45-degree angle.

Suppose we wish to go further and describe the same line in more detail, with reference to an xy-plane measuring 100 units along each axis, as shown in **Figure 44**b. In the computer science culture, we would express the line's 'growth' as a function involving a parameter called 'Maximum_x' and a variable called 'x', as follows:

$$y = \text{Maximum\_x} - x$$

As an afterthought, or as a test of the function, one might bring in some actual values this way:

If Maximum_x = 100 and x = 20, then y = 100 – 20 = 80

If Maximum_x = 100 and x = 90, then y = 100 – 90 = 10

The sets of sample values presented immediately above are represented by '(20,80)' and '(90,10)' in **Figure 44**b.

By contrast, authors of mathematics textbooks(71) habitually short-circuit the step where a function is expressed solely in terms of its abstracted parameter(s) and variable(s). Instead, they let some nice round *value* such as 100 serve — by unspoken agreement — as proxy for the Maximum_x *parameter*, as follows:

$$y = 100 - x$$

Students love this (especially if the value chosen is 100 or 1) because it looks clean and friendly, having gotten 'right to the point' instead of cluttering the page with an ugly term such as 'Maximum_x'. Early on, using a value such as '100' or '1' or '4.7' this way may seem harmless, but there comes a time when the function must be considered on its own terms, according to its true nature (as captured by

71. I drew **Figure 44**b as a bare bones takeoff on problem #9 in Hughes-Hallett *et al.* (2005), p. 397: "Find the total mass of [a triangular region] which has density $\delta(x) = 1 + x$ grams/cm^2." In computer science style, the density function to be integrated would be written as 'Maximum_x + x_i' instead of '1 + x'. This is not to say the latter style is unique to Hughes-Hallett; to the contrary, it is ubiquitous and understandably appealing. For example, browsing in Salas and Hille (1990), one of the most beautiful and meticulous calculus textbooks ever written, one sees the same objectionable notation style, circa p. 333, e.g. The practice has been internalized for so long in the mathematics culture that it is probably not even visible there; just part of the wallpaper.

'Maximum_x' in this case); otherwise, the student will find no way forward to the next part of the problem. From my simple example using a single slanted line segment, one must extrapolate to imagine the ultimate impact on the student, when he or she is tangling with three-dimensional vector calculus, for instance. Long story short, '100' is a kind of fool's gold, an instance of The Path to Hell is Paved with Good Intentions.

Thus we see that the business about the equals sign (serving double duty in mathematics to cover [1] value assignment and [2] equivalence testing) is not just a fluke or notational nicety that we've unfairly chosen to quibble over. Rather, it is symptomatic of a cavalier attitude in the mathematics culture about the distinction between variables and values, generally. It's as if the mathematician (or physicist) says, "Sure, we *understand* that distinction. But we're really clever and quick, and whenever we want to we'll just trash it to save time. Others who lack our skill may be bothered by the practice, but we need it to remain comfortable and nimble in our wonderful super-brightness, the style of which would be cramped by your hideous-looking parameter names and named constants" (this last being an allusion to the computer science practice of representing '3' by 'THREE' in certain contexts, even if the function is not actually 'about' the number three as a maximum or minimum but simply uses the number three in special ways). But it's not a matter of opinion or style. Those who use a value as proxy for a parameter are just wrong.

Finally, there is a related issue of saying 'set z to zero' when the intent is 'set the right side of the equation to zero':

$$z = y + vt - \tfrac{1}{2}gt^2 \text{ [~ Eq 2.12y in Serway \& Jewett]}$$

In a sane, legitimate interpretation, 'set z to zero' would mean "we've plugged values into the right-hand side of the equation and find that the whole thing *evaluates to* zero; therefore, we now set z to zero to represent that fact." But in the prevalent culture, what is meant typically by 'set z to zero' is more like the opposite; properly written down it would look like this...

$$y + vt - \tfrac{1}{2}gt^2 = 0$$

...or, in words: "[For a special purpose,] we are assigning the value 0 to the whole expression $y + vt - \tfrac{1}{2}gt^2$ [as this will allow us to tease out some information about one of its constituent parts.]"

Again, in computer science such sloppiness as illustrated above (saying 'set z to zero' when you mean 'set $y + vt - ½gt^2$ to zero') is unthinkable, since it would lead to bugs and thence to inane remarks by journalists about 'computer errors'. To avoid hearing those inane remarks, one prevents bugs. To prevent bugs, one thinks straight. To think straight, one says, 'set z to zero' only if he or she means it. Not just because one is tired or lazy.

Meanwhile, where is chemistry in all of this? As an outside observer, I would venture that the lines of influence run as follows...

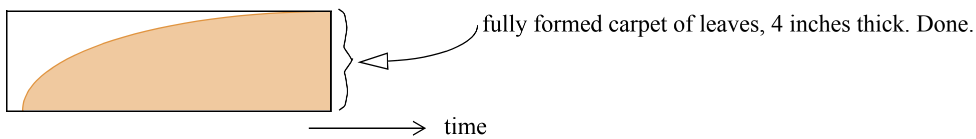
mathematics culture ==> physics culture ==> chemistry culture

...where the arrows denote both inherited practices (such as vagueness about '=' and parameters) and, when retraced right-to-left, a pecking order. The logic would go like this: Mathematics itself is beyond reproach and it provides the underpinning to physics (Wigner's 'Unreasonable Effectiveness...', page **149** above); since physics is thus married already to mathematics, chemistry accepts the ready-made view of mathematics as provided by the physics lens. Only an alien intruder would dare comment on the dysfunctional aspects of this Holy Trinity.

If one doubts the adverse effects of the math-physics culture on chemistry, one needs only watch closely what goes on in a typical chem lab report. Take the case of Nyasulu et al. Here we have the kind of minimalist in the label that is close to your author's heart (as expressed in Chapters **I** and **II**), but what *I* can't help noticing is the travesty of circular logic in the Data and Calculation section of the paper (Nyasulu *et al.*, p. 843). Here we see concrete examples of the kind of vagueness alluded to earlier, where the line between parameters and variables and the line between inputs and outputs is blurred. (If we are less polite, a better word than 'blurred' would be 'nonexistent'.) A primary goal of the exercise described in the Nyasulu paper was to (re-)discover the ideal gas law constant. (I.e., in computer science terms, the gas constant is to be an output.) Yet a *published* value of the gas constant was snuck in as an unacknowledged input *to* one of the inputs *to* the whole process (occurring behind the scenes of the so-called 'Data' section). And this is only the tip of the ice berg, too peculiar to warrant further description here. This travesty concocted by a trio of authors (and their students) go past the whole multi-peer review process at the *Journal of Chemistry Education*, the top journal in the field of "chem ed". So yes, the need for computer science concepts to help clean up the math culture mess is manifest.

Limits in the Book of Nature vs the Limit-*ed* Earthly Attention Span

- What one expects is that objects in nature, say the carpet of dead leaves in a forest, will accumulate in a neat and boxy fashion like this:



- What one gets is limits, which take on the following aspect instead:

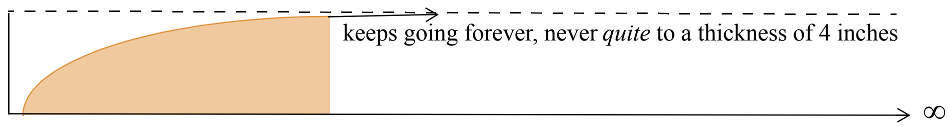


FIGURE 45: Of Leaves and Limits

The difference that I've tried illustrate above is admittedly subtle. But if you want to learn what *really* happens[72] in this universe, as distinct from what bipeds wish would happen, then this is your big chance to find out. In the first illustration, a carpet of dead leaves builds up and then stops at a certain limiting thickness (determined by the ratio between how many leaves fall per year and how many leaves decay). But the first picture is a lie. The second part of **Figure 45** shows what really happens. Yes, the carpet of dead leaves has a distinct *notional* upper limit, represented by the dotted line, but the carpet never actually achieves that upper limit — not in a hundred years, not in a billion years. That's the mind-bend: a 'limit' is a number that is glaringly obvious in a given context, yet never actually attained. Therefore, it's a lie to say the carpet is '4 inches thick'.

The question of limits might put one in mind of Einstein's aphorism, "Subtle is the Lord, but malicious He is not." Then, in connection with 'malicious', one might ask, Is this a case of the Lord being 'willfully' subtle in the pursuit of some tricky agenda, or is that just the way numbers behave, all by themselves? To help answer this question, I've constructed a rough model of the falling leaves, simplified in such a way that it uses arithmetic only (while preserving the general outline of the real

72. "The trouble with college math classes...is that their sheer surface-level difficulty can fool us into thinking we really know something when all we really 'know' is abstract formulas and rules for their deployment. Rarely do math classes ever tell us whether a certain formula is truly significant, or why, or where it came from, *or what was at stake*... That we end up not even knowing that we don't know is the really insidious part of most math classes" (David Foster Wallace, *Everything and More*, p. 52, italics added).

problem which we'll show later dressed up properly as a differential equation):

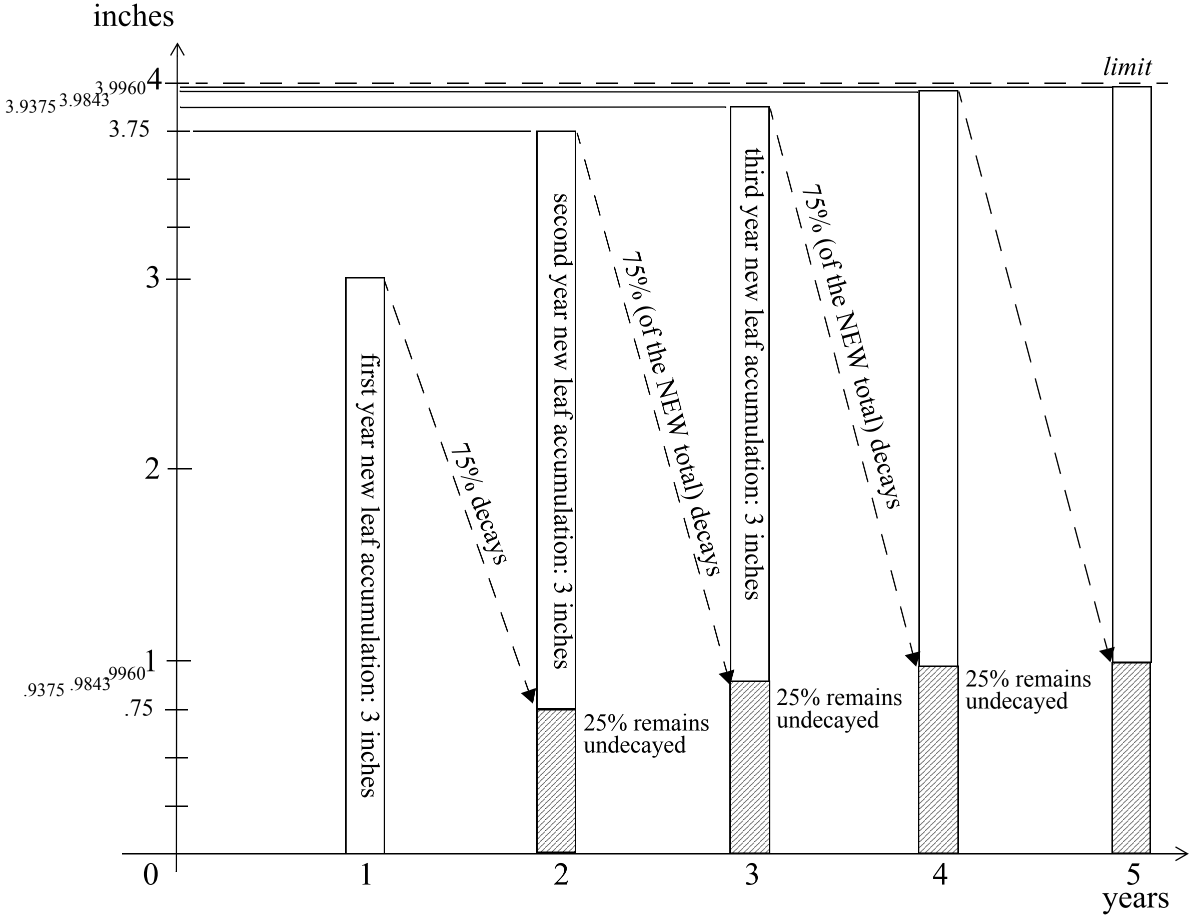


FIGURE 46: Anatomy of a leaf carpet

In **Figure 46**, we fudge the question of t=0 and let the story begin, in essence, at t=1, with an accumulation for the year of 3 inches and with 0 inches of decayed leaves. (Later, in the dressed up version, we'll provide a better picture of what happens in-between t0 and t1.) But even in this crudest of all possible approximations, the asymptotic approach to 4 inches becomes immediately evident, and likewise the state of virtual equilibrium: **Figure 46** suggests that from year 5 onward, new accumulation will continue at 3 inches (since that's how we defined it at the outset) and decay will be very VERY close to 1, so that the net depth of the carpet will remain very VERY close to 4. Forever. We've discovered all of this with simple arithmetic, no calculus required. As for 'willfully subtle' or 'just the way the numbers behave', looking at **Figure 46**, I would be inclined toward the latter. Try constructing similar diagrams using different initial assumptions — such as 2 inches of falling leaves per year and a 55% decay rate; 1 inch per year and a 60% decay rate; or 2 inches per year and a 40% decay rate. You'll see that all of these exhibit a similar pattern, with leveling at (virtual) equilibrium points of 3.63, 1.66 and 5.00, respectively. Conclusion: That's 'just the way the numbers work', with no mystery per se. Only it's a process that happens to be less-than-intuitive to the biped brain.

Now for the closer look I promised. The left side of **Table 5** contains a variation on the crude arithmetic in **Figure 46**; the right side contains the dressed up model using calculus.

TABLE 5: Leaf Carpet Arithmetic

Year	Plot using arithmetic (represented by the x's in **Figure 47**)		Plot using a differential equation[(a)] (represented by the o's in **Figure 47**)
	Total * 25% = Remainder (i.e., the undecayed portion)	3 inches of new leaves + Remainder from previous year = New Total	
0	—	[3 +0 = 3][(b)]	0
1	3.00 * .25 = .75	3 + .75 = 3.75	2.11
2	3.75 * .25 = .94	3 + .94 = 3.94	3.10
3	3.94 * .25 ≈ .99	3 + .99 = 3.99	3.57
4	3.99 * .25 = .9975	3 + .9975 = 3.9975	3.80
5	3.9975 * .25 ≈ 1	3 + 1 = 4	3.90
6	4 * .25 = 1	3 + 1 = 4	3.95
7	4 * .25 = 1	3 + 1 = 4	3.97
8	4 * .25 = 1	3 + 1 = 4	3.9900
9	4 * .25 = 1	3 + 1 = 4	3.9953
10	4 * .25 = 1	3 + 1 = 4	3.9977
11	4 * .25 = 1	3 + 1 = 4	3.9989
12	4 * .25 = 1	3 + 1 = 4	3.9995
13	4 * .25 = 1	3 + 1 = 4	3.9997
14	4 * .25 = 1	3 + 1 = 4	3.9998
15	etc. for Eternity?	etc. for Eternity?	3.9999

a. The differential equation $dL/dt = 3 - .75L$ is solved as $L = 4 - 4e^{-.75t}$. Then $4 - 4e^{-.75(1)}$. = 2.11, $4 - 4e^{-.75(2)}$. = 3.10. And so on.

b. The sum '3 + 0 = 3' is just for priming the pump, as it were. In this model, we don't pretend to know what transpires in the period between Year 0 and Year 1. By contrast, in the rightmost column, zero at the start really means zero, and we could also have found values at 1 month, 6 months and so on if desired. That's the payoff for using calculus.

This time, the person constructing the arithmetical model has shown some impatience, rounding off a value in Row 3 (to 0.99) and again in Row 5 (to 1). Given these adjustments along the way, how confident can we be that the equilibrium state suggested by '3 + 1 = 4' in Rows 6 through 15 is real? From the discussion of **Figure 46**, we have reason to believe that patterns of this 'falling leaf' variety lead only to a virtual equilibrium, never to a literal equilibrium. So it's safe to assume that the literal equilibrium seen here (as 3 + 1 = 4 for Eternity) is only an artifact of the rounding in Rows 3 and 5, which in turn was triggered only by an arbitrary urge-to-round, nothing scientific.

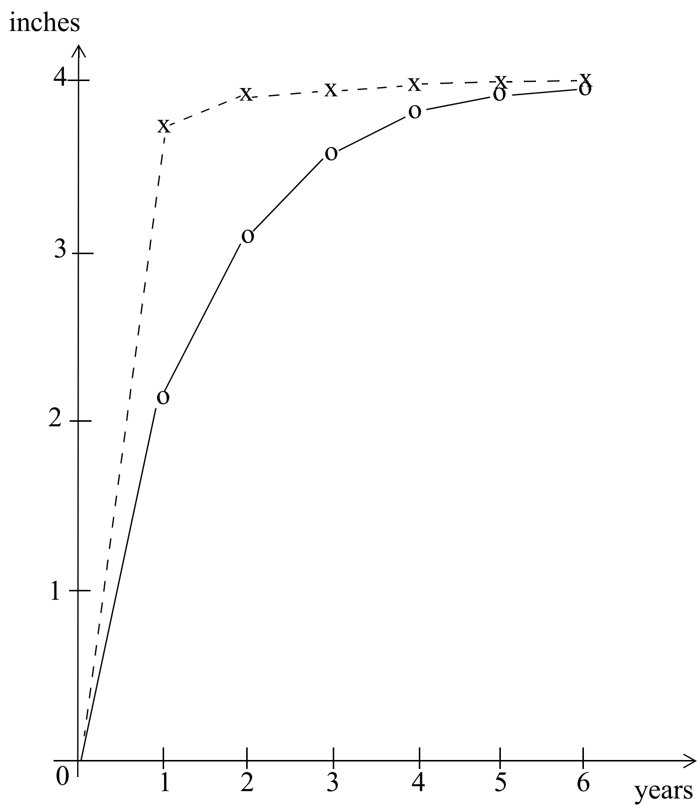


FIGURE 47: Approximate history (x's) and exact history (o's) of a leaf carpet

Now for the calculus approach (rightmost column of **Table 5**, represented by the o's in **Figure 47**). In years 0, 1, 2 and 3, the calculus-based model differs significantly from the arithmetical model (because it is far more accurate), but eventually it seems to agree with the arithmetic version — almost. How/Why/When do the two methods of calculation reach full agreement? Here's the dirty little secret: Those bipeds who use the calculus version engage in a kind of doublethink: Up through year 10 or year 11 or year 12 or wherever it happens to 'feel right', they continue to think *limits*, meaning 4 can never be reached, and the appearance of equilibrium is only approximate. Then boredom sets in and they change their tune, saying in effect, "Well, anyone can see that it is 4 in *essence*, and for all practical purposes the floor of the forest *is* in an equilibrium state where 3 + 1 sums to 4 for Eternity." At this point (say, in the implied 16th row of the table), Column 5 stops looking so fancy and looks just like Column 4 instead.

What I wish to point out is that the 'erudite' calculus approach is, from Nature's viewpoint, only slightly less sloppy than the naïve arithmetic approach, once you get beyond the first 3 or 4 years of falling leaves. What happens 'for Eternity' in the forest is *not* a state of equilibrium but a state of never-quite-reaching-four (or whatever the limit happens to be). In most situations, the engineer is justified in dismissing this kind of nuance as immaterial to the work at hand, but the philosopher and the mathematician have no excuse for 'rounding off for expedience' in such cases. To say 'the *limit* is 4' is one thing. To say, '*my* number is pretty much 4' is another. By engaging in the latter practice, the Establishment undermines its own intellectual foundation and sells itself short. You earthlings *do* have the capacity to understand much of nature. You need only 'stay awake' as it were, and overcome certain provincial notions about what is boring or not boring.

Yes, the concept of a limit is subtle, but as mentioned in the discussion of **Table 5**, the mathematics priesthood is willing to follow their own subtleties only so far, then even they become bored and sweep the rest under the carpet. Time to go home.

The falling leaves problem is well suited to introducing these ideas because it starts out so simply (with an annual leaf-fall of 3 inches precisely), quickly becomes complex (causing one to think in terms of limits), and finally becomes simple again (when *both* the laity using arithmetic and the priesthood using calculus reach their respective limits of boredom and jointly proclaim the thickness of the carpet to be 'essentially 4'). For an even better understanding of the culture clash between earthling impatience and Nature's leisurely pace, one can explore the realities and illusions of the Gabriel's Horn Paradox. While the falling leaves problem can be worked out as though it were a 2D problem on flat paper, the Gabriel's Horn Paradox is, by its nature, a 3D problem, and for that reason it takes longer to set up and explore. Logically the Gabriel's Horn Paradox belongs here, but to avoid making this chapter inordinately long, I've moved that discussion out to **Appendix C: Gabriel's Horn for Eternity, not to Infinity**.

Terminal Velocity of a Hailstone (The Subtle Lie)

Here is an example that is qualitatively very different from the dead leaf example, though mathematically very similar: For convenience, a falling hail stone or a plummeting sky diver is often said to reach 'terminal velocity' meaning a maximum speed, an upper limit imposed by the physics of the situation. But this is a lie. Hail stones and sky divers never stop accelerating even if they continue to fall for eternity. How can I make such an outlandish claim? Because the notion of 'terminal velocity' is a half-truth exactly analogous to the 'depth of the carpet of dead leaves in the forest' (which, as we have seen, must forever increase, not stop literally *at* 4 inches the way one is inevitably tempted to characterize it for expedience).

Suppose we are told that a hailstone's mass, m, is 4.80×10^{-4} kg and its drag coefficient, C, is
$2.50 \times {}^{-5}$ kg/m. Assuming the acceleration of gravity, g, to be 9.8 m/s^2, we now have all we need to solve the equation $F = -mg + Cv^2 = 0$ for v, terminal velocity, and make the statement, "The hailstone's terminal velocity is –13.7 m/s."[(73)]

Granted, in countless situations, that's all you need to say, because the figure –13.7 will be sufficient to take you onward to whatever your next step might be. End of story.

But if you're interested in what hailstones actually do, you should know that the above calculation is only a crude approximation of nature. What's really going on is this: At 2 seconds into its fall, the hailstone's speed is –12.6 m/s. At 3 seconds, its speed is –13.5 m/s. At 3.4 seconds, it has attained 99% of its terminal velocity. At 6.2 seconds, 99.99% of its terminal velocity.[(74)] And so on, such that 100% of terminal velocity (i.e., a literal –13.7 m/s) is *never reached*, not in five hours, not in five eternities. We see now that this thing called 'terminal velocity' is a chimera, an abstraction, a theoretical limit; and in that way, it is exactly analogous to the supposed 'thickness' of the fallen leaf carpet in the forest mentioned earlier. No matter how tedious this kind of pattern may be to a biped, it clearly has very deep roots in nature, so one might want to pay attention.

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73. The calculation involves taking a square root. This in turn gives us a choice between +13.7 and –13.7. We opt for the latter by way of indicating an object that is falling, not rising in the air.
74. Source: Gordon, McGrew, & Serway, *Student Solutions Manual & Study Guide for Serway & Jewett's Physics for Scientists and Engineers*, 6th Edition, page 90, problem #45.

Here we are reminded too of Wigner's 'The Unreasonable Effectiveness of Mathematics in the Natural Sciences' (page **149** above). How could common sense predict that slowly accumulating dead leaves in a forest and the plummeting hailstones above would follow *one* pattern, and that the pattern would be modeled by differential[75] calculus? That mathematics should be capable of bringing all this together is what Wigner meant by 'unreasonable' (see page **149** above).

Escape Energy of an Electron (The Even Subtler Lie)

The energy required to remove one electron from an atom, aka the ionization potential of a given atomic element, is analogous to the thickness of a dead leaf carpet (page **173**f) and to the terminal velocity of a hailstone or skydiver (page **178**). In all three cases, the convention is to take something abstract and pretend it is concrete (i.e., to pretend that 'approaching a limit' means the same thing as simply 'being the limit'). In **Figure 48**a, I present the conventional notation scheme for showing electron energy levels in a hydrogen atom. In **Figure 48**b (the lower half of the same figure), I present a proposed alternative notation scheme.[76]

Long ago, the convention of 'zero = maximum' was imported from calculations of gravity and potential energy to calculations of electron energy levels to create a ladder of values as shown in **Figure 48**a. In the case for gravity, if vector notation is used, the attraction between two objects is manifest as a negative value, and repulsion as a positive value — all by convention (not because 'negative energy' is required). When imported to the context of electron energies, the zero maximum

75. In the earlier example, for modeling the dead leaves, the underlying differential equation was $dL/dt = 3 - (3/4)L$. In the present example, for modeling a hailstone, the underlying differential equation is $dv/dt = g - (b/m)v$. This is essentially the same equation in a different guise. And as we have seen, both cases involve a limit which is *approached* asymptotically in nature, while the biped speaks of the limit as though it were a kind of speed limit simply *attained*, because 99.99% is deemed 'close enough' to 100% that one may be forgiven for ceasing to report the discrepancy.
76. Method of calculation: Using values from **Figure 48**a, in **Figure 48**b we have 13.6 – 3.4 = 10.20, 10.20 + (3.4 – 1.511) = 12.09, and so on. If it feels like we are working the numbers 'inside-out' to create **Figure 48**b, I would say this is only because our starting point, the conventional presentation shown in **Figure 48**a, is itself perversely inverted, while ours is the 'right' way. (The series –13.6, –3.4, –1.511... is the same ladder of eV values that we saw already in **Figure 33** on page **128**, where the focus was on the Balmer series, redefined by Bohr in terms of the wavelengths that result from certain 'quantum leaps' between these energy levels. The series is calculated by plugging different values of *n* into the equation $E = -13.6\text{eV} / n^2$.)

results in a negative ground state (–13.6eV in **Figure 48**a). But this in turn gives the superficial appearance of an analogy — as though electrons are being *modelled on* planets. And yet, for a very long time preceding both Bohr *and Rutherford*,[77] there had been concern and/or acknowledgement that one could *not* use a planetary model to explain the atom. Moreover, Bohr immediately declared *any* kind of mechanical modelling for the atom as 'hopeless', never mind planetary or non planetary:

> No attempt will be given at a mechanical foundation as it seems hopeless.
> — Bohr as quoted in Pais, pp. 196 and 211 (and in Arabatzis, p. 121)

Thus, the conventional scheme for electron energies is problematic even before we get to the question of limits, which I'll try to describe next: In the conventional notation scheme one's attention is focused on 'the difference between –13.6eV and 0'. This upside-down arrangement of the parts makes it easy to imagine that there is *no* limit involved, only a pair of distinct end points, –13.6eV and 0, which imply a maximum of 13.6eV in absolute terms. (Who needs a limit?) Part of the trouble here is that one does not generally think of a value, say –1.511, being 'rounded up to zero'. By contrast, my scheme makes us notice that the number 13.6 *is* a limit (represented by the dashed line), as various values in the form '13.xx' pile up closer and closer to it, in a relationship reminiscent of 'rounding up'.

Incidentally, one thing not to worry about here is whether zero can be a 'real' energy level. The aim is to create a ladder for showing energy *differences* (e.g., to explain the Balmer series), not absolute energies. Thus, my zero as the ground state may look paradoxical at first sight, causing one to complain, "But even in its ground state, surely the electron must have *some* finite energy, not an *absence* of energy"; but really this is no stranger than setting zero as the upward limit in the conventional scheme. We've merely done a left-to-right flip on the number line; or, a vertical flip, to state it in terms of the scales used on the left side of **Figure 48**.

77. Popular accounts (and some textbooks) tend to perpetuate two related errors at this point: [1] In connection with Thomson's 1903 model, they repeat the nickname 'plum pudding model' without comment; [2] they suggest that concerns about a planetary model are triggered only by the arrival of Rutherford's model in 1911. The truth is very much at odds with that neat story (and its implications). First, Thomson's model was *dynamic*, so 'plum pudding' was a hideously poor nickname for it; see Arabatzis, p. 119, note 27. Secondly, concerns that a planetary model for the electron would not hold up date back to Thomson's *1897* model, never mind his 1903 'plum pudding' model! See Pais, p. 181, note 83.

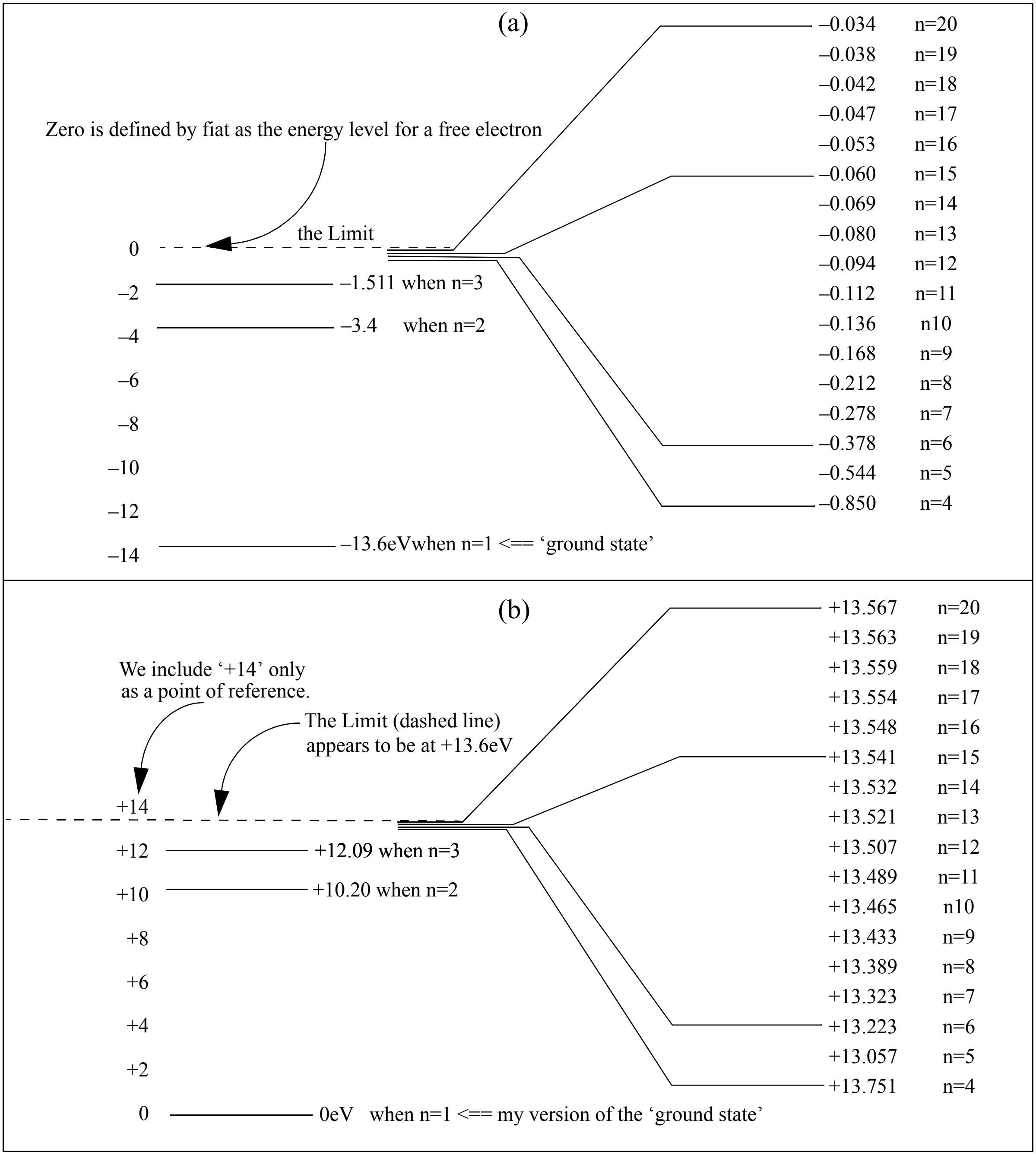


FIGURE 48: Energy Levels for Hydrogen — conventional way and 'my way'

As pointed out in **Chapter IV** (on page **111**), ionization potential is a topic that can easily fall into the crack between chemistry and physics:

- Thus, Serway & Jewett barely even acknowledge this topic in their 1283-page textbook, and then only in passing, by way of a single *problem* (i.e., nothing in the text per se)!
- Giancoli, on p. 792, gives reasonable coverage to the *topic* but is constrained to only hint

at its asymptotic *nature*, since his textbook is by design the friendly kind that doesn't require calculus background.

Counterexample: For an honest look at ionization potential *as* a limit, see Langford & Beebe, pp. 236-237 and 260-261.

Viewed in isolation, accumulated dead leaves, or hailstone terminal velocity or ionization potential may seem to have no need for asymptotic subtleties: from a pragmatic standpoint why *not* just cut to the chase and talk always about the rounded-up value, to where the imaginary limit resides? I understand that viewpoint, but what I'm trying to suggest here is that if you stand back and look at all three together, it may be that Nature is trying to tell us something important. Subtle though it is, and irrelevant to the day-to-day tasks of working forest management experts, working meteorologists and working physicists, this business about limits is threaded so deeply into the fabric that it must 'mean something'. If the something in question is not a subtlety of Nature herself, then the something must be human folly: the fact that there is something basic and simple out there in the universe for which the biped consistently feels the need to bring in the heavy artillery of calculus, thus obscuring the real pattern. It's a lesson to stay aware of constantly, not sweep under the carpet as the Establishment is prone to do.

Absolute Axes (Sans Arms)

Powerful though the cartesian coordinate scheme is, don't you wonder sometimes if perhaps it is also a trap? What if it cuts short other ways of thinking about numbers? What if it possesses a peculiarly human stamp that brands its user as provincial, not a citizen of the universe?

Consider the case of the arctan function. In **Figure 49**a we see a conventional depiction of the arctan function:

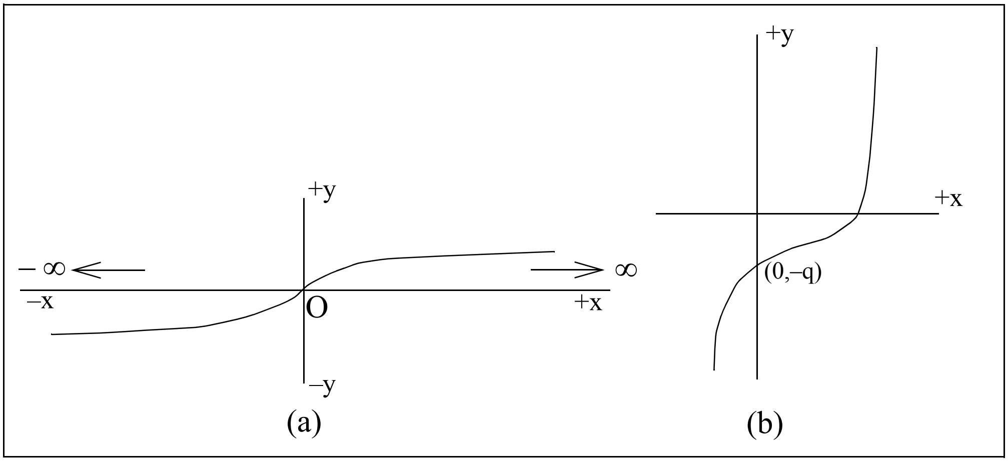


FIGURE 49: Happy Arctan and Depressed Cubic

In words, the arctan function starts at x = –∞ and increases always, passing happily through the cartesian origin, O, continuing to increase on x, all the way to x = +∞, while approaching a positive value on the y-axis asymptotically.(78) Similarly, a depressed cubic starts at y = –∞ and passes through (0, –q) as it continues to increase on the y-axis, all the way to y = +∞, while approaching a positive value on the x-axis asymptotically. This is depicted in **Figure 49**b. (A depressed cubic is a function of the form $y = x^3 + px – q$; see Nahin, p. 11.) Viewed from a slightly more abstract vantage point, these are two functions that simply 'increase always'. True statement. That's what they do. Granted there are certain constraints, but within those constraints, the two functions increase for eternity. Accordingly, what if their graphs, understood from *their* point of view, so to say, have the

78. Editorial aside: For my money, the arctan is the most beautiful of all the standard functions. Indirectly, the arctan function makes an appearance in Nietzsche's *Thus Spoke Zarathustra*: "Where we halted, there happened to be a gateway. 'Look at this gateway, dwarf!' I continued. 'It has two faces. Two roads come together here: no one has ever walked to the ends of them. This long lane backward lasts an eternity. And that long lane forward is another eternity.' " (Appelbaum, tr., page 121.)

mode of existence suggested by **Figure 50**?

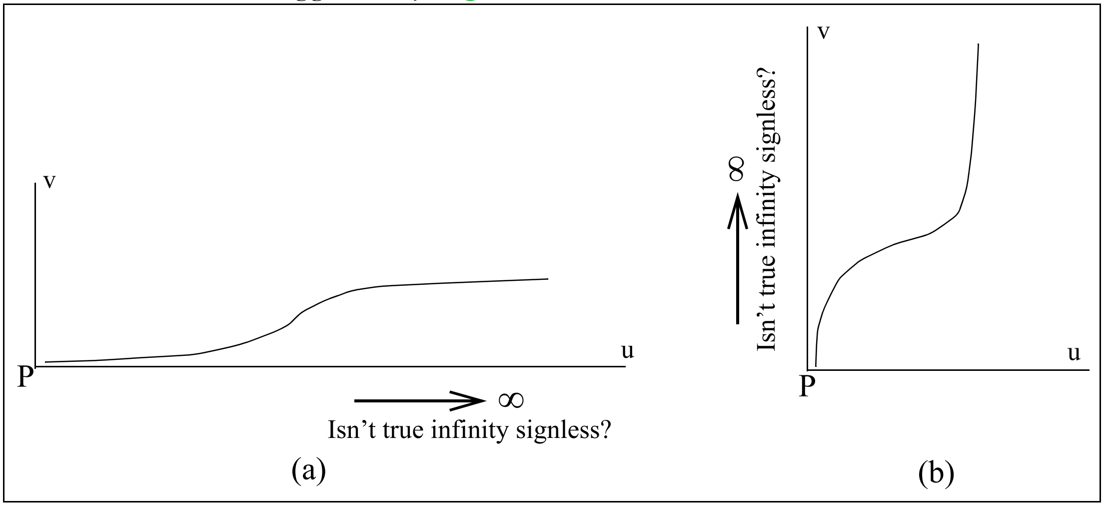


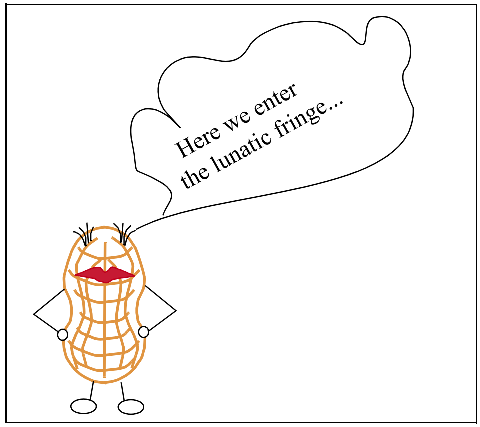
FIGURE 50: Arctan and Depressed Cubic Residing in Their Native Habitat?

In words, the hypothesis of **Figure 50** is this: In Nature, all functions arise from an absolute origin, P, not the biped's artificial origin, O. In this scheme, there is literally just one u-*axis* and one v-*axis*, each pointing the way to a signless 'true infinity'. This is contrasted with the 'x-*axes*' and 'y-*axes*' of which the biped mathematician will speak sometimes, reminding his students that 'x-axis' is only a convenient shorthand for 'the positive x-axis and negative x-axis taken together as one line on the cartesian grid'.

In regard to the so-called imaginary numbers, Gauss once commented:

> If this subject has hitherto been considered from the wrong viewpoint and thus enveloped in mystery and surrounded by darkness, it is largely an unsuitable terminology which should be blamed. Had +1, –1 and $\sqrt{-1}$, instead of being called *positive*, *negative* and *imaginary* (or worse still impossible) unity, been given the names, say, of *direct*, *inverse* and *lateral* unity, there would hardly have been any scope for such obscurity. — quoted in Nahin, p. 82; italics added

What Gauss is saying is that a label such as 'negative' or 'imaginary' may take on a life of its own, thus hindering clear thinking in the future, even though it may be understood by its author 'today' as a purely arbitrary and abstract symbol with no agenda; so choose labels carefully! Gauss's passage has no *direct* bearing on the question I've posed about the arctan and depressed cubic functions, but it does suggest a general way of thinking that would embrace such questioning rather than dismiss it out of hand as the ravings of an 'outsider'.



VI The Riddle of Information 'Glurth' (in an Information Age)

As used of late on your planet, the term 'Information Age' seems to carry at least three layers of connotation in its grandiose sweep:

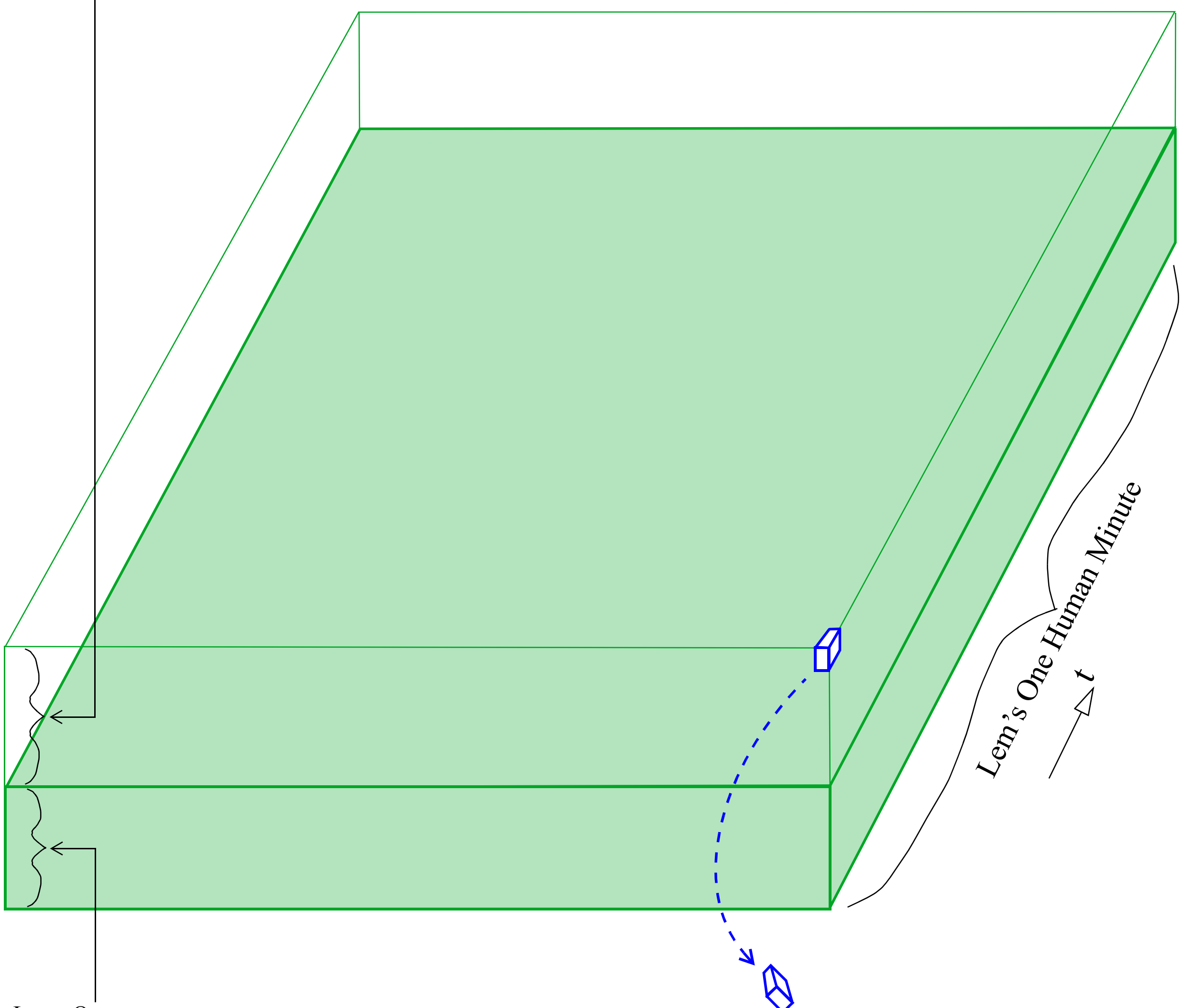
- It implies the existence of the *media*, with notions of The News connecting any given point on the globe to all other points in real time.
- It implies the existence of databases, eLibraries, and search engines — Himalayas of *data* available for 'mining' by tools that can transform it into *information*, such that one enjoys the sum of all biped *knowledge* at his/her fingertips.
- To some, the term seems vaguely suggestive, also, of something called *information theory*, which is somehow presumed to play an important supporting role in the great drama.

Under sub-topics numbered [1] through [3], we will explore each of the three bullets in turn.

[1] Inherent in the human condition, there is a severe *data-incomprehension* problem

In **Figure 51**, I've tried to convey subjectively (i.e., it is 'not drawn to scale') the immensity and importance of the data-incomprehension problem, which is described in Stanislaw Lem's *One Human Minute*. (Lem appears also on page **403** in connection with the visionary scholarship of Leonard Meyer.)

Layer Two:
A representation of all the ‘extra’ events that transpire during that same one-minute interval: poems composed, movie scenes shot, jokes created, land mines triggered, hurricanes suffered, diseases contracted, the good and bad works of 5 billion souls all around the globe.



Layer One:
The everyday constants of the global human condition, say one minute’s worth of weddings, copulations, births, nursings, deaths and funerals, as described in Lem. This is something *beyond* our comprehension (so its presumed contribution to ‘information overload’ would be a moot point).

Journalism: The merest crumb of Layer Two is knocked or dragged into the sewer called ‘journalism’, where it is held up self-righteously as a fair representation of The World and as a piece of What You *Must* Know (often with the facts themselves having been sadly bungled, however).

FIGURE 51: What Do Humans Do in a Minute?

In **Figure 51**, the way we've represented journalism and The News relative to Layer Two should come as no surprise: to some degree all are aware already of the frequently arbitrary nature of news filtering and selection, and especially its bias toward the horrific ('because it sells'). The main point of the graphic is the presence of Layer *One*: the idea (articulated by Lem) that the bipeds cannot even comprehend their *basic* condition as a collective species, never mind the extras. As a natural extension of Lem's point, one should add: Then how dare the journalist presume to make a self-righteous fetish of the news — 'you *need* to know this' — a mere crumb that has fallen into his lap from Layer *Two*?

Through ignorance or willful misrepresentation, the purveyors of news and technology will forever promote the illusion that 'we know', 'we inform', 'we control' — and the challenge is to filter out all that self-important noise. Meanwhile, what does *nature* do? She *oblivionates* data, thus preempting 99.99999% of all potential information. That is a fact, against which the claims of the journalism establishment become ludicrous.

You earthlings are not unlike a super-colony of bacteria living in busy but dull ignorance of your own collective state. This is because your true condition is literally beyond human comprehension, which means the promise of the media is a huge, arrogant impossibility (more from dullness of imagination and ignorance of science, I suspect, than from a desire by the media to deceive their public).

[2] The universe is a *data sink*, one big Stupidhole

Looking at **Figure 51** and **Figure 52** together, the take-away should be clear: *You* are very small. A cyclone is big. A cosmos-sized Stupidhole is really really big. If all the cyberspace technology in existence were harnessed to one person's will, it would still be swamped in an instant by the Stupidhole juggernaut.

How does this bode for biped pretensions to an Information Age? Not well.

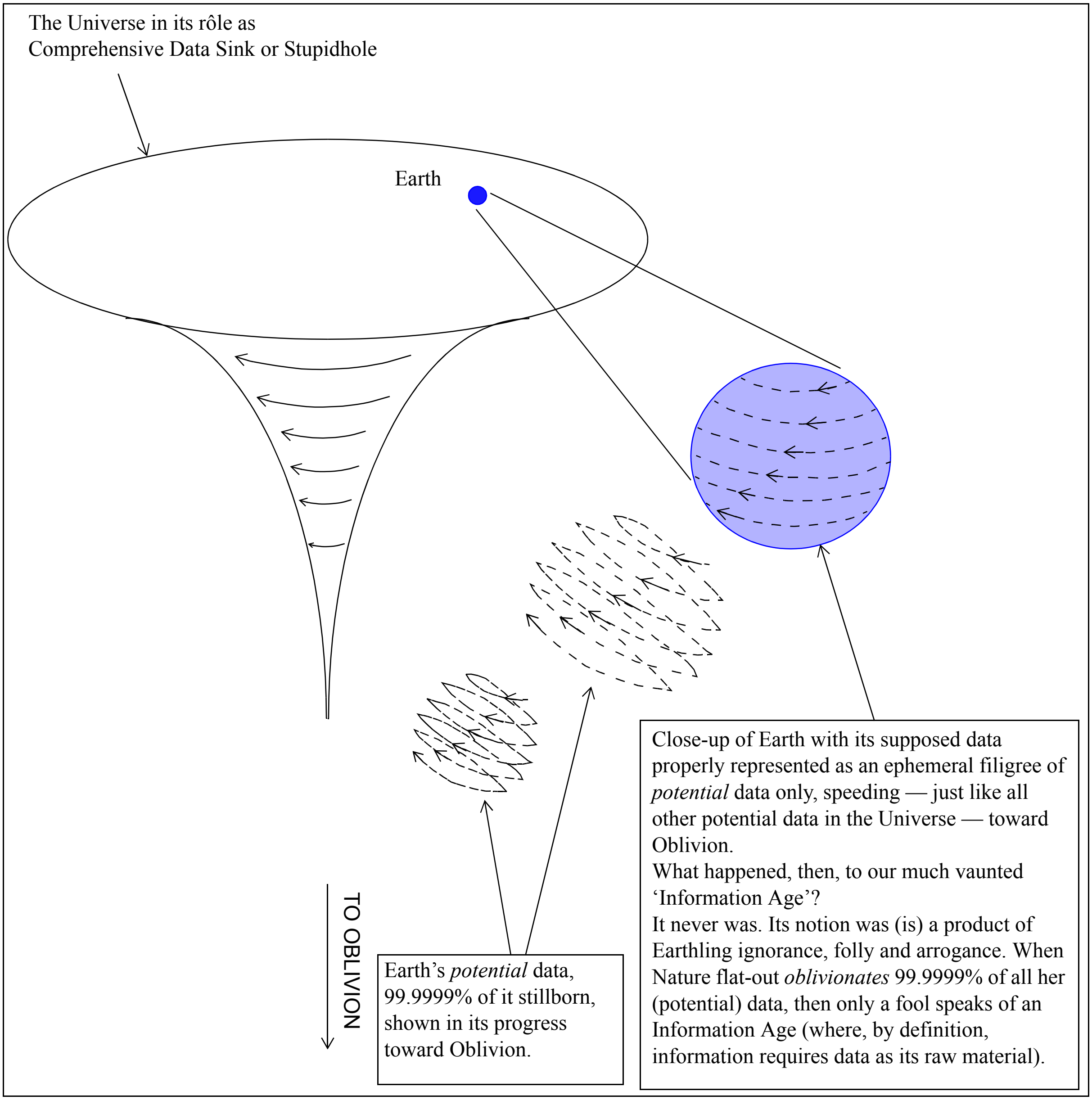


FIGURE 52: Correcting the Information Fallacy:
Nature *oblivionates* her potential data to the tune
of 99.9999%. Only the *remainder* is available to become Information fodder

No one doubts that bipeds are in love with information, and have achieved remarkable things in that realm. For example, somewhere in **Figure 52** there must be a dot that could represent *google.com*, a powerful search engine without which your author could not possibly have completed this volume. But it would *only* be a dot. That's the rub. **Figure 52** is meant to suggest another kind of Copernicanesque shift, a rude awakening to how the world is *actually* textured as distinct from how bipeds *wish* it were textured, as regards information.

Quite aside from the impossibility of 'knowing the human condition', there are problems concerning the very concepts 'data' and 'information' — severe, intrinsic problems that do not hinge on a particular context such as 'the human condition'. What Lem points out is that one cannot even grasp a *static* picture of the human population, a freeze frame showing all of its 'routine' activities of a given moment (weddings, orgasms, births, nursings, deaths, funerals), never mind its noteworthy or 'newsworthy' activities of that same moment (awards, acts of kindness, jokes invented, music composed, murders committed); yet the 'Information Age' implies that computers are running day and night to provide us with *dynamic* pictures of all that and more. It's a lie.

An example to meditate upon: According to John Baez's calculation, to specify the state of one raindrop requires some 500 exabytes, which is to say, '100 times the information in every word ever spoken by human beings'.(79) And, I would add, that would only be good for 'this instant'. Then, if we cared at all sincerely about this little raindrop, we would have to do it all over again to capture its state in the next instant, and the next instant, and so on — whatever the proper granularity of 'one instant' might be deemed to be! (And never mind the big fat complicated raindrop; 'only' one atom of tungsten would break you information bank in a trice.)

The Paradox of an Information Glurth

The word 'glurth' is my coinage to convey a juxtaposition (real) dearth and (seeming) glut. The situation is reminiscent of the concept of stagflation in economics (stagnation + inflation paradoxically blended): Simultaneously we have 'information overload' (in the sense indicated in Lem's *One Human Minute*) *and*

79. See http://math.ocr.edu/home/baez/iniformation.html, where John Baez also summarizes results from Peter Lyman *et al.* at Berkeley: *How Much Information? 2003*. The Lyman website relies in turn on Roy Williams' *Data Powers of Ten* (Cal Tech) for some of its pages. Compare the **Water Glass Experiment** on page **43**.

information dearth, in the sense explored by Poundstone (objectively) and by Borges (subjectively): not enough atoms in the universe to represent all the data 'out there' and build the Great One Super-Dooper Kick-Ass Computer the biped lusts for, the one that might give him 'The Answer: 42' (see page 159).

How can there be 'too much information' AND 'too few atoms' at once? Such is life at the macroscopic scale: a contradictory *mess.* (Think of the physiology of sight: umpteen billion bits of data reach the eye each second, but only a few thousand of them actually register with the brain.)

According to Kaplan & Kaplan (p. 203), forensics is concerned with "...obscure links between people and crimes that may lie hidden in a mass of data." In one sense, this is a mouse view of the world: There seems to be plenty of information, a haystack of information, and the problem is to find the needle hiding in it. But really what the detectives need is a *new* haystack to look in, though this is rarely understood or acknowledged. Later on the same page, Kaplan & Kaplan quote the following from Richard Leary: "...see what's missing in the light of each hypothesis; *then* engage in searching for that new data. It's common sense, but it's not common practice." This provides support for the point I wish to make: Yes, subjectively, there seems to be 'plenty of information' or 'too much information' sometimes; but objectively, we live in an information black hole — all the time.

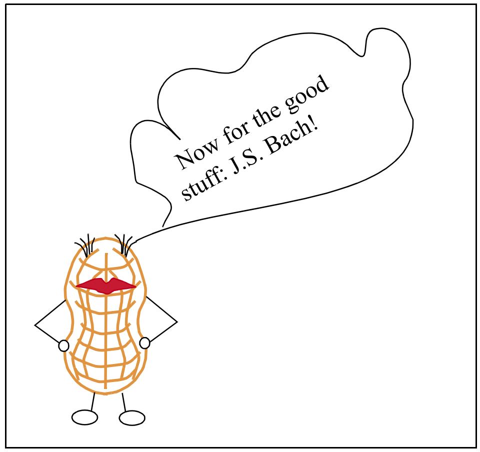
When contemplating the folly of The News as fetish and trying to put it in proper perspective, one might be reminded of the toadstool in *Moby Dick*, circled as it was by a colony of ants in a display of religious fervor. To those ants, the toadstool undeniably was *something*, but...

[3] There exists a semantic cesspool on the surface of which float a miserable pair of turd-words: *information theory*

To the public, the term 'information theory' SUGGESTS '*a* theory of *information*'. Fair enough. But to an engineer, 'information theory' DENOTES '*the* mathematical theory of data communication *signal-to-noise ratios*'. So, a question like the following must be posed at some point: "If the thing called 'information theory' by the engineers is really a theory of signal-to-noise ratios, then who is/was in the laboratory working on an actual Theory of Information, the one the public naïvely believes must exist, as the cornerstone of the Information Age?" The question has no simple answer, and the topic is onerous, so your author has relegated this *bête noire* to **Appendix D: The Fifty Years' Gibberish: So-Called Information Theory** and **Appendix E: Theory of Information**.

Chapter summary.

The term 'information' turns out to be bogus from within (because of the history of so-called information theory which is really signal-to-noise theory); from the outside (where *One Human Minute* puts the lie to The News); and also intrinsically, because the universe itself is intensely information-hostile, no matter how the bipeds might wish to construct a web of self-deception around this favorite pseudo-topic of theirs. (There is an old saw about death and taxes being the only certainties. To those two, a third should be added: Whatever makes the universe tick, it is certain to be something other than information.)



VII Epilogue

...It is a land where beauty's meaning flowers;
Where every unplaced memory has a source;
Where the great river Time begins its course
Down the vast void in starlit streams of hours.
Dreams bring us close — but ancient lore repeats
That human tread has never soiled these streets.
— second stanza of 'Hesperia' by H.P. Lovecraft
(Yuggoth XIII, in Joshi, ed. page 69)

All of the previous chapters had this aim: to help the reader through a pair of Copernicanesque inversions, after which one should see the world as depicted in **Figure 24**b (page **82**) and therefore understand the importance of coming back to basic chemistry, the Heartland, as suggested by **Figure 29** (page **95**). Given the all-out 'assault' of those chapters upon conventional biped ways, it may seem incongruous or contradictory if we now turn to a description of 'what the earthling does right'. But all of the earlier objections or debunkings had to do with physical realities or illusions, whereas the topic of this epilogue will be something that is, by definition, nonphysical: the soul.

Just because a certain kind of entity at the macroscopic scale is implausible as a life-form (more like a Tinkertoy® agglomeration), that doesn't prevent its hollow shell from housing a spirit.

Consider the film *Toy Story*. It provides a natural bridge between my notion of humans as a 'Tinkertoy®' *non*-lifeform (**Chapter I**) and the desire to save one's soul. Since the soul is hypothesized as something non-physical, this — by an odd twist of the logic — leaves the door open for a household appliance or a toy to possess one (as in *Toy Story*), or for an inanimate rock to possess one (as in the Shinto religion). By extension, it should be possible to preserve the idea of a human soul, even if your bodies have been redefined as mere 'Tinkertoy®' assemblages as proposed in **Chapter I**.

The Māyā Connection

Rather than trying to build my case step by step 'from the proton's perspective', I might simply have directed the reader's attention to the venerable concept of Māyā (in Hinduism). There too, 'all is illusion' and the well-established image of Brahma as ocean and Māyā as a surface 'froth' is easily tied back to **Figure 24**b. In building the case my own way, one might say that I've provided an 'independent proof' for the Hindu argument, making it that much stronger. Also, by making the atom the focus as in **Figure 24**b, I am offering something substantive as the antidote to Māyā, namely an entity with which one may readily commune via basic chemistry, while pursuing other pieces of the puzzle of one's existence or nonexistence.

Possibly we all agree on Māyā the illusion already. But what evidence is there that Ātman (the spirit) is real? From your western classical music I would cite the following in evidence...

- 'Air on the G String' by J.S. Bach (from his *Orchestral Suite No. 3*)
- 'Adagio' by Samuel Barber (from his *String Quartet*)
- 'Buciumeana' by Béla Bartók (number four among his six *Roumanian Folk Dances*)
- *Gymnopédie* #1 by Eric Satie

...and from your popular music, these:

- 'A Box of Rain' by Garcia-Hunter of the Grateful Dead
- 'Knockin' on Heaven's Door' by Bob Dylan
- 'A Whiter Shade of Pale' by Brooker and Reid of Procol Harum

Any one[80] of these alone makes a seemingly irrefutable statement that "Yes, the soul exists, and here you hear its voice." And together...

Yes, among your composers there are several who provide a premonition of the wonders that must exist inside the living atom (the wonders hinted at by **Figure 2**b, page **13**). But the next part is more difficult: now the earthling must humble himself and realize those are *only* premonitions.

When push comes to shove, there can be no contest in a *direct* comparison of earthling art forms to the subatomic art forms of my world. In the fraction of a second it takes to read the word *Humanities*, one of the atoms in the dry ink on the crossbar of the letter 'H' will have exhibited more of your hoped-for 'attributes of the Humanities' than all artists collectively will exhibit in their millions of years from super-baboon to kaboom. *That's* what an atom does: It celebrates Truth and Beauty, in such ways as to make a mockery of your own aspirations in that department — past, present and future. The ink may be 'dry' in your world, but the atoms in it are alive in my world. And try to remember, there are lots of those atoms around: approximately three times 6×10^{23} in only four teaspoons of water, for instance. And for *each one*, what we say above holds true. The competition is overwhelming.

Other Problems of the 'Humanities' in academia

First, in passing, note that the Humanities are most meaningful to someone approaching them *from the hard sciences*. But most members of Humanities departments have no such background. In general they are people who went *directly* 'into the Humanities', while regarding science with some combination of dread, skepticism, distaste and disapproval. But theirs is a nearly nonsensical path, once you understand that the raison d'être of the Humanities is to serve as a check and

80. Actually, I've inadvertently entered one item on both lists: According to the liner notes for 'Paler Shade of White', Gary Brooker 'nicked' the tune from Bach. Thus, we have a double dose of Bach: Explicitly on the first list and implicitly on the second list. In fact, it turns out we are looking at the *same* Bach composition on both lists: 'Air on the G String'! (The Bob Dylan item might look slightly out of place at first, but as recorded by Guns N' Roses and used in the sound track of the Naomi Wallace film, *Lawn Dogs*, it will be seen to belong on the list.)

balance on the sciences. The Humanities are very useful *for* scientists, far less so for the 'Humanities majors' themselves.

Now the main problem: The better a composer is, the more your academics wish to take ownership of that composer's supposed 'humanity'. In the process much of the message gets thrown away. Certainly Beethoven knew how to market himself to the masses: his late symphonies are accessible, while his late string quartets and late piano sonatas often are not. But *that* doesn't give someone the right to shove his total output into a cubbyhole labeled HIGHEST EXPRESSION OF THE HUMAN SPIRIT. Were such a phrase applied to, say, Verdi or Melville, one could entertain the idea. (I'm thinking of Verdi's *Falstaff* and Melville's *Moby-Dick*, especially Chapter 26 where the author, speaking as Ishmael, proposes a kind of general human goodness that floats freely, independent of any grubby particulars at ground level: "Men may seem detestable...but man, in the ideal, is so noble..."). But Bach and Beethoven are very special cases. These two demand an 'opposite' treatment from the one dished up for general consumption on the slop line of the Liberal Arts cafeteria. True, Beethoven deliberately employs a range of devices to reach his audience, including his own version of 'mass appeal' where the symphonies are concerned. This end of the spectrum in Beethoven's music is what leads some Humanities types to trot him out as though he were just-another-Handel.[81] To me, far from being representatives of your biped spirit, Bach and Beethoven are clear examples of Humanity having been granted a rare *reprieve* from its native brute condition. These two composers provide an *elevating* glimpse into alien terrain that is no *longer* Dorothy's Kansas, something akin to the 'breeze from an alien world' in the baritone accompaniment to Arnold Schoenberg's *String Quartet No. 2*, and *that's* what you should praise and be thankful for when listening to them.

At this juncture, the biped might raise the following objection:

"The voices of Bach and Beethoven are alien, you say. But as every music-lover knows, Bach is the Center, the one blazing sun at the very heart of all western music, the one whose style is most accessible and beloved of people, whether sophisticated or simple, and in all parts of the globe (potentially if not yet in fact). How dare you classify him as *non*human, an example of extraterrestrial intelligence. That's absurd."

81. Described by one of your biped commentators as the poster child for suburban complacency, the epitome of Minnesota Smug.

A partial answer follows. Let's call it the Bach Arithmetic Paradox. Yes, Bach's style is — among many other things — admirably accessible, familiar, beloved. How could one dispute any of that? One might even say that Bach's voice is so normal, so bland, so unsurprising that it is devoid of style; a kind of blended white light of all the western musics that simply *is*. I agree whole-heartedly about his universal appeal, his central position in the universe of music. All the way down to his 'blandness' if you like. As though he were the musical equivalent of water, let's say.

But here's the conundrum that casts a long shadow over the simple *listener's* perspective on Bach:

Why, then, is it next to impossible(82) for any *other* musical giant (and never mind a first-year counterpoint student!) to emulate that *so* familiar voice of his?

If you analyze his counterpoint, it appears to obey a surprisingly simple set of rules, but watch out! Using arithmetic as a proxy for the actual rules of counterpoint (which are also simple enough but possibly exotic to the general reader as they involve intervals between voices), I'll try to convey how strange the student feels when attempting to enter Bach's world by setting up an imaginary dialogue. Speaking from beyond the grave, Bach says to a student back on earth:

"Here are the main rules: Vertically, find pairs of digits that sum to 4 or 5. Horizontally, form Bach-like tunes. There you go."

The student says: "Okay, for the vertical rule, that would be 2 + 2 or 2 + 3, you mean."
Bach: "Yes, 2 + 2 or 2 + 3. And of course 1 + 3 or 1 + 4."
Student: "Sure, I knew that: Those two as well."
The student writes a few measures of his exercise.
Bach: "Now you're using one plus three and one plus four, as I suggested, but you've forgotten all about two plus two and two plus three, it seems."

Student: "Well, yes. Two plus two and two plus three — I didn't exactly *forget* those

82. Instead of saying 'impossible', I say 'next to impossible' out of respect for Johannes Brahms. He falls into a Bach-like stride in *A German Requiem*, toward the end of third movement and toward the end of the sixth movement. Also, Samuel Barber strikes a Bach-like tone in the famous 'Adagio' from his string quartet, mentioned elsewhere in these pages. But these exceedingly rare exceptions — one of them self-amazed and exuberant, the other in a slow, haunted whisper — make the puzzle itself all the more compelling. These are the proverbial exceptions that prove the rule about emulating Bach: it can't be done!

two combinations, I've just, er, stopped *using* them for the moment."

Bach: "What-*ever*."

The student hesitates, somewhat taken aback by Bach's having descended into the sarcastic sing-song of a Valley Girl. Then the student writes some more.

Bach: "And now the opposite: You're remembering to use the first two combinations, but you've stopped exploiting the second two combinations, alas! (And we haven't even spoken yet of zero plus four or zero plus five!)"

Student: "Er..."

Bach: "See, this is what drives me to distraction: Why is it that only I, Johann Sebastian Bach, can keep *all* of these very simple rules in my head at once, and actually use them to *make* music? Isn't it curious?"

Student's first try, remembering some solutions:

upper voice:	1	4	3	4	1	3	4	4	1	1	1	1	1	4	1
lower voice:	3	1	1	1	3	1	1	1	4	4	3	3	3	1	4
sums:	4	5	4	5	4	4	5	5	5	5	4	4	4	5	5

Student's second try, remembering other solutions:

2	3	2	2	3	3	2	2	2	3	2	2	3	3	2
2	2	3	2	2	2	3	3	2	2	3	2	2	2	3
4	5	5	4	5	5	5	5	4	5	5	4	5	5	5

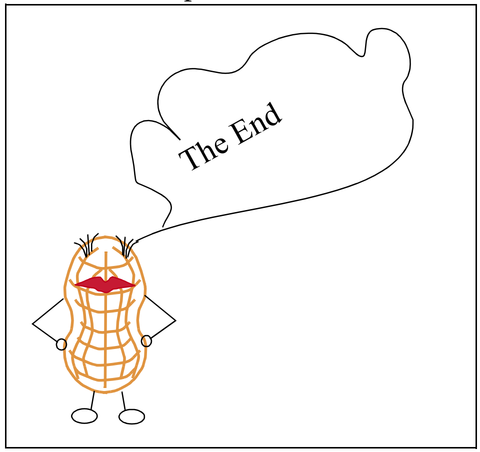
J.S. Bach, exploiting all solutions all the time:

upper voice:	5	1	2	3	1	1	2	3	1	3	4	5	0	3	4	5	0	2	2
lower voice:	0	4	3	2	3	4	3	2	3	1	1	0	5	1	1	0	5	2	2
sums:	5	5	5	5	4	5	5	5	4	4	5	5	5	4	5	5	5	4	4

What are the rules of the game?
"Find combinations that sum to 4 or 5"
We're using this simple rule as proxy for the (slightly) more involved rules of musical counterpoint.
It's the overall *contrast* between what our 'Student' is doing and what 'Bach' is doing that counts, not the details.

FIGURE 53: An Arithmetic Analogy to Illustrate the Bach Conundrum

Thus the music of J.S. Bach: As direct and obvious and familiar as the bicycle in the driveway, yes. But this particular bicycle has a peculiarity: No one except Bach knows how to ride it. Its gears turn by the rules of an alien intelligence. Otherwise, every first-year counterpoint student would hop on and gleefully ride that bike for a spell, before moving on to discover his/her own vehicle of expression.



Appendix A: The Periodic Table

George Gamow shows the periodic table as if drawn on a curved surface that resides in 3-dimensional space (Gamow, 1947, pp. 136-137). Many years later, that same whimsical shape was realized *in* three dimensions and patented by one Roy Alexander, who mass produced it on cardboard as an educational aid for school teachers to buy — with no credit given to Dr. Gamow or another as his source. However, once you see the 3D contraption in person, you realize that it is not practical, unless it were constructed of a see-through material such as Lucite, instead of cardboard: The continual twirling of the object or peering around its backside soon becomes tedious: After five seconds, it sinks to the status of coffee table novelty.

In **Figure 54** (on page **203**) I've tried to combine the best features of a traditional flat table and a curved version — thinking specifically of the one drawn by Gamow (and commercialized by Alexander). I believe this hybrid form might be optimal, as it suggests just enough of the 3D aspect without large chunks of the table being hidden off-stage. (Even Gamow's flat-*tened* presentation of the 3D version suffers somewhat from that problem, by the way, prompting him to split his drawing into a Front View and Back View, which is slightly bungled as he jots down 'Ba' where 'Sr' should be, to the left of 'Y', and '(K)' where he intends '(Kr)' above '(Xe)'. Thus, if even *Gamow* could be confused by the full 3D version...)

An aesthetic note:

Of late there seems to be a tendency to index the atomic number and atomic weight (actually the atomic mass) as follows: sometimes with the atomic number above and the atomic weight below, i.e., in a north-south arrangement (or vice versa), sometimes in a southwest-northwest arrangement, which is to say with the superscript and subscript both hanging off the left edge of the alphabetic symbol. Perhaps the rationale for the north-south practice is that decimal places in the atomic weight have more breathing room that way? And I'm guessing the rationale for the southwest-northwest travesty ($^{14}_{7}N$) might be that the northeast corner is already used to show exponents and electron configurations and ionization states, and the poor student would be overwhelmed with confusion if the northeast corner were used also for atomic weights. I find neither of those putative rationales persuasive. There is only one arrangement that looks *right*, and that's the southwest-*northeast* arrangement. (To make sure this wasn't a figment of my imagination or a false childhood 'memory', I found it captured for posterity, as it were, in Gamow, 1947, p. 159, and 1966, pp. 58-59.) Having missed the memo saying we should use only flat-footed uncouth notation from now on, in **Figure 54 (The Periodic Table)** I revert to the 'old way', giving the atomic number as an index in the southwest corner, and the atomic weight in the northeast corner, where it belongs:

$$\boxed{{}_{7}N^{14}}$$

A mnemonic aid

One should memorize the electron configuration for radon:

$$\texttt{Rn: [Xe]}6s^2 4f^{14} 5d^{10} 6p^6$$

In effect, this one configuration encapsulates all others up through atomic number 86. Thus, it serves as a convenient reminder of how to write configurations generally.

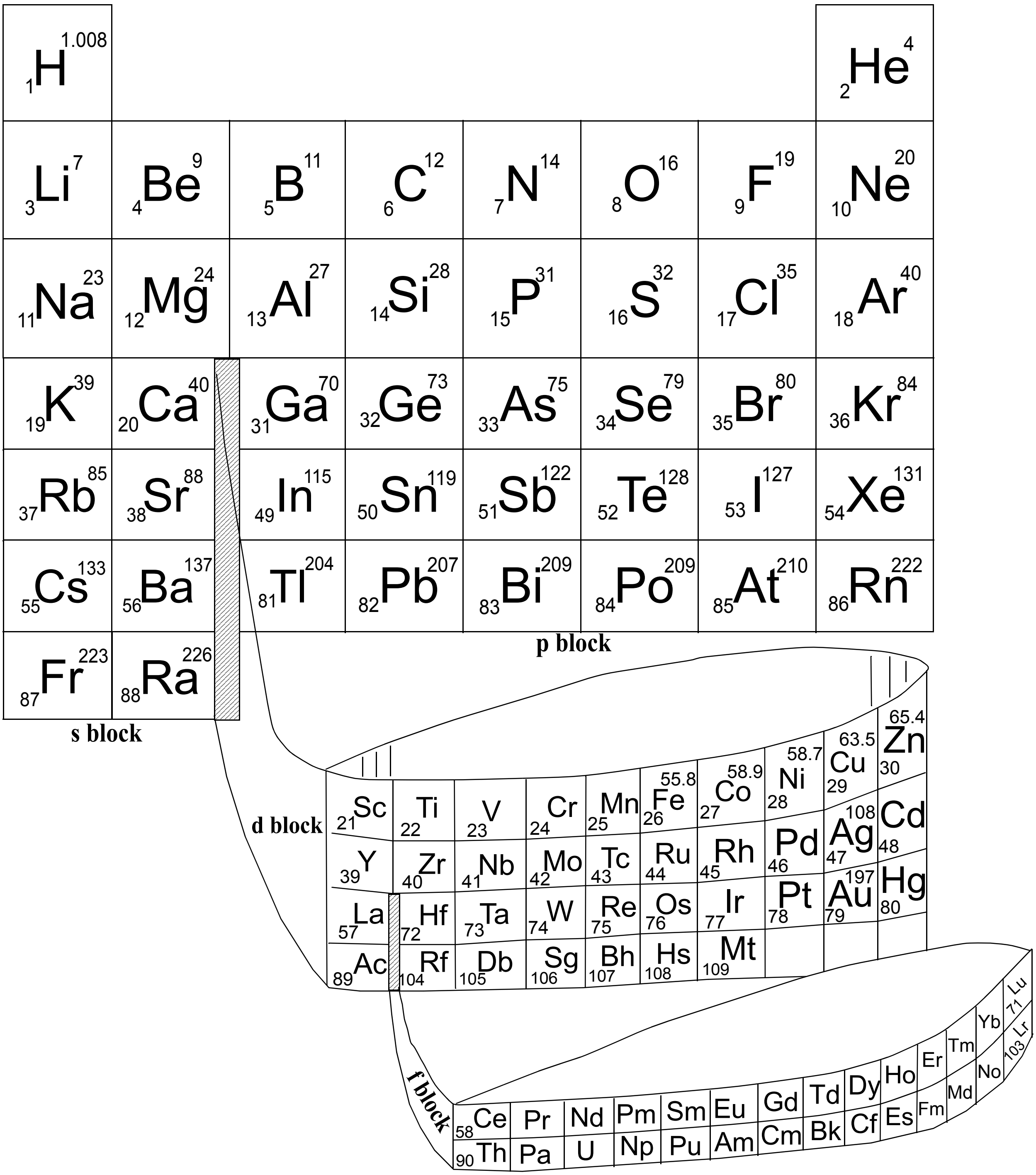


FIGURE 54: The Periodic Table

Appendix B: Heat Engines and the Cycle-Design Gotcha

After listening patiently to some new scheme for software development, a colleague of mine named Scott would often preface his remarks by saying, quietly, "Well, but the Gotcha is..." Meaning, he had already looked far ahead and around the corner from where the other person was focused, and had seen a nearly insurmountable difficulty lurking near the end of the design process. I've never tried building a steam engine from scratch (only two varieties of Stirling Engine, from kits, this being a more exotic form of heat engine); but it seems clear to me that in traditional heat engine design it will generally be the valves that are 'the Gotcha'.

True, one can write detailed *treatises* on heat engine *theory*, all in terms of a schematic that looks something like this, with never a valve in sight:

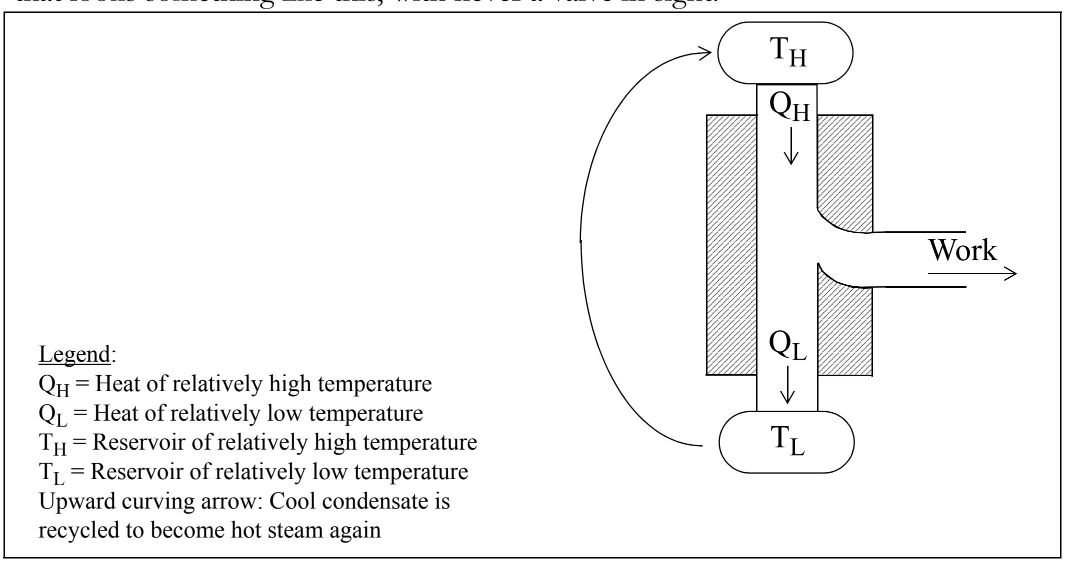
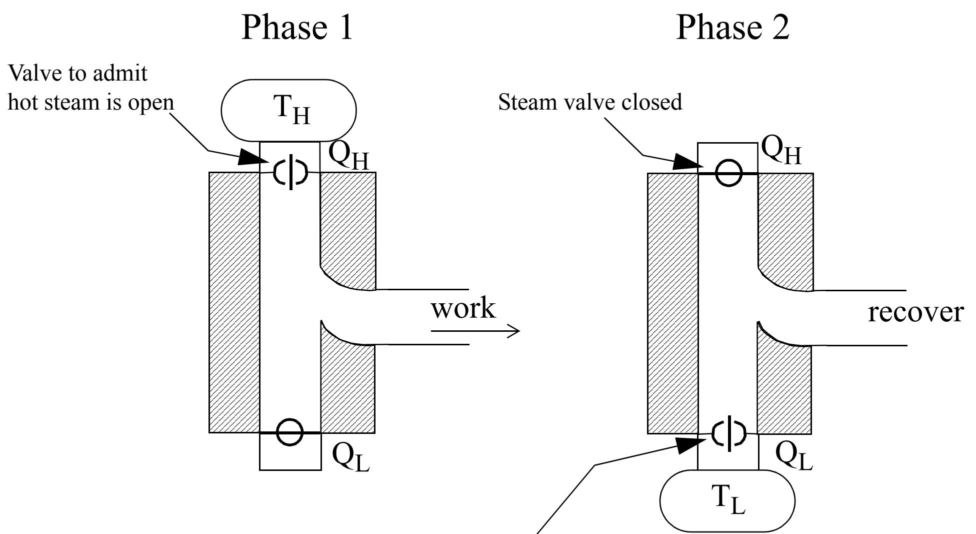


FIGURE 55: Heat Engine Schematic 1 of 2: Sans Valves

Nor have I anything against such treatises: the one by Van Ness, for example, is a classic; sheer delight. Still, sooner or later one must descend to the next level of detail, where the necessity of valves to define phases becomes evident:



Top valve is open so that cooler steam can escape and condense. Afterwards, as water, it will be recycled from the T_L reservoir to the T_H reservoir, for reheating and reconversion into steam. Connecting the two reservoirs, there would be a conduit which would probably contain a pump and more values, but none of these latter elements is shown in this diagram. It may be deemed 'detailed' only by comparison to **Figure 55**.

FIGURE 56: Heat Engine Schematic 2 of 2: with valves

But even if this level of detail (**Figure 56**) is provided in a book, still there probably won't be a word about how to achieve the proper opening and closing of those valves, once for each cycle. Typically, such 'obvious' and boring parts of the design are left to the reader's imagination. And yet, without this precise little dance of the valves, there is no engine (barring Area 51 'space alien' technology, or other exotic concepts on the lunatic fringe of the patent office that delight in circumventing the mundane).

So, how *do* the valves get opened and closed at the crucial moment(s)? Probably it wouldn't be practical to train pet mice to operate them, with sips of a martini as their incentive.

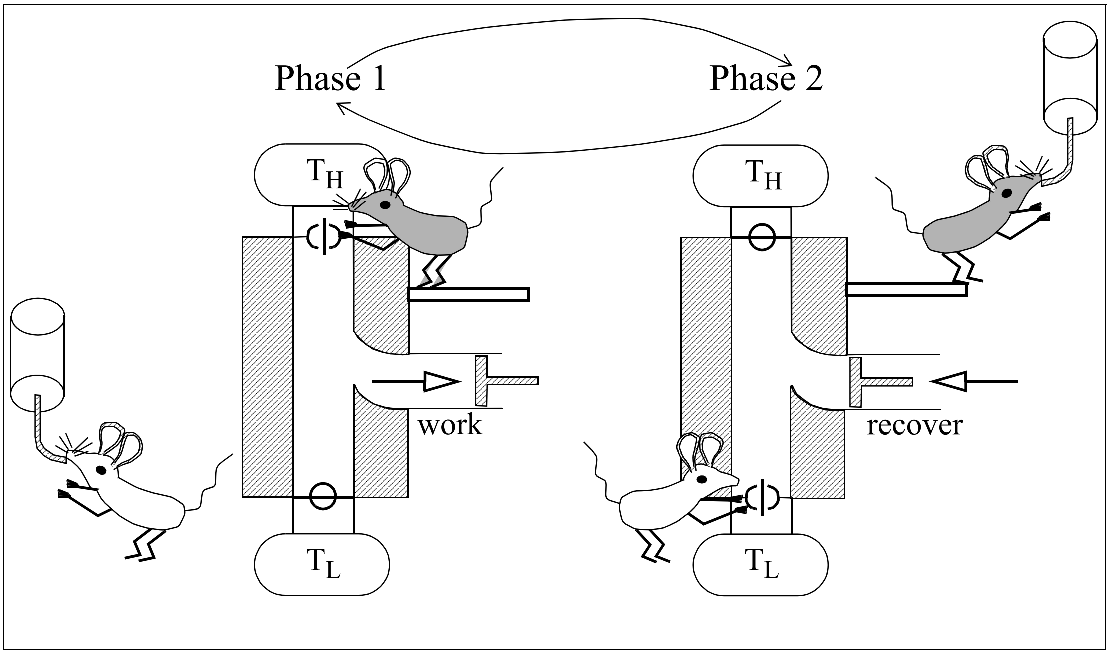
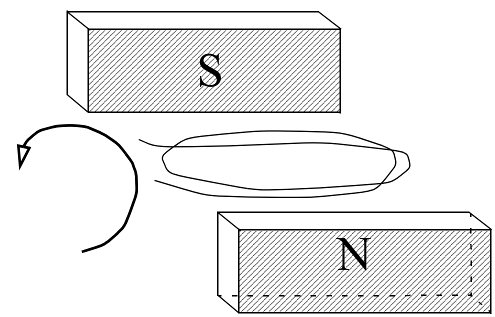


FIGURE 57: Steam Engine with piston and trained mice to handle the valves

Soon the mice would be too woozled to do good work. All would receive their pink slips or worse. So it looks like one has no choice but to go to the shop, roll up his sleeves, and design some species of self-activating valve. (That was my daughter's good suggestion.) Or a pair of valves interlinked by gears and levers and pulleys, reminiscent of a cuckoo-clock's innards. (That would have been my own Rube Goldberg approach, doomed to failure.) Hey, and let's not forget the conduit and pump for recycling the condensate from T_L to T_H! In short, all this 'other stuff' threatens to become a mini-project with a life of its own. Next thing you know, eighty or ninety percent of your total time on the project will have been spent on *this* silliness, with precious little remaining for enjoyment of the good stuff — theories harking back to the Carnot Cycle and the Clausius Inequality. (For example, why does such a machine *require* a temperature differential? Suppose "...the steam was at the same temperature throughout the system. This would mean that the pressure of the [steam] being exhausted would be the same as that on intake. Thus, although work would be done by the [steam] *on* the piston when it expanded, an equal amount of work would have to be done *by* the piston to force the steam out the exhaust; hence, no net work would be done. In a real engine, the exhausted [steam] is cooled...so that the exhaust pressure is less than the intake pressure"; Giancoli, p. 433.)

But don't feel too put-upon. As we'll see shortly, this '80/20' or '90/10' business is all part of a much larger pattern, in Nature. Don't go blaming your own ineptitude with gadgets or something even more off-the-mark like Bad Karma.

For our next example, let's look at electric motors. Specifically, let's imagine that you are building the *first* electric motor ever, rather like Thomas Edison struggling to get his first functional light bulb lit. Let's say the date is 1820, shortly after Hans Christen Oersted discovered the interplay between electric currents and magnetic fields, and you've inkled a way to exploit this phenomenon: In your head you have this picture of coiled wire between two permanent magnets, oriented so that the south end of one magnet will contribute an upward nudge on the coil, and the north end of the other magnet will contribute a downward nudge on the coil (when current is flowing in it).



Concept: A coil will be set in motion, somehow, between two bar magnets.

FIGURE 58: Motor schematic 1 of 2: at highest level of abstraction

And if the coil is wrapped around a cylindrical rotor, say a chunk of cork for this prototype, and if the cork rotor is pierced end to end by a knitting needle for its shaft, then the revolving shaft could even have a wheel or a gear mounted on one end, able to 'do work'.

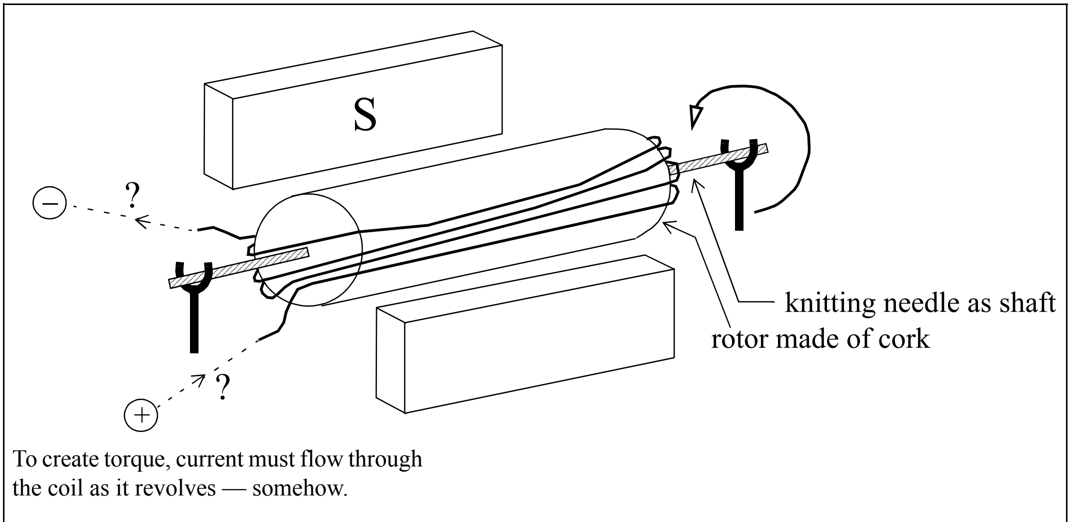
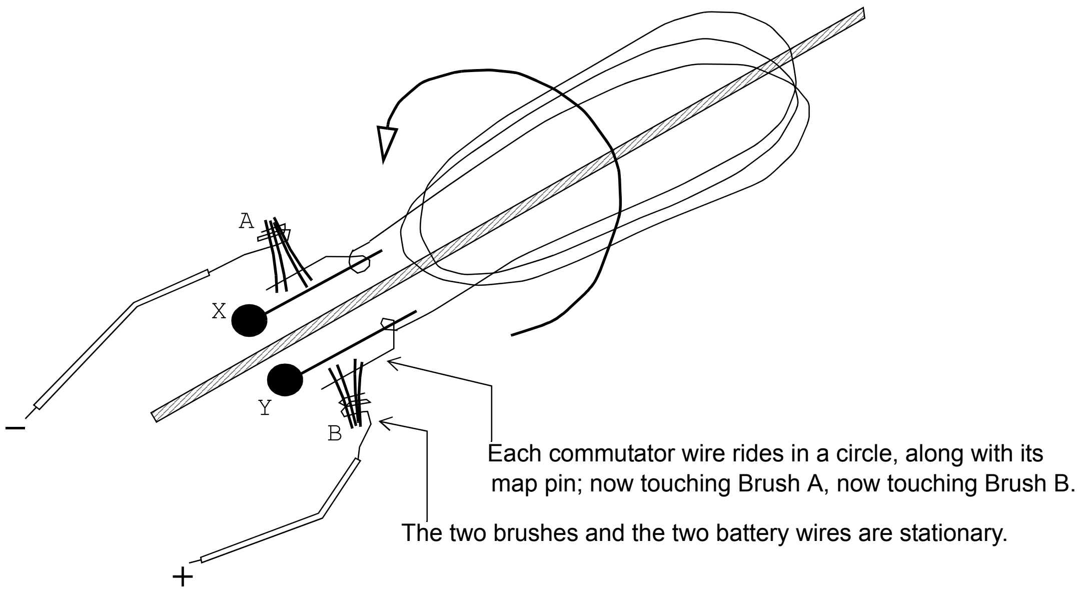


FIGURE 59: Motor schematic 2 of 2: less abstract - with rotor added

But wait; we said the coil needs current running through it, didn't we? How to deliver electric current to an object in motion? What a fool's errand. It sounds impossible, even paradoxical or crazy. But suppose you stick a pair of map pins in one end of the cork rotor, and arrange two stationary wire 'brushes', one facing up and one facing down (so as not to go 'against the grain'), in close proximity to the two map pins. See the objects labeled A and B in **Figure 60**.



For context, please refer back to **Figure 59**, where you can see a depiction of the cork rotor and bar magnets. Here we exclude those components, except for the naked armature coil and shaft, and we add details of the commutator, consisting of two map pins (X and Y) and two brushes (A and B), whose role is to bring current into the device from a battery (represented schematically by +/–).

FIGURE 60: Detail of the 'brushes' (= the Gotcha) for a simple electric motor

Now, as the rotor begins to turn, Pin X will be near Brush A at the beginning of the each revolution, and Pin X will pass Brush B halfway through each revolution, at which point Pin Y will have swung around to the vicinity of Brush A. And so on. (This is a 'split commutator' approach, to use the engineering term.)

Now all we have to do is bring the two ends of the coil out onto the map pins where they can 'go along for the ride', during which they will briefly touch Brush A and Brush B, in alternation, allowing the circuit to close for an instant, twice for each revolution of the rotor. Is this crazy, or might it actually work? The 'Gotcha' is how to make those commutator wires and their brushes. In particular, what material for the brushes? What shape? What orientation? How much pressure should a brush exert against its commutator wire as the latter comes flying past, riding round and round on its map pin?

Because this is the first time ever that such a device was built (we are pretending), you might well despair or doubt your sanity at this point. In the end, a good 80% of your time will have been devoted to the brushes, and only 20% to the device proper, including all that beautiful theory about the right-hand rule, and the torque (τ) being equal to the product of the magnetic dipole moment (*NIA*) times the strength of the field in Teslas.[83]

Sound familiar? It's the story of the Heat Engine, all over again.

The exasperating thing about the brushes is this: If the pressure exerted by a brush against the commutator wire is just a shade too strong, the brush will act like a brake shoe and inhibit the rotor's movement. The motor is dead before it ever starts. Conversely, if the pressure against the commutator wire is not quite firm enough, electrical current will flow only weakly and intermittently, if at all, from the battery into the coil of the armature, and the motor will have no power. Err by only a small fraction either way, and you have no motor.

I know these things because I designed and built this version of an electric motor once, on a whim. Call it a mid-life crisis or something. Later, I realized that all my difficulty with the brushes was merely a matter of scale: Generally, it's quicker, faster, cheaper to try something out on a small scale. The brushes, however, are an exception to that rule: Picture a large heavy rotor turning against a pair of wire brushes, as crude as two whisk brooms, say, or even against two heavy metal slabs in the role of pseudo-brushes, and you can see that these nuances of too much pressure or too little pressure would simply vanish. (And it fact, that's how a real motor is constructed, more or less by brute force.) Nevertheless, I believe the 'problem of the brushes' on my midget motor illuminates a fundamental pattern in Nature. So I have no apologies for telling you its story. Moreover, don't forget that we can go the other direction, too, and make the challenge of those brush tolerances a million times *more* difficult by building a PC disk drive — essentially the same problem intensified to mind-boggling proportions at the microscopic level.

Nor does it stop with different kinds of engine or motor. Ask a computer programmer where the most effort is spent, and she will probably tell you, "Not on the heavy lifting, but on the I/O and the error checking and the UI and of course the design documentation, which I hate." First let's get some of that jargon out of the way, then we'll enter her world:

- 'heavy lifting' means the good part — the neat, powerful, gee-whiz part of the program, typically having to do with math computation or text manipulation. (We programmers get very excited about text manipulation; it's hard to explain why.)

83. Giancoli, p. 571.

- I/O means Input/Output — finding and reading the input files; formatting and 'writing' the output files; sending stuff off to the printer or through a modem to the internet.
- UI means User Interface, i.e., the details of how the program will 'present itself' and interact with its human users, to elicit data and offer warnings or error messages, or perhaps even flash the Blue Screen of Death.

Now the 'heavy lifting' might be challenging, or not. That depends on the nature of the customer's specifications, on what similar puzzles the programmer may have solved in the past, and so forth. But the certainty is this: all those 'auxiliary' but inescapable parts of the program *will* involve a considerable effort. So, once again, the 80/20 pattern emerges (on average) in the creation of computer programs (which many of us programmers regard as a kind of 'machine', sharing with real machines the same frustrations and joys of design).

Asked for an off-the-cuff response, I believe that most programmers would attribute *all* of the 80% to the bother of having to construct a bulletproof UI. ("You can never know for sure what crazy thing the user might try, so you spend all your time building in defenses against... whatever.") And I'll admit that in my programming days I often shared that mindset of being "frustrated with the users" — but only to a degree. I've also always harbored a suspicion that much of the 80/20 aspect of programming is only Nature's voice trying to tell us something 'real' about the world. It's something about the nature of programming *itself* that blows the task up into this funny 80/20 configuration. That's my minority opinion.

In developing this view, I was surely influenced by the title *Nailing Jelly to a Tree*, written by Jerry Willis and William Danley, Jr., at the very dawn of the personal computer age (1981). The notion that the difficulties of programming are largely intrinsic, *not* to be blamed (excessively) on something external, is clearly expressed in their title. And when I revisit the programming landscape in the context of electric motors and heat engines, it strikes me that the 80/20 Gotcha Law cuts across all three design fields. Here is a sample program, to show what I mean:

Anatomy of a computer program, to point up similarities between a real engine and a software ‘engine’:

the weird stuff is inside the big sideways ‘U’ (colored region)

80

Line#

```
1   until ($getkey eq “q” or $getkey eq “Q”)
2       {
3       print “Enter time in seconds, like \n”;
4       print “2 or 1.4 or 1.00010 or 1.00001 (but not 1) \n”;
5       $t = <STDIN>;
6       chomp ($t);
7           $new_position = 100-(16*($t**2));
8           $delta_p = 84 - $new_position;
9           $delta_t = $t - 1.00000;
10          $ratio = $delta_p / $delta_t;
11      print “At $t sec, the instantaneous speed is $ratio \n”;
12      print “Press q to quit or ENTER to run it again \n”;
13      $getkey = <STDIN>;
14      chomp ($getkey);
15      }
```

20

‘the heavy lifting’

(= Work)

FIGURE 61: Anatomy of a computer program

There are two kinds of magic in this tiny PERL program, called inst_speed.pl. The main event, the math computation, occurs at lines 7-10. This is the ‘heavy lifting’. This is the part that corresponds to the Work branch seen earlier in **Figure 55**.

A math student or physics student, innocent of computer programming, would grock immediately the gist of lines 7-10 and even how they work (if not the rationale for the notation system: a dollar sign before each variable name; two asterisks in lieu of superscripting; semicolons that seem to act like periods). He would see that these lines have something to do with instantaneous speed (a topic in physics and calculus, that we’ll explore briefly below).

What the student would surely find puzzling at first would be ‘everything else’; namely, all of lines 1-6 and all of lines 11-15:

- Why the ‘until’? Do what until what?
- What is ‘$getkey’ and how does it equal q or Q?
- Where does the q or Q come from anyway, and why are we talking about them even before the program begins? Why both upper case and lower case?
- Why the curly braces at lines 2 and 15: { }? That seems needlessly abstruse.

- And what the heck is '\n' sprinkled about in lines 3, 4, 11 and 12?
- And who is 'printing' what?
- Why all the blah-blah-blah about "2 or 1.4 or 1.0010 or 1.00001 (but not 1)"?
- What could '<STDIN>' possibly be, in this supposedly simple program?
- What is chomp? An example of geek humor?

Those are a few of the questions that might occur to the student. For here (in lines 1-6 and 11-15) we've entered a new place, the realm of computer *logic*, governed by a new kind of magic that has little to do with computer *math* magic (lines 7-10), where our hypothetical student would feel more at home.

To my way of thinking, the lines enclosed by the big sideways '**U**' correspond to the Gotcha of the commutator brushes in an electric motor and the Gotcha of the valves in a steam engine. Literally and graphically, these lines of code (1-6, 11-15) concern the problem of *cycling*: The program is no good unless it can [1] control its input (i.e., elicit only *proper* values of $t) and [2] allow the user the option of looping back to try out *varying* values of $t — *quickly* and *conveniently* and *gracefully*. In a cycle. Not by pulling the power plug out of the wall and restarting the computer each time! Every bit of the funny-looking stuff in lines 1-6 and 11-15 is driven by one of these practical considerations. There is nothing extra, nothing (purely) whimsical, nothing (gratuitously) arcane. In my opinion, it's not so much computers or their operators that are weird, it's Nature herself dictating the kind of weirdness we see within the borders of the sideways '**U**'. But I'll return to that theme a bit later.

First, our 80/20 theme needs to be updated with this new example:

While the software developer is focused typically on the heavy lifting part of a program (lines 7-10 in this example), often she finds that other parts chew up 80% of her effort. Often there is even a feeling of paradox about this: After all, lines 7-10 are not trivial: They show you how instantaneous speed works, dramatizing the approach of a falling object to its 32 ft/sec limit in the vicinity of t = 1 second, by a stroboscopically close examination of the event on the 't = 2 side', as it were.

Suppose for a moment that we knew only how far the object fell during the zeroth second (16 ft) and didn't know its instantaneous speed at t = 1. In that case, another way to obtain the answer '32 ft/sec at t = 1' would be to infer it from the 't = 0 side' via algebra: The average speed must be 0 + X / 2 = 16 ft/sec. Solving for X, we could draw a fairly confident conclusion that the instantaneous speed at t = 1 must be 2 * 16 = 32 ft/sec. That's one way.

But the approach from the 't = 2 side' is far more exhilarating, since it works *for anything*, even when you have no alternative method of getting the answer (such as the average speed method just mentioned in passing). It's this calculus-oriented approach (from the 't = 2 side') that the program dramatizes by inviting you to enter values such as 1.4 and 1.0001 to see how they behave. Of course you know where this is heading: Both lines of investigation lead ultimately to a generalization about the rate of acceleration for gravity, as g = 32 ft/sec/sec (where 'second per second' adds yet another nuance to the discussion). In fact, these are all parts of a puzzle that occupied the best minds of Europe for a couple hundred years, notably those of Galileo, Leibnitz and Newton. And even with the calculus handed to me on a platter (via Berlinski, pp. 95-103 and 160-162), setting up the magic of lines 7-10 was not a cakewalk. It took me some effort to distill Berlinski's delightful but long exposition down to my four lines of PERL.

So, it's not that lines 7-10 are trivial. It's just that they require *relatively* little effort, in contrast to 'all the other stuff' before and after. And the disproportion sticks in your mind and comes back again and again on different projects. In this example, a count of the lines reveals a ratio that is closer to 75/25 than to 80/20 literally. Elsewhere, it's easy to find programs where the ratio is more like 97/3, or even 99/1, if we include all the comment lines (or 'in-line documentation') in our not-heavy-lifting category. But 80/20 is a well-known concept in business, so we use that expression for the sake of its familiarity. For example, if you discover by analysis that 80% of your sales are correlated with 20% of your activities (or regions or sales reps), it behooves you to learn what is special about that 20% and focus your attention there. From a distance, this will seem similar to how we look at things in computer programming. But up close, there is this crucial difference: In programming, we often don't have the luxury of *not* paying attention to 'all those other things' in the 80% region. So we grin and bear it, acknowledging the pattern but not attempting to modulate it so greatly as suggested by the business version of 80/20.

True, in **Figure 61**, I *have* done some 'modulating': I've deliberately left out some of the potential '80%' items. But that's only for expedience, to give you a quicker cleaner illustration. In real life, that would never do: We would never just *ask* the user to enter only such-and-such values (!); we would also do rigorous behind-the-scenes checking to make it quite *impossible* that a user could ever go outside the legal range and cause *us* the humiliation of the program barfing at run time on a stupid 'division by zero' error or whatever.

Recall the commutator brushes on an electric motor: These brushes are surely not 'the motor'; they are merely a final annoying detail of how you get electricity conveyed *from* the battery *to* the soon-to-revolve-we-hope armature, poised between two magnets, where the 'heavy lifting' is meant to occur. Another kind of magic. And yet, one can easily spend 80% of his or her time on this 'detail' of the commutator brushes, a kind of relative to the 'UI' problem, without which there is no motor at all. Similarly, lines 7-10 alone "do not a program make"; in isolation, their status would drop to that of a pseudocode snippet — a few lines sketched on the back of a Country Kitchen place mat, perhaps, an unproven concept not yet tested inside a living breathing program, so to say.

From the inauguration of the personal computer age (in the early 1980s), I've always regarded computer programming as a vehicle for discovering something basic about the texture of Nature. Accordingly, there have even been times when I regarded my (mundane) programming tasks as a form of prayer. And the parallelism noted here between software development and physical engine design only reinforces my conviction that this is 'what it all means'. In looking at the size or weirdness of the '**U**', I assign only part of the blame to our human users of the program. The thing to realize is that some programs are written to be used (invoked) only by other programs, forever 'untouched by human hands'. And still they have this basic 80/20-ness about them. That's where you begin to see that the dominance and quirkiness of '**U**' must be something intrinsic to programming itself. It must not be *just* a matter of idiot-proofing your code when the program happens to be one that will be launched by a human and thus needs 'protection' from that wily human user.

Now *why* Nature wants to be so weird, I have no clue or insight to share, except to say it's another of her Mona Lisa smiles, perhaps. A feline aspect of Nature. I'm just offering my perspective on the *what* and the *how* of it, that's all. Programs are weird.

Finally, a note about 'procedural programming' vs. graphically-oriented programming and Object Oriented Programming (OOP). Have you ever wondered why a certain company, such as amazon.com, can get it right for on-line ordering, and everyone else seems to fumble, unable to design a system that works? I have a theory: Not only is Nature weird; Nature is procedural. She likes and demands procedural programming. But most programmers these days are graphically oriented. It's as if they believe that by 'painting' all the right icons on the screen, that will make it magically spring to life and be a real program. And of course they wouldn't look at old books about procedural programming; everyone knows that OOP is in and procedure programming is passé. Well, everyone except God and Nature and the Universe, that is. And a few of us greybeard programmers from a bygone age. On the staff at amazon.com, they obviously have some of us (or some young programmers who are smart enough to understand the importance of procedural thinking). A thousand other wannabe companies don't, and that's why they are unable to design even a 'simple' web site that works.

Now for the moment of truth: Can all the above (Figures **56**, **61** and **64**) be subsumed by the following, as a kind of universal prototype?

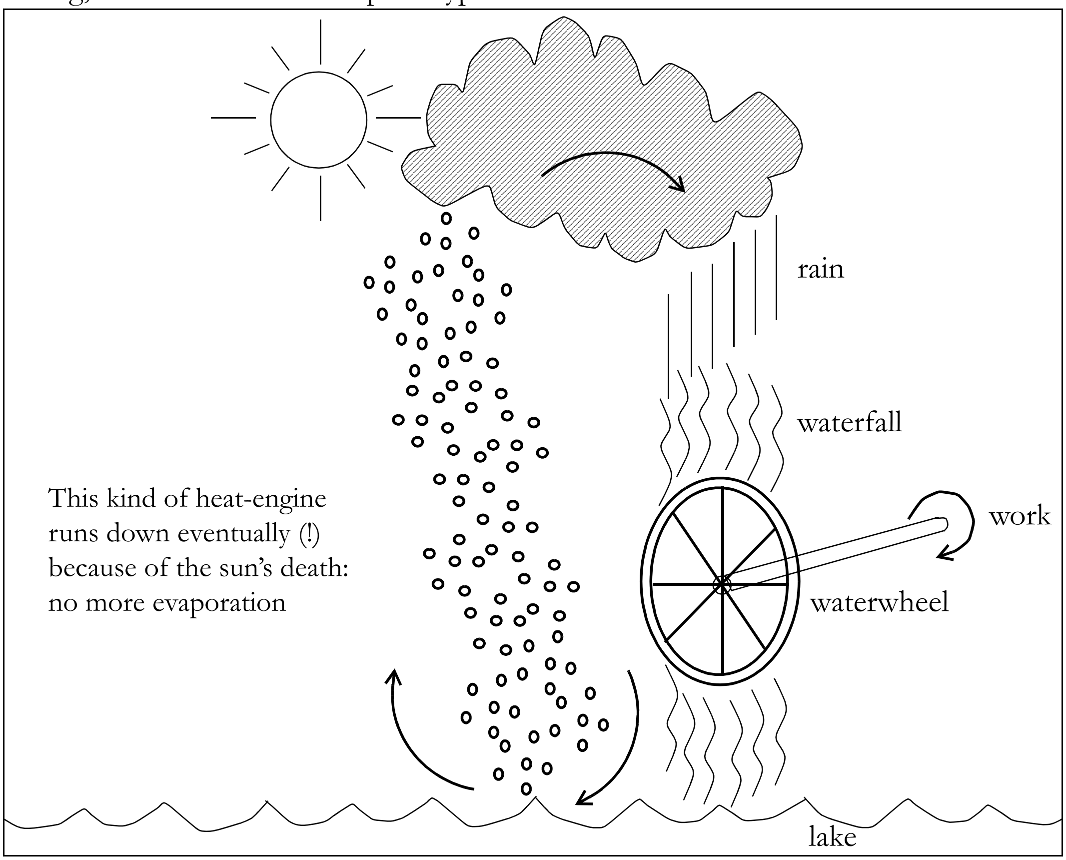


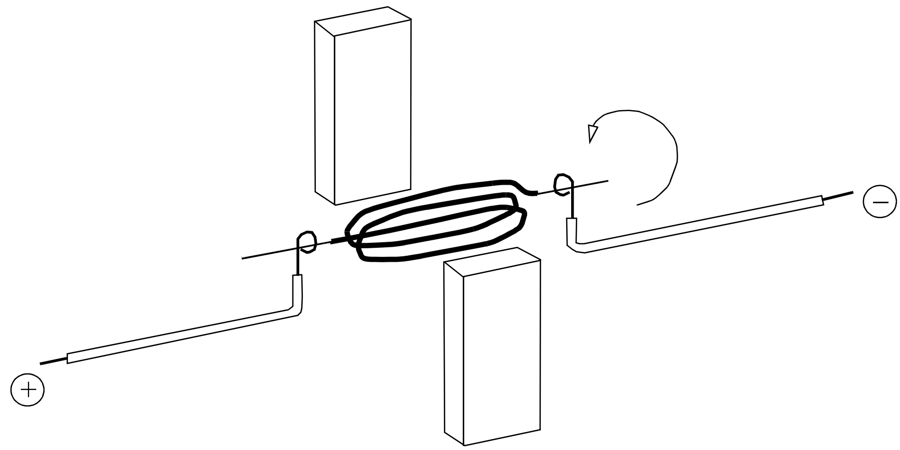
FIGURE 62: The waterwheel in Nature as prototype for all the above

I think we can answer with a qualified yes. The answer is *not* yes if you take the sun and earth for granted; in that case, **Figure 62** would only be a picture of lots-of-energy-for-free, day and night, seemingly without limit, not until Doomsday should come and the sun blink out. Rather, I'm thinking of the scenario where you possess only the clever *idea* of a waterwheel, but not yet the reality of a sun and an earth and a waterfall to make it go. In creating 'everything else' to make the waterwheel go *plash-plash*, you would surely be in the ultimate 80/20 situation, not to say a 99.9999999/0.00000001 situation, and then some! True, it wouldn't be a very exciting kind of 'motor' by modern standards, since it would lack portability and scalability, and it would be enslaved to the vagaries of geology and climate. But that's beside the point. We know that in antiquity, such *was* regarded as a perfectly good 'motor'. Hence, it has its place in this discussion — as the underpinning prototype, the Mother of all Motors.

To round out this appendix, we'll conclude with a look at minimalism in motors.

The Mystique of Simple Motors

With the discussion of **Figure 60**, I've tried to convey the frustration one might experience in building what seems to be 'the simplest-possible electric motor'. The tedium of the final 'detail', the brushes, worked well as an illustration to bolster my 80/20 Gotcha principle. Now for the rest of the story: Some years later, having become a connoisseur of K-12 'science activity' books, I realized that there exists a design concept that is still more primitive, by a notch or two. In one of its variants, it takes the following form: an empty tuna tin (no lid, no label) with two bar magnets clinging to its north and south sides, respectively, and with a few turns of wire placed casually across the open top of the can, oriented east to west, and supported by two eye-loops that have been fashioned with pliers from the stripped ends of the battery wires. When I first saw the picture, it seemed too good to be true: Many such 'easy projects' simply don't pan out, whether because of an 80/20 Gotcha that lurks in a footnote never written, or because of a vague and dishonest design plan (e.g., often they specify a 1.5-volt battery where 6-volts minimum are required), never once tested by the "author of several books for young scientists". But this one I had to try no matter how skeptical I was. It appeared to be my Holy Grail, an artifact straight from the Promised Land (per my private definition, I mean).



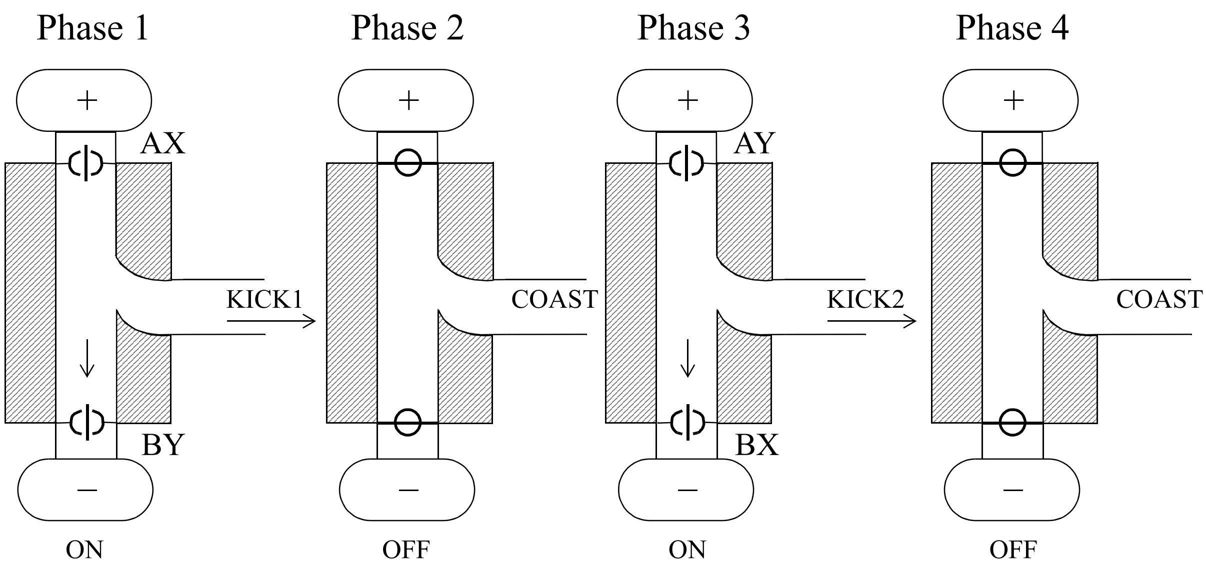
Having seen these humble innards of the Tuna Tin model (described more fully in the text), one will realize that when I speak of "elegance" and aesthetic appeal, I'm not using these terms in quite the usual way. The Tuna Tin motor is arguably inelegant, and yet... Perhaps we may hold it up as an example of "Soviet elegance"? All will become clear as we proceed.

FIGURE 63: Minimalist Motor: Tuna Tin model sans tuna tin

And it was. Moreover, it came clattering to life immediately. No headaches. No repeated trips to the hardware store for some missing secret ingredient of the design. No 80/20 Gotcha to chew up the weekend. It. Just. Bloody. Works.

Now *why* it works is another matter entirely.

But before tackling the special case of the Tuna Tin model, we need to back up for a moment to review the general theory. Whether written for grade school consumption or for students of college-level physics, every theory of operation for electric motors that I've ever seen takes the following as its premise: You *must* interrupt and reverse the electric current halfway through each cycle, as though batting the blades of a propeller alternately down with one's right hand and up with one's left hand to impart continuous motion to it; *otherwise*, the motor will just jerk stupidly back and forth in a small repeating arc, instead of smoothly turning over to purr at so many RPM. Seen in this light, the split commutator appears to be a necessity, not just a commercial refinement, for smoothing out the motion, say, or for maximizing power. And it all sounds perfectly reasonable (as set forth in Giancoli, p. 573, for example).



Legend:
AX/BY refers to the state of the split commutator as depicted already in **Figure 60**.
(Brush A is in proximity with Pin X and Brush B is in proximity with Pin Y.)
AY/BX would be its state after the coil rotates 180 degrees.
(Brush A is in proximity with Pin Y and Brush B is in proximity with Pin X.)
Phases 2 and 4 represent the longer periods in-between when there is no contact at all between pins and brushes, and the motor simply coasts.
+ and – are the two halves of one notional battery, broken apart for the sake of the schematic.
This is topological sleight-of-hand, if you like, for matching this schematic to the general shape of the heat engine schematic in **Figure 55**.

FIGURE 64: Electric Motor Theory of Operation

Figure 64 is an abstract representation of the motor already seen in **Figure 59** and **Figure 60**; this is the standard model. However, it may appear exotic at first glance because I've chosen nonstandard symbolism to point up the underlying unity of the electric motor paradigm and heat engine paradigm. Seen this way, the only real contrast is in the number of phases: For the electric motor, we must think in terms of four phases (or states) instead of two phases (**Figure 56**), because the pin-brush combinations AX/BY and AY/BX both occur once on each revolution of the armature, spaced out by much longer periods where no electrical contact is made (labeled 'coast' in the figure). Saying it another way, ON OFF ON OFF = one cycle.

Because of the way the current in the wire interacts with the field of the adjacent magnet, it must be reversed at KICK2 from the direction it took at KICK1. Otherwise, KICK2 would 'fight' KICK1 instead of helping it along. In terms of **Figure 60** (back on **page 210**), at KICK1 the current must flow out of the armature lead that rides on Pin X, and at KICK2 (after the rotor has brought everything around 180 degrees), the current must flow into the armature lead that rides on Pin X; and vice versa for Pin Y as it makes the circuit.

Now look again at **Figure 63**, please. Surely *this* model flies in under the radar of the textbook theory, to exercise a different principle? The armature leads are pointing east and west, that's the obvious difference from the standard model, where both point west (in terms of **Figure 60**). So the current must flow in one direction only. There can be no 'reversal'. The 'brushes' in this instance are two tiny loops of wire, positioned at either end of the minimalist armature coil. Threaded through each of the two loops, not unlike two stiff threads through the eyes of two needles, the leads protruding from either end of the armature would seem at first glance to be in *continuous contact* with their respective 'brushes'. Lying down in the eye-loops, under the force of gravity, this pair of wires must play both an electrical role (as commutator surrogate?) and a mechanical role (as pseudo-shaft, to encourage revolution of the coil). Whatever kind of commutator each wire might represent, there's nothing 'split' about it.

And here's the irony: precisely because the armature loop is made so *casually* in this kind of 'kitchen counter' experiment, it will be a bit *lopsided*, and because it is so lightweight and just a bit lopsided, it will tend to wobble and *bounce* slightly as it revolves, interrupting the flow of electricity, and this in turn allows it to fall into a two *two-phase* cycle of KICK-COAST. From a distance, the two-phase KICK-COAST motion of the Tuna Tin coil appears no different than the four-phase cycle of the standard model, with its KICK1 COAST KICK2 COAST pattern. In truth, though, the Tuna Tin model *is* heterodox. One might even say it saddles us with an Inverse Gotcha, in the following sense: Yes, the device itself works fine, but it does so for such an obscure reason that one is in jeopardy of either [a] making ill-informed guesses as to why it works, or [b] spending an inordinate time discovering the truth(84) of why it works! Or, if you wish to look on the bright side, one may say the Tuna Tin model is the rare case where Murphy's Law works with us and not against us (because it's the imperfections in the shape of the coil that lend it buoyancy and

84. Confirmed for me by Robert Gardner, *Electricity and Magnetism* (1994), pp. 60-61.

thus an affinity for falling into a two-phase cycle, this being the only one that is viable, absent a split commutator.)

At any rate, the model depicted in **Figure 63** was my Grail, my ideal: exactly what I had been dreaming of in the way of a very simple motor that differed hardly at all from the abstraction of **Figure 58**.

* * * * * * * * * * * * * * * * * * *

What really was the point of building the motor depicted in Figures **58** through **60**, and later the one whose 'innards' are depicted in **Figure 63**? When the urge struck me, first in my mid-forties, again in my mid-fifties, I couldn't have told you much about it except to say only half-kidding that it was a kind of mid-life crisis, an obsession with 'toy motors'. It was just something I had to do. Gradually over the ensuing decade I've come to understand what I was seeking. Something more interesting, I hope you'll agree, than Grandpa with his scale model trains.

Let's set up the context. We live in a sea of large internal combustion engines, fashioned to be big and powerful (and even obvious, in the case of muscle cars); we're also surrounded by electric motors, most of them fashioned to be small to medium-sized, as quiet and unobtrusive as possible. But for all these examples of electromagnetic technology in the human environment, most of us have no real 'rapport' with such technology. (And this becomes the major theme in the writings of Robert Pirsig, incidentally.) At first, one might retort that we *are* taught in school to appreciate electric motors, thanks to ubiquitous 'science projects' such as the one depicted in **Figure 63**. But not really. Here's the irony: To my ear, the tone of most such 'projects' says, in effect, "This is just a kid's gadget to twiddle, a gimmick to stave off boredom in class, with the hope that we may *later* lure you into science per se"; whereas, when Peter Barton created his Ur-motor, it *was* science, absolutely, right at the cutting edge. And yes, it was *also* a kind of toy, but a toy of the philosophers, with hints of the divine, as it did its circular dance in quicksilver, debuting in the very same year that Beethoven premiered his *Ninth*. Yes, it was 'only' a primitive motor, precisely because it *was* on the raw cutting edge of all such understanding; yet it *also* managed to be magnificent, like the model of a temple on a scale of 1000:1. All of that and more.

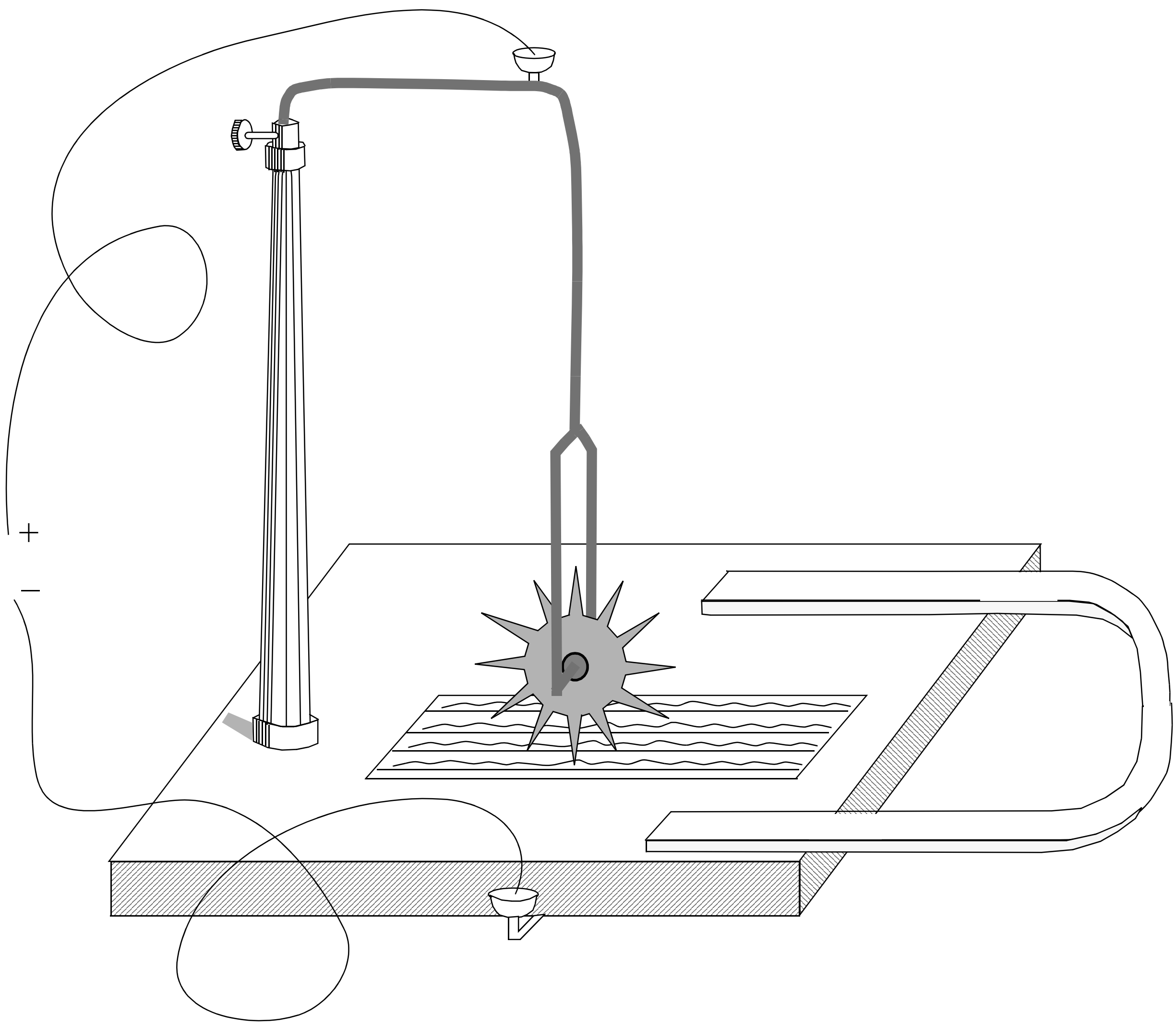


FIGURE 65: Barlow's Wheel as Alpha and Omega

The device[85] pictured in **Figure 65** represents the magic I was trying to [re]capture, without quite knowing it at the time of my quixotic Tuna Tin quest.

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85. For my money, this is the one that counts as the first electric motor. No doubt Farady's swizzle-stick magnet that swam laps around a wire in a tumbler of mercury (two years earlier) was a necessary way-station on the road to this achievement. But in Barlow's one device we find both the Alpha and Omega of electric motors: It is our Alpha in the sense that it shows us at a glance the potential of *all* such motors into the distant future; it is the Omega in the sense that it also defines the far limit in simplicity/elegance/*élan*, never to be surpassed — all in that *one* moment of history, as it inevitably strikes us today. Such heady times those must have been! But full of horrors, too: Think of Beethoven screwing in his ear trumpet to hear his own trumpets; think of the mortality rate for infants *and* their mothers...

Details of the apparatus I've depicted in **Figure 65** (after a nineteenth century drawing that is reproduced in Parker, p. 38): It consists of a horseshoe magnet with its two arms extended along opposite sides of a mercury bath in which a spur-wheel is suspended. The spur-wheel is free to revolve in response to current coming down through its stem and axle, into the spur's metal, still lower through the mercury, and thence back to the voltage source. I interpret the two acorn-shaped cups to be additional receptacles for mercury, for ease of forming an electrical connection. (Both literally and figuratively, everyone went crazy over mercury back then, not just the Mad Hatter.) Although a few antique Barlow Wheels survive in museums (www.sparkmuseum.com offers stunning photos on-line of every imaginable electromagnetic device of the nineteenth century), the spirit of that epoch is even better conveyed by contemporary drawings of them, I believe. My version of the picture tries to be faithful to the original except that I've added battery wires, and in labeling them '+' and '–' I've introduced a slight anachronism: All of this would have been new, new, *new* in 1823, predating any such a notation convention, even predating the implied atomic theory and concept behind such symbols for positive and negative terminals!

When it comes to heat engines (for the conversion of thermal energy into mechanical energy), the analogous quest has no such happy ending(s) as the Tuna Tin model of Barlow's Wheel. But other kinds of wondrousness can be noted along the way.

The Stirling Engine — intimations of minimalism on the heat-engine front?

From the web, one gathers that there is a whole subculture of Stirling Engine enthusiasts out there. I found the home page of Koichi Hirata especially helpful in learning the basics of Stirling Engine operation and theory (khirata@gem.bekkoame.ne.jp).

What follows is my own interpretation, possibly a bit heterodox, of how the Stirling Engine relates to the steam engine.

While the steam engine involves a complex interplay of *steam* and *condensate* and *water*, the Stirling Engine is simply an *air* engine. This immediately sets it apart and even invests it with an aura of slight mystery, I think. It is thus especially appealing to people of my temperament who are attracted to "elegance" and minimalism, or to a machine that seems to beat the system or perhaps save the earth.

Recall for a moment those textbook primers on steam engine design, with the boiler and condenser explicit, and an overlay of mechanized plumbing implied, to make the beast behave and not blow up. At first sight, the Stirling Engine would seem to require nothing analogous to that cuckoo-clock baggage of valves and gears (or the trained mice of **Figure 57**).

What are *its* components? Just two pistons!

Oh, and their cylinders are joined by some sort of conduit for air to pass through at diverse temperatures. That's the third major component of a Stirling Engine.

And here we begin to inkle that the 'minimalism' and 'simplicity' of this engine might be illusory. I would liken the Stirling Engine to certain personalities that are smooth and bland on the outside, yet subtly thorny and tricky within.

We'll break the design of a Stirling Engine down into two major categories:

- Theoretician's Contribution
- Mechanic's Contribution

Historical notes: As for the Reverend Robert Stirling himself, it would appear most likely that he wore both hats. It's only for the sake of a mental exercise that I propose thinking in terms of a Theoretician's Contribution first, followed by a Mechanic's Contribution. Also, one might note that the earliest hot-air engines constructed by George Cayley and by Robert Stirling were of a form called Beta-type (nowadays), with the two pistons shishkebabbed on a single rod. The ensuing discussion, however, will center on the Alpha-type which links the two pistons in a less overt manner, and keeps them side-by-side on separate rods. But this too is a minor point. Incidentally, Cayley was unable to make a convincing prototype because of a Gotcha: The difficulty of making an airtight cylinder in the year 1807. Ten years hence, Stirling fared better with his cylinders, and thus has his name more closely associated with the invention, even though it seems obvious to us that Cayley did it first.

A. Theoretician's Contribution to the Stirling Engine design

A schematic of the generic Stirling Engine cycle as consisting of four phases named HEAT, EXPAND & MOVE, COOL, SHRINK & RETURN is given in **Figure 66**:

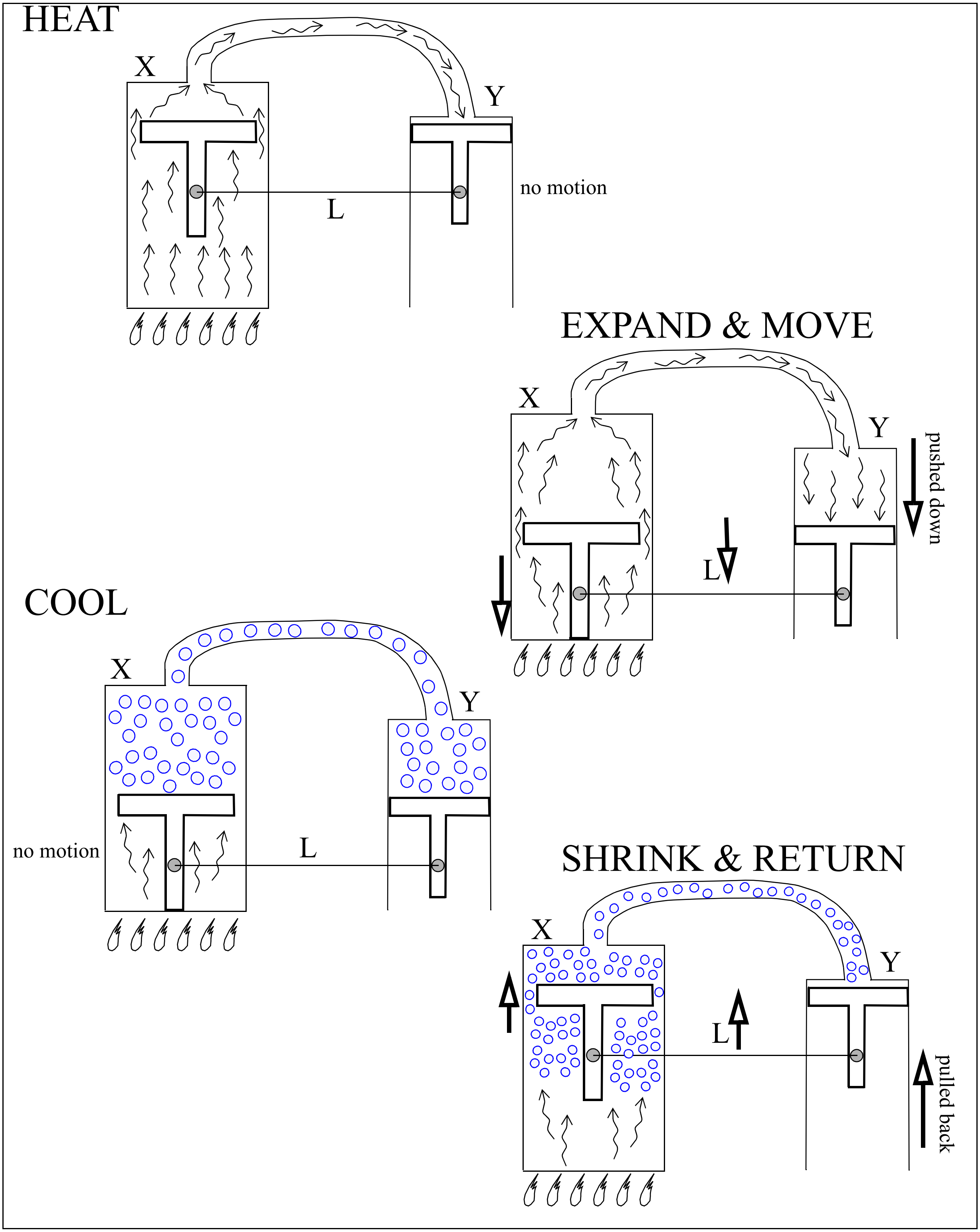


FIGURE 66: Schematic of Stirling Engine Cycle

Each of the four phases in turn:

HEAT. In **Figure 66**, we depict Piston X as too small for its cylinder — deliberately *not* air tight, that is to say. By contrast, Piston Y is closely fitted to Cylinder Y. For now, L should be regarded as only a conceptual Linkage (with no physical detail specified or implied), joining Piston X to Piston Y 'at the hip' and forcing them, somehow, to move either [a] in concert, or [b] not at all.

EXPAND & MOVE. In this phase, Piston Y is pushed down *slightly* (the change need not be dramatic) by the warm expanding air arriving from Cylinder X. Concurrently, linkage L brings Piston X along with it: the pistons move down in tandem in both cylinders.

COOL. Most of the air is cooler now (less hot) because Piston X has taken over — by *displacement* — the lower part of Cylinder X, the area that is in closest proximity to the heat source.

SHRINK & RETURN. The contraction of the air from cooling allows the system to return to its original volume; i.e., the system returns to its equilibrium state. Accordingly, Piston Y returns to its original position. Concurrently, linkage L brings Piston X along with Piston Y. The cycle is ready to be repeated from the top. In other words, the state of the system at the end of the SHRINK & RETURN phase is indistinguishable from its state at the beginning of the HEAT phase. We have come full circle.

B. Mechanic's Contribution to the Stirling Engine design

The Mechanic's contribution will be the working out of L, the linkage, in physical terms. This is where we begin to see something analogous to the valves of a steam engine; in a Stirling Engine, in contrast, the linkage cannot be separated out and postponed as a mere 'implementation detail'. Rather, it must be tackled right along with the theoretician's part of the design in an all-or-nothing fashion, early on.

Specifically, the linkage would have to be provided by some species of crankshaft-with-flywheel rigmarole, as depicted in the lower part of **Figure 67**:

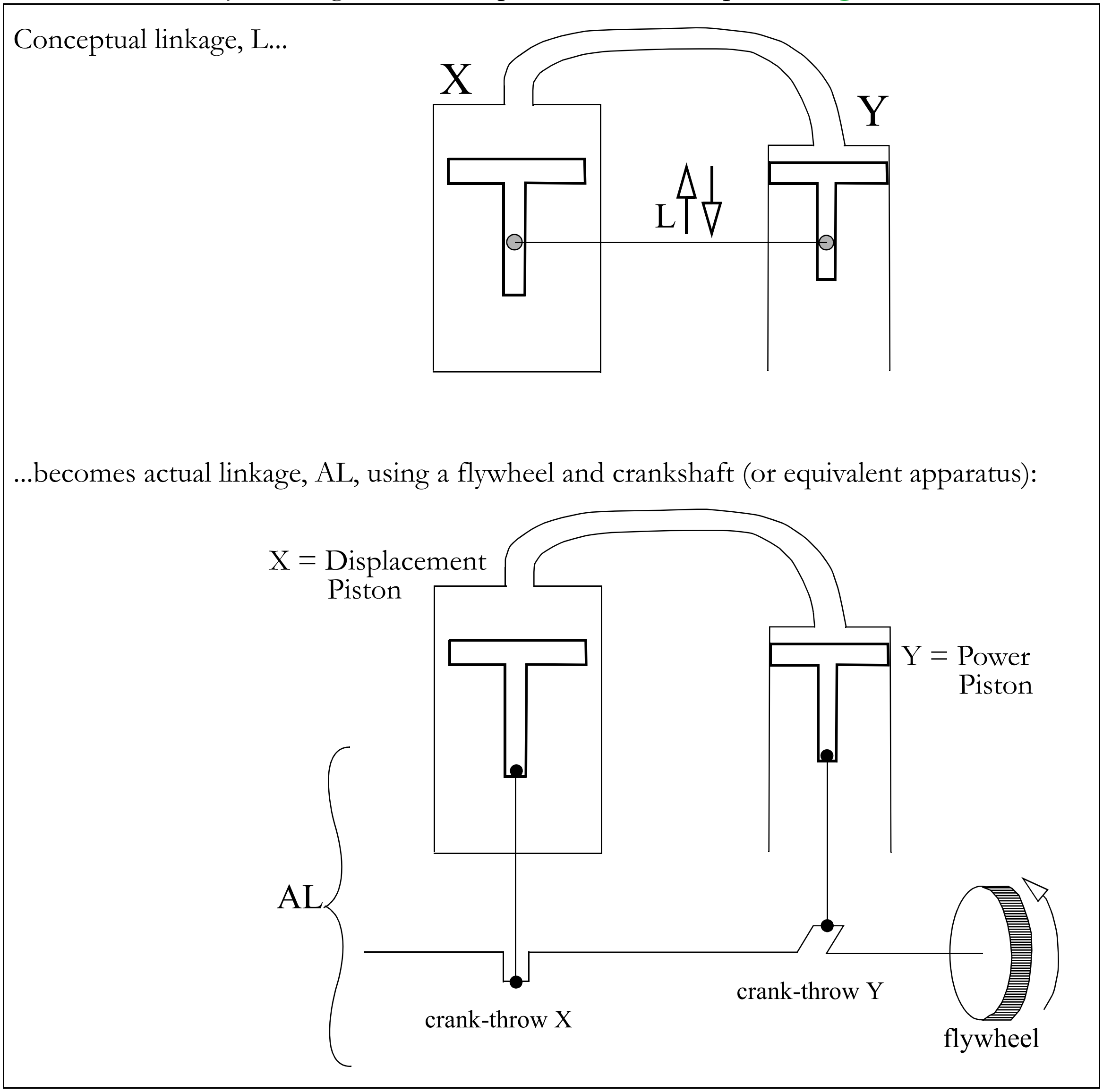
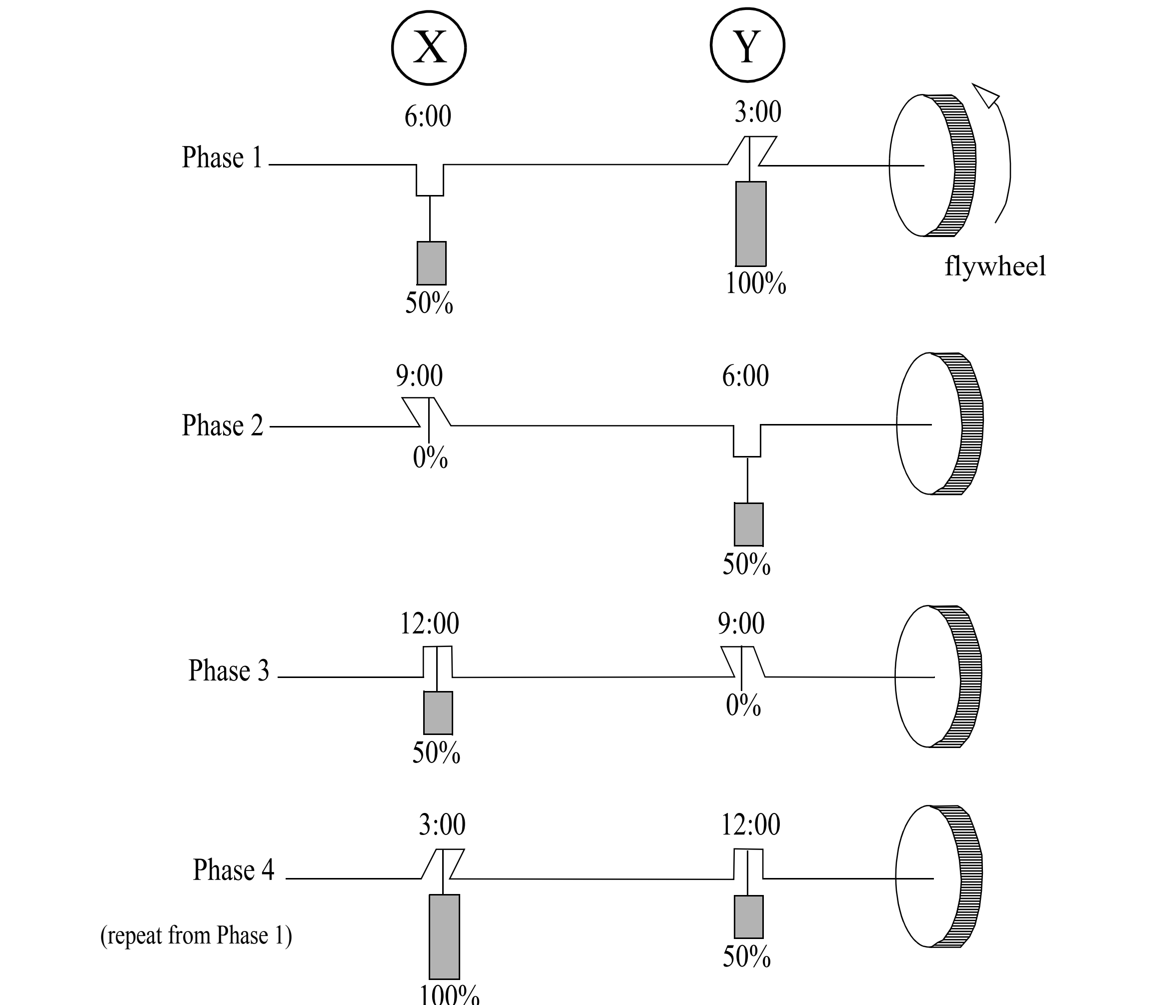


FIGURE 67: Conceptual Linkage, Actual Linkage

But what should the exact relation be between the orientation of crank-throw X and that of crank-throw Y? In **Figure 67**, we've used only an impressionistic notation, suggesting that probably the two crank-throws should be differently phased, i.e., not turning in sync. That's our hunch. To see the actual scheme employed in a Stirling Engine, please refer to **Figure 68**.



Note:
This is not a 'picture of a machine' — not quite. Rather, it is a state diagram (a 'state machine') in which I have symbolically combined [a] crank-throw orientation data for Pistons X and Y (as 6:00 o'clock, 3:00 o'clock, etc.) and [b] piston positions (as 50% extended or 100% extended, etc.), as observed on a kit I purchased and assembled, when 'exercised' in slow motion.
The two layers of data — [a] and [b] — I've merged into a high abstraction and attached to pseudo-crankshafts above.
Key:
Column X contains the Displacement Piston data.
Column Y contains the Power Piston data.
6:00 = 6 o'clock position of crank-throw (always at a 90-degree phase angle, i.e., off by '3 hours' from sister piston).
% = how far piston has moved in its cylinder for the phase indicated.

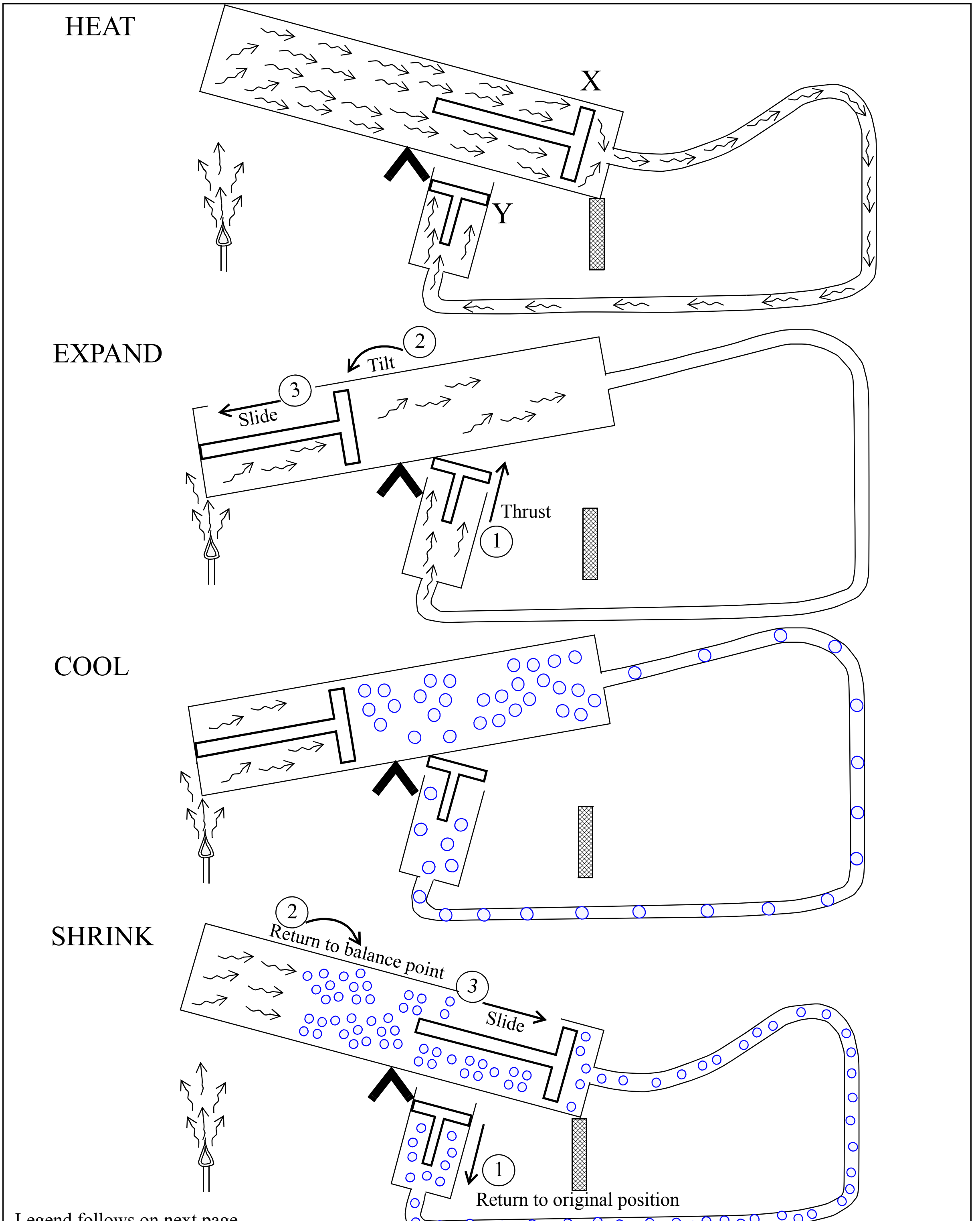
FIGURE 68: Stirling Engine State Diagram

Concluding thoughts on the Stirling Engine design: the Conservation of Gotcha

In Stirling Engine design, there is nothing that jumps out at us as an 80/20 Gotcha candidate, lurking down the road, unless one wished to mention the requisite precision-machining of the cylinders and pistons, to tight tolerances. (For me personally, that would be an insurmountable Gotcha, more on the order of ∞/1 than 80/20, so I pay a bit extra and order only the kits that have pre-machined parts.)

But discounting the role of the *Machinist*, for the sake of discussion, let's refocus on that of the *Mechanic*, as described earlier. Even though there is no evident 80/20 Gotcha headache suggested by the Stirling Engine paradigm, I believe it follows a kind of Conservation of Gotcha Law in the following sense: the Mechanic's Contribution is both complex (**Figure 68**) and *integral* to the basic functioning of the engine. It's just that we pay 'now' instead of paying 'later'. Figuratively, we may say that the difficulties are 'marbled in', giving Stirling Engine design a sort of figure-8 or Klein Bottle quality by comparison with the 1-2-3 linearity of steam engine design. (In this regard it is reminiscent of computer programming, too: the oddly 'wrapped' form of **Figure 61** comes to mind.) In other words, no matter how clever our trained mice are (from **Figure 57**), they can not be brought in at the eleventh hour in hopes they will be a surrogate for the Stirling Engine Mechanic whose gift to us is depicted in **Figure 68**.

And what about a minimalist Stirling Engine, a Stirling Engine analogue to the Tuna Tin motor? First, please have a look at **Figure 69**, which would seem to be a twisted variant (partaking of Area 51 space alien technology?) on **Figure 66**:



Legend follows on next page

FIGURE 69: Stirling Phases Revisited

Legend for **Figure 69**

heat source

fulcrum (rotation point for Cylinder X)

warm air

air that is cooler (less hot)

support post for Cylinder X

X Displacement Piston & Cylinder

Y Power Piston & Cylinder

The four phases, each in turn:

HEAT. Piston X is narrower than Cylinder X, allowing hot air to pass out through the conduit to push up on Piston Y. (No motion yet.) So far, this matches what we said in the context of **Figure 66**.

EXPAND & TILT LEFT. Pressure on Piston Y is sufficient to move it up (thrust). This causes a tilt across the fulcrum, and Piston X will slide down.

COOL. Most of the air is cooler now (less hot) because Piston X has taken over (*displaced*) the left half of Cylinder X, where the heat source is.

SHRINK & TILT RIGHT. Having cooled somewhat, the air occupies slightly less volume than before, and this allows Piston Y to fall back to its original position, which in turn allows Cylinder X to tilt back to its 'home' position. The cycle is ready to be repeated from the top.

As the reader will have guessed, what we're looking at in **Figure 69** *is*, in fact, a schematic of the rock bottom minimalist Stirling Engine already! (I've abstracted the schematic — reverse engineered it, one might say — from the details of a kit I purchased, the Test Tube Stirling Engine aka Simplified Stirling Engine #1896, from www.baileycraft.com for $17.95.) In **Table 6**, I provide a laundry list of the kit's components side-by-side with the function each satisfies in terms of the earlier **Figure 69** schema.

TABLE 6: Test Tube Stirling Engine Parts List

This component of the physical Test Tube model...	...corresponds to this schematic element in **Figure 69**[1]
test tube	Cylinder X
5 marbles	Piston X (= Displacement Piston)
large stopper	Cylinder Y
bracket and O-rings	
balloon (with neck cut off)	Piston Y (= Power Piston)
3 rubber bands	
small stopper (for test tube)	conduit from X to Y
plastic tubing and hose fittings	
cabinet hinge and O-rings	fulcrum and support pillar In **Figure 69**, these are physically separated. In the Test Tube kit, their functionality is found combined in the cabinet hinge plus metal plate mounted atop the bracket.
small metal plate to hold test tube horizontal	
candle	heat source
hook and washers	—

1. And most of these in turn will recall the generic Stirling Engine schema given in **Figure 66** and **Figure 67**.

And the Gotcha is...?

The counterweights, of course (which I excluded from **Figure 69**, not to detract from its theoretical elegance with this unfortunate bit of reality): The kit comes with half a dozen washers and a hook to hang them on. Only by adding or subtracting these counterweights near the right end of Cylinder X can you discover the precise equilibrium point that will induce the continual and 'automatic' seesawing across the fulcrum (as distinct from FIDDLE, TILT, KLUNK, FIDDLE, TILT, KLUNK...)

Still, for all its messiness, the Test Tube model does demonstrate that the linkage, L, of **Figure 66** *can* be implemented by a direct 'joining at the hip' after all, thus avoiding the whole flywheel-and-crankshaft assumption of Figures **67** and **68**. That's new information.

And in that aspect, it recalls the close match of the (actual) Tuna Tin motor (**Figure 63**) to the (conceptual) scheme of **Figure 58**, thought earlier to be such a high abstraction. Also, one might note the parallelism of EXPAND, COOL, SHRINK, HEAT in **Figure 69** (beginning on Phase 2 and wrapping around to Phase 1) with ON OFF ON OFF in **Figure 64**. But this we could have gleaned already from the abstract scheme of **Figure 66**. We didn't need the Test Tube model for that particular insight.

All in all, the Test Tube Stirling Engine lacks the appeal of the Tuna Tin motor, I think. The former is too kludgy and higgledy-piggledy and rife with 80/20 Gotchas: air leak; broken part; broken rubber band; wrong position for Y; plastic tubing's contents improperly primed (by mouth); suboptimal counterweighting; candle too tall or too short; and so on. As such, it can hardly convey that feeling of "This is it — something wondrous yet simple."

However, I hasten to add that a kit of an *actual* Stirling Engine — the kind with a flywheel and precision-tooled cylinders — *is* delightful and *does* provide exactly those overtones of Simple Motor Mystique. It's just that on the inside, as we know from **Figure 68**, the beast is complex.

Appendix C: Gabriel's Horn *for* Eternity, not *to* Infinity

In this appendix we continue a thread begun in Chapter **V** about Limits, an area where science fails to 'finish what it started', thus spreading — albeit only semiconsciously — untruths about such processes as dead leaves piling up or a raindrop falling or an electron seeking a new energy level, to name just a few of the many context where the offense occurs. To the biped scientist, these are merely white lies, a matter of pragmatism, how to advance swiftly to the next level of toilet bowl vortex engineering (or whatever). But to an independent observer, whether that be Nature personified or God or just a funny little space alien of high intelligence, such falsehoods are egregious. Hence my feeling that they deserve extended treatment here. This time the discussion will be longer, with detours more likely, because [1] we will be dealing with a 3D problem (whereas piled-up leaves and falling raindrops we were able to boil down to a notional 2D problem); [2] we will be dealing more directly with the concepts of *infinity* and *eternity*; and [3] we will be dealing also with *paradox*, not for its own sake but because the *seemingly* paradoxical aspect of the Gabriel's Horn problem can help shed light on the infinity/eternity issues, even as we endeavor to demystify or debunk that aspect. (Not that this can make much sense on the first page of a 20-page essay, but for those who might be anxious to know where we are headed: eternity will be the tool we use for debunking the Gabriel's Horn paradox.)

In Part I of this appendix, except for certain footnotes that anticipate Part II, I limit myself to an objective statement of the Gabriel's Horn *function* (by which we mean 'the rotation of function y = 1/x through the third dimension', as illustrated in **Figure 71** on page **241**). In Part II, the discussion proper begins (on page **245**), picking up the 'limits and leaves' thread alluded to above, and spinning it out in the direction of the infinity/eternity questions, along with various others, including the obvious one: "How shall we demystify the 'paradox'? "

Part I: Exposition of Gabriel's Horn

The Gabriel's Horn Function (hereafter 'GHF'), if known at all to the general reader, will most likely have been encountered as the jumping-off point for the paradox. (This is its role in Clegg, pp. 239-242, for example.) But between the covers of calculus textbooks, that same rotated function lives a quieter life. There it is often treated *almost* as if it were just another integral (or pair of integrals) to solve.

Some examples: In Salas, in the section on Improper Integrals, our function appears as *Example 3*, where the author provides this bland hint of something unusual: "It may surprise you somewhat, but the volume is not infinite. In fact, it is π" (Salas, p. 603). In Stewart, p. 587, the function is found at the back of Chapter 9, in Exercise 27; the author adds parenthetically, "The surface is shown in the figure and is known as Gabriel's horn." In Hughes-Hallett, p. 435, the function appears in a 'Project' at the back of Chapter 8. The Project has a name, Surface Area of an Unpaintable Can of Paint, but the author stops short of using the loaded term 'paradox', nor is the nickname 'Gabriel' mentioned. To summarize, in none of the calculus texts just cited is the p-word used, although Hughes-Hallett strongly hints at a paradox; and only in Stewart is the nickname 'Gabriel's Horn' mentioned.

Putting it all together, there is something rather odd in the way these three text book authors dance around the subject, as though in compliance with a directive never to call it out by its (full) name. At any rate, I will begin by imitating their approach, in the sense that I will try to look at the GHF first as the source of 'just another integral', so to say, and thus build a foundation for the much broader discussion in Part II, where we bring in its supposedly paradoxical aspect, among others.

The plain version of the function, before it gets 'rotated', is an innocent-seeming equation containing only an 'x', a 'y', and a '1'. Its curve is shown in **Figure 70**.

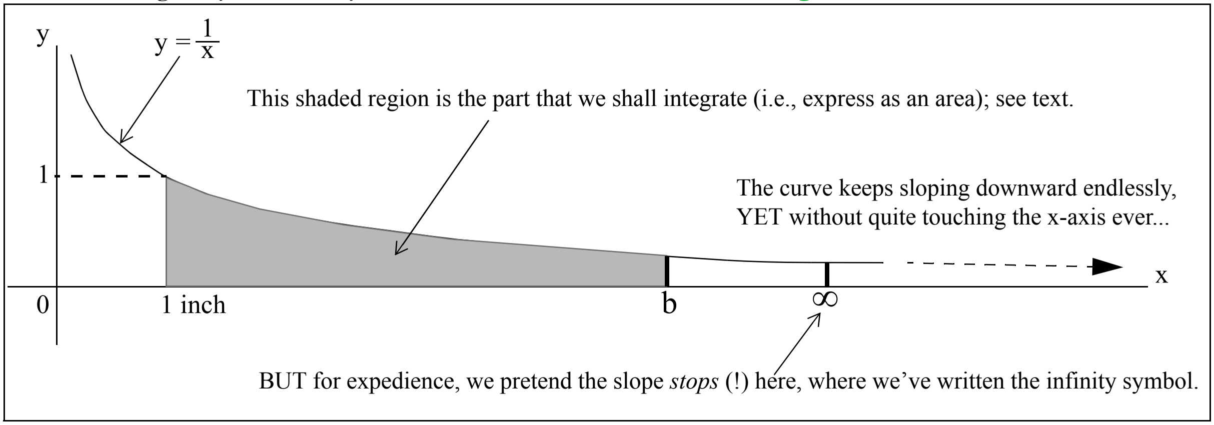


FIGURE 70: The function y = 1/x integrated from One to Infinity

My drawing is rough, not computer-generated. Conceptually, its curve goes on ceaselessly to the right, approaching but never quite touching the *x*-axis. However, to establish a visual framework for calculating the area under the curve starting at $x = 1$, we interrupt the curve at an arbitrary point labeled '∞', and we also label an intermediate point as '*b*' representing "any big number that we might wish to try out as a proxy for infinity." (And to the left of that I specify '1 inch' where normally one would see only the numeral '1'; this is only for the sake of making the ensuing 'solid' version more tangible, easier to think about.)

Now we have enough data defined to try integrating the function $1/x$ from 1 to *b*, as shown in EQ 3:

$$\int_1^{\infty} \frac{1}{x}dx = \ln x\Big|_1^{\infty} \approx \ln x\Big|_1^{b} = \ln b - \ln 1 = \ln b \qquad \text{(EQ 3)}$$

In words, "the area under the curve between 1 and *b* is [almost!] equal to the natural logarithm of *b* (whatever value you happen to choose for *b*), expressed as square inches."

To give the flavor of how the numbers behave, here are a few sample calculations of the area under the curve (shaded region), for four arbitrary points on the x-axis (different values of *b* chosen at random):

At b = 10 inches, the area thus far along the x-axis is 2.3 sq in.
At b = 90, the area thus far is 4.5 sq in.
At b = 900, the area thus far is 6.8 sq in.
At b = 9,000,000,000, the area thus far is 22.9 sq in.

The areas above were calculated this way:

$$1/x\, dx = \ln(b) - \ln(1), \text{ e.g., } \ln(90) - \ln(1) = 4.5 - 0 = 4.5, \text{ and so on.}$$

In other words, pick an arbitrary test value, and the further out you go, the larger the area will be, and not by drabs and dribbles; but *neither* does the area grow by leaps and bounds.(86)

Now for the solid, 3D version, which takes shape as a ‘horn’ of sorts:(87)

86. In passing, note the ‘exoticism’ of this pattern: that something could edge along at such a steady *slow* pace yet aim itself unmistakably in the direction of *infinity*. Saying it another way, even though the curve keeps falling, the area under the curve does not taper to something negligible, as one might reasonably have anticipated with many other functions. Rather, the area keeps right on growing. And even though it grows so extremely slowly, that doesn’t preclude its signaling to us: ‘Destination: Infinity’. Although the main argument of this appendix still lies far ahead, already we have a glimpse here of the problem about the Book of Nature behaving one way and the biped mind behaving another way. The pattern just described is exceedingly non-intuitive to the biped, a major source of his boredom and discomfort in trying to stay awake and read a few pages in the Book of Nature.
87. Details: For convenience, we speak of a horn shape, but be careful. By fiat, Gabriel’s Horn begins at 1, not at 0; otherwise, the integration techniques for determining surface area and volume wouldn’t work. And looking to the east, as indicated by a label in the graph, our notional ‘horn’ goes off the page, growing ever thinner, without end. Meanwhile, in-between 0 and 1, what happens? In this region, one may be tempted to draw a kind of ‘French horn bell’, for the sake of a finished image (on one end at least!), but really the curvature here *too* is the kind that heads off into Infinity. **Figure 70** barely hints at this aspect, but in the upper part of **Figure 71** I’ve extended the curves that lie close to the y-axis in a way that I hope will suggest their asymptotic (literally, ‘not meeting’) nature.

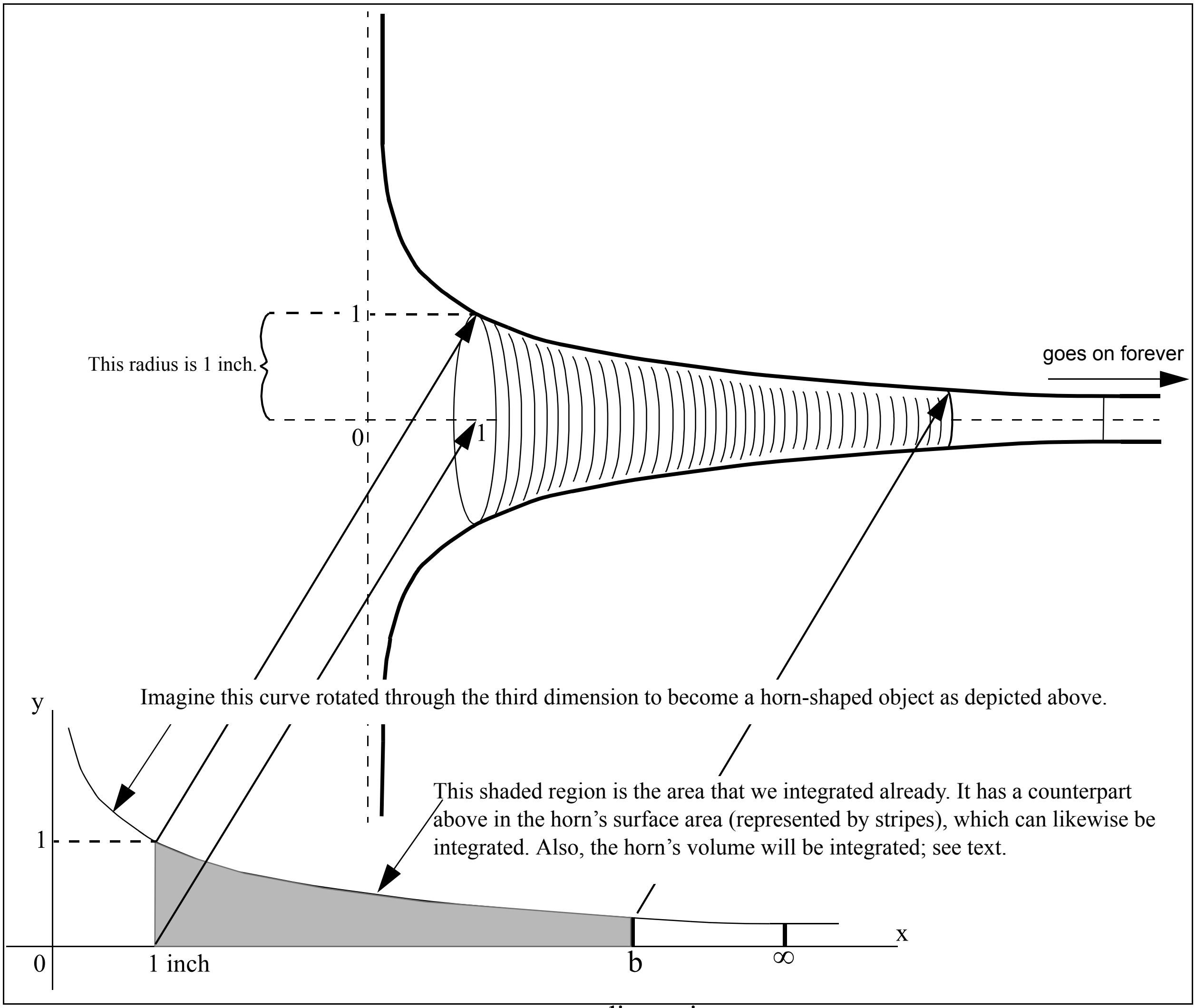


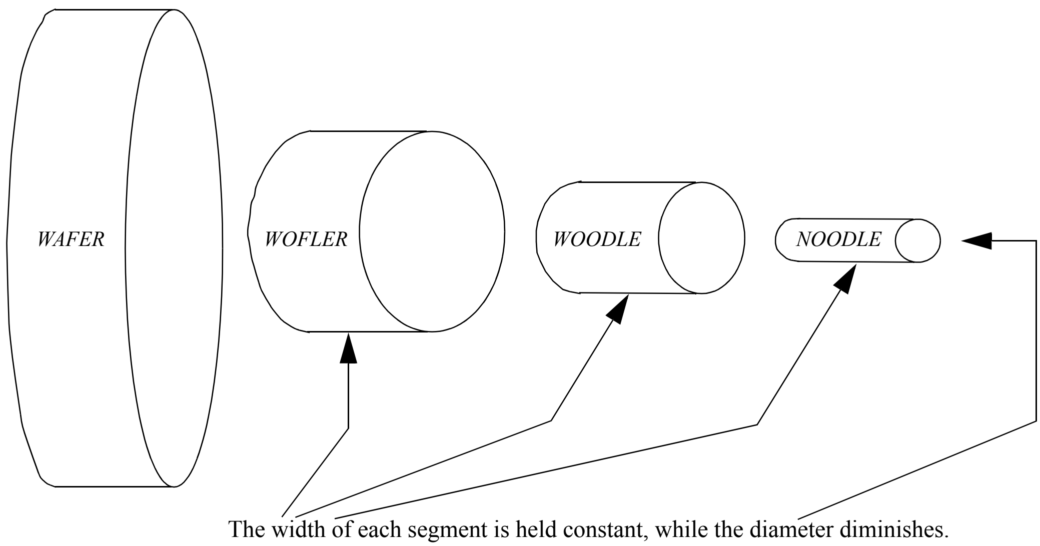
FIGURE 71: Rotation through the third dimension to obtain a solid horn shape

Having formed this picture in our minds of a 3D horn, there are various questions we can ask about it. In particular: What is its surface area? What is its volume?

In **Figure 71**, a simplistic way to relate the 2D shaded area to the horn's surface area (tiger-striped region) is to say that if the former is infinite then the latter must be 'more than infinite'. Or, if I wanted to sound slightly less rustic and make an actual guesstimate, I could say the horn's surface area must be about six times that of the 2D shaded area, which is to say 'six infinities'. (The factor 'times six' we obtain by analogy with the ratio of a cylinder's surface area to the area of its half-silhouette, which works out to $2\pi{:}1 \approx 6{:}1$.(Using this shortcut, we have calculated a *surface of revolution*, but with limited use of calculus methods.)

In short, turning the surface of this object blue would require some six infinities of blue paint. Not sure how many gallons that would work out to, but it sounds like a lot.

Now for the other question: How much paint needs to be poured into the interior of the horn to ‘fill it completely’?(88) For this part of the calculation, we’ll employ the concept of a *rotated solid*, whose volume one may discover by the *disk method*, illustrated in part by **Figure 72**.



Here we rethink Gabriel’s horn as an endless train of disks of uniform width but diminishing diameter, until they are virtually all width and no diameter, having morphed from ‘wafers’ into ‘noodles’.

After devising this scheme as a visual aid, I was amused to see that one Julian Fleron, Assistant Professor of Mathematics at Westfield State College, had published a “Gabriel’s Wedding Cake” version of the integration, with a similar graphic (a five-tiered cake, where I use a four-part wafer/noodle) and similar motivation. It appears in *The College Mathematics Journal*, Jan 1999, Vol 30, No. 1, pp. 35-58.

Optical illusion: Due in part to an optical illusion and in part to my amateur draftsmanship, the four sample objects may seem to have varying widths (or sideways cylindrical ‘heights’ if you like), but with a ruler you can confirm that the widths are uniform.

FIGURE 72: The disk method: Or how to turn a wafer into a noodle

88. Hold that thought, as they say. In Part II, the phrase ‘fill it completely’ will reappear as the punch line.

We imagine the horn sliced into uniform disks of varying radius, beginning with radius = 1 for the largest one (since the value of y is 1 for the point x = 1, our semi-arbitrary 'beginning of the horn'). The area of the circular face of any such disk is $A = \pi r^2$, or, translated to the terms of **Figure 70** and **Figure 71**, $A = \pi y^2$. This is to say $A = \pi(1/x)^2$ after we've substituted the function '1/x' for 'y'. (But since $1^2 = 1$, our area formula in its final form, inside EQ 4, will be $1/x^2$ instead, just to look cleaner.) Meanwhile, the width of a given disk can be represented abstractly as Δx, which becomes *dx* for the integration that will reveal (...drum roll...) the total volume of our notional solid as:

$$V = \pi\int_1^{\infty}\frac{1}{x^2}dx = \pi\bullet 1 = \pi \qquad \text{(EQ 4)}$$

Lest the non-math major think '*V*' in EQ 4 stands for *Voodoo* instead of *Volume*, I've provided an expanded version below as EQ 5, showing some of the intermediate steps that take us from 1 to π. As before, we employ the device of letting *b* serve as proxy for infinity, where *b* means 'any big number you care to plug into the equation':[89]

$$V = \pi\int_1^{\infty}x^{-2}dx \approx \pi\frac{x^{-1}}{-1}\Bigg|_1^b = (-\pi)b^{-1} - (-\pi 1^{-1}) = \pi\left(\frac{1}{1}\right) - \pi\left(\frac{1}{b}\right) = \pi - \pi(0) = \pi \qquad \text{(EQ 5)}$$

In words, "The volume of the horn, measured from 1 to *b*, is equal to[90] *pi* cubic inches."

Let's also look at some intermediate calculations of the horn's volume. For ease of comparison, in assigning values to '*b*' I use the same four arbitrary sampling points that we used earlier for the flat, 2D area calculations:

At b = 10 inches, the volume thus far along the x-axis is (9/10) π or 2.8 cu in.

At b = 90, the volume thus far is (89/90) π or 3.1 cu in.

At b = 900, the volume thus far is (899/900) π or 3.14 cu in.

At b = 9,000,000,000, the volume thus far is 3.14159 cu in.

This time the tapering off of the horn is having a dramatically different influence on the numbers: It is causing the volume to get 'stuck' for eternity just shy of π. So, "while the amount of paint required to *coat* the vessel's surface is astronomical (in the long run), the

89. The tall vertical bar in EQ 5 is shorthand for: "Assign to x the top value [b in this case], then assign to x the bottom value [1 in this case), then subtract the two resultant evaluations of the expression to the left of the vertical bar, one from the other." Which is what we see happening after the four ensuing equal signs, where the calculations are all algebra, not calculus per se.

90. By mindless *convention* we say 'equal to' at this juncture. But that's the kind of nonsense that makes a mockery of the whole notion of Limits; see Part 2.

amount required to *fill* it will never go much beyond a modest 3.14 cubic inches." (This was the motivation for appending the word 'inch' to the '1' label early on, so that we would wind up here with a tangible amount, easy to particularize: roughly the volume of a coffee cup.)

In math jargon, our first series was 'divergent' and 'infinite' while this second series is 'convergent' and 'finite', trapped forever just beneath the π ceiling, as it were.(91)

We'll conclude Part I with a graphic of the convergence to π, flattened out as a 2D picture:

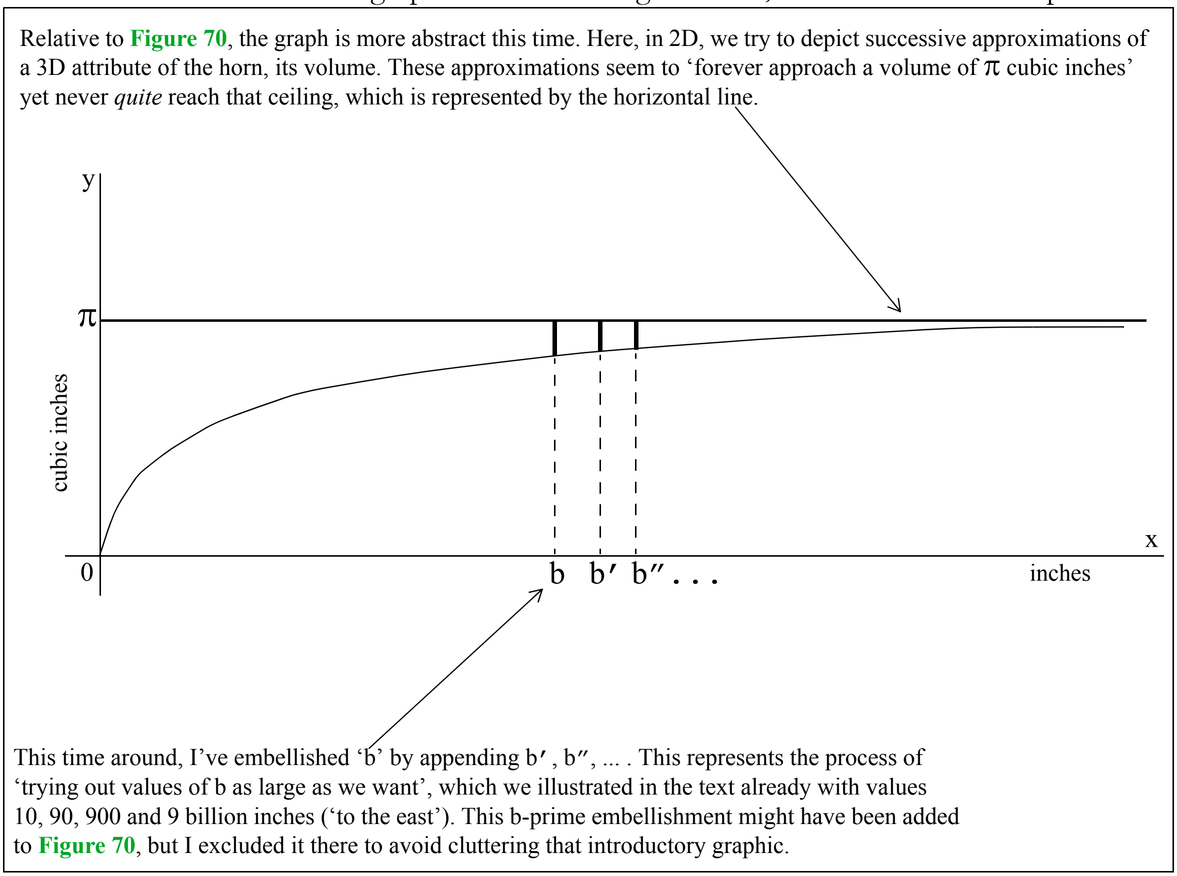


FIGURE 73: Picture of a Conventional 'Convergence to Pi' [SIC]

As before, the x-axis indicates 'how many inches out am I on the skinny part of the horn?' Meanwhile, the y-axis tracks the corresponding volume in cubic inches. Note that in labeling one point 'π' on this graph (or another point as '∞' in **Figure 70**), we anticipate what will typically be discovered only *after* one has worked through the b, b′ , b″... discovery process.

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91. As we near the end of Part I, I must bite my tongue to avoid remarking on the terms 'divergent' and 'convergent'. These concepts and terms lead to a world that is something like Alice in Wonderland (in the pejorative, metaphorical sense of something slightly dysfunctional or pathological) yet worse, in a way, because on the surface they all seem so rational and sane. In The Compleat Math-Speak Glossary, the entries for these two terms (on page **261**) will further explain my concern.

Allowing ourselves this kind of anachronism makes for a pretty picture, but there is a price to pay: It obscures the flavor of the guess-and-confirm process that typically leads up to such a picture. (In this regard, a better label on the y-axis might have been a noncommittal '3 cu in' or '4 cu in', but I decided to show it the conventional way, as if we already 'knew where we were going', right into the neighborhood of π.) This concludes our exposition of the Gabriel's Horn function. Now for its 'unusual features', some of which are genuine, others chimeric, the fault of the observer.

Part II: Discussion of Gabriel's Horn

Eternal Process or Infinite Thing? Betting on the Wrong Horse

Once upon a time in a faraway land, there lived Queen Mathematica Infinity. One day she peered into the Looking-Glass of Science, and said,

Mirror mirror on the wall, who's *the fairest of them* all*?*

Meantime, Nature, decked out in her finest Robes *of Eternity, knew perfectly well who was the witch and who the princess in woody retreat, biding her time till Motherhood. The saga begins on the Twelfth of Never....*

Is there a substantive difference between the concepts of the eternal and the infinite? The question may seem pointless if one's premise is: " 'eternity' is just a literary term for 'time extended along an infinite x-axis.' " With that approach, one pours eternity into a physical mold and erases any potential difference. If, on the other hand, one were to associate eternity with *processes*, and infinity with *things* (objects), then we would have a genuine contrast that might be worth exploring. In short, the idea would be that 'eternity happens, infinity is'; this is a view that many of us probably lean toward already, although we might not have had occasion to articulate it. And when it came to the GHF, we would then be more inclined to say, 'it's a process that goes on for eternity' (this being just barely conceivable in my opinion), rather than say, 'it's a thing of infinite extent' (which is certainly not conceivable, hence presumptuous). But avoiding the charge of presumptuousness is not the only motivation for favoring eternity over infinity. As suggested by the 'mirror mirror' vignette, who is to say that Eternity isn't in fact The One out there in the woods where it counts? Then it really doesn't matter what is said in the ivory tower. All of that becomes irrelevant overnight. At that moment of epiphany, all those who have been betting on infinity (or wrangling over its definition, or enumerating power sets of Cantor), will realize finally that they've been betting on the wrong horse. I, for one, feel it that way already in my bones: I don't need to see the dead rodent evidence, held up in a small plastic baggie. Infinity for me already has the stench of something dubious, an embarrassing dead-end in intellectual history. Accordingly, in Chapter **V**, I tried already to bring eternity into the discussion, but my efforts there were uncomfortable: Most of the examples I used had a local, earthbound flavor (literally and figuratively: the raindrop falling, the leaves piling up), which made them not conducive to the infinity/eternity debate, except by stretching one's imagination in odd new directions. By contrast, Gabriel's Horn is naturally suited to such treatment. (But its exposition requires more space, hence this appendix.)

It strikes me that one reason Eternity is not part of mathematics might have 'simply' to do with cultural habits: It might go awkwardly into the current notation system.

Or perhaps not. Let's try. As we saw in Part I of this appendix, an infinity is typically surmised with help from the device depicted in **Figure 74**a:

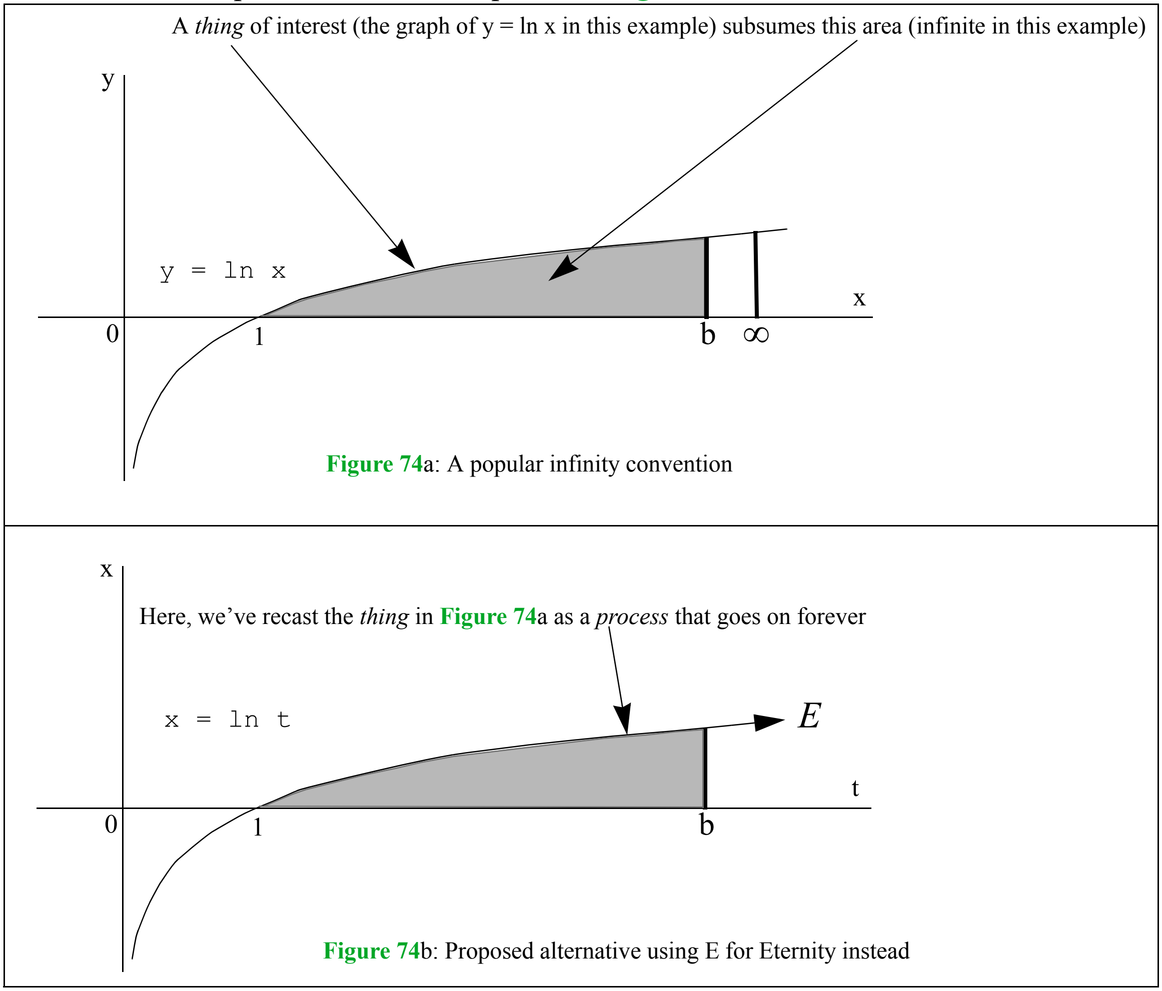


Figure 74a: A popular infinity convention

Figure 74b: Proposed alternative using E for Eternity instead

FIGURE 74: A popular infinity convention and proposed alternative

Here are some of the nitty-gritty details we omitted in Part I: To make such a problem feel concrete, we draw an arbitrary vertical line at the far right and label it '∞'. Next, we draw another arbitrary vertical line somewhere to its left and label it 'b'. Clearly, the whole thing is outrageously 'not to scale', and that's fine: Up to this point, it's more a matter of aesthetics than math — whatever is pleasant to the eye and feels right. The variable 'b' then becomes our proxy for infinity. Meaning, we can try different values of 'b' in the function, assigning values 'as large as we need', to persuade ourselves that we seem to be heading toward infinity or converging on a limit. In Part I we saw the technique used both ways: once to discover a case of divergence (to ∞), illustrated by **Figure 70**, and once to discover a case of convergence (to π), illustrated by **Figure 73**. It seems almost unnecessary to add that the scheme is elegant, beautiful, deceptively simple, powerful and time-tested. I think it exemplifies mathematics at its best: using terse, elegant symbols to swiftly reveal something that at first seems unknowable. But for all that, the scheme is also wrongheaded in that it poses, implicitly, the following dumb question: "What happens *when* the train pulls in, *to* Infinity Station (or *to* ∏ Station)?" A better question would be: "What happens *as* the train glides on, *for* Eternity?" (or "How does the train behave *as* it hovers, Zeno-style, *in* the atomic-scale neighborhood *of* Pi?") To me, these differences are anything but trivial. So no, I'm not here today to sing the praises of mathematics; rather, my purpose is to seek better ways of thinking, a reformulation from first principles. For example (if only the incentive were present!), wouldn't it be just as easy to devise a notation for representing eternity instead of infinity? Consider **Figure 74**b, for instance.

There's no law against using such labels as I've 'daringly' applied in **Figure 74**b: in lieu of 'x' we have 't' so that time can have an identity of its own,[92] independent of space; and in lieu of '∞', we have 'E', no longer anchored to a specific point on the horizontal axis but floating freely above that axis, to suggest an open-ended process. The device of using variable 'b' survives from **Figure 74**a, but now its role changes slightly: Here I intend it as the proxy for some physical aspect *of* an eternal *process*, no longer proxy for a *thing* in its *totality*.

Trying this notation scheme will not turn you into a frog, I promise. It's just that the above is academically 'rude' or 'inappropriate' or 'simply not done', as though one had begun drinking soup directly from his bowl, rather than sip it with a spoon. This concludes my pitch *for* adding 'E' (or its functional equivalent) to one's notation repertoire. For more perspective on the arguments *against* extending the '∞' tradition, please refer to The Compleat Math-Speak Glossary below (page **259**f.), where this discussion is continued, indirectly, via certain entries in the table.

92. Using 't' as the fourth dimension (as implied by **Figure 74**b) is well established, but allowing 'E' for 'eternity' into the mix — that's the blooper, the *cultural* faux pas. But I would argue that it is not an *intellectual* faux pas.

Twenty Degrees of Separation: Raising Atomic-scale Awareness through a Pair of Thought Experiments: *Paint the Whole Horn* and *Watch the Koch Machine*

In various 'popular' presentations of Gabriel's Horn, its presumed paradoxical aspect is dramatized by an image involving paint: We are invited to imagine what happens if we try to paint its entire surface area and also fill it up with paint. The paint needed for the former step will need to be measured out in illimitable oceans, yet the latter step requires only a cup of paint. In this approach, we are taking on faith the results of integration (an infinity of square inches for the first case; π cubic inches for the second case, roughly one cup) seen already in Part I. Thus a sort of paradox to end all paradoxes is born.

But suppose one objects on principle to the terms 'infinite' and the 'finite' being (mis)used that way, because in fact the so-called horn is really a process that never stops. Or suppose one would prefer a demonstration that didn't involve (hide behind?) so much calculus. Are there other, more transparent ways to proceed? Indeed there are! We can make a 'roll-your-own-paradox' by stopping at some intermediate point along the way, then switching to algebra instead of calculus. Here are some details of how that might work:

Even though the process itself never stops, we can *imagine* that it stops at some arbitrary point by fiat, say at b = 9,000,000,000. That's perfectly legal.

For the test value b = 9,000,000,000, we saw (on page **239**) that the shaded area in **Figure 70** is calculated to be 22.9 square inches. Next we'll assign an arbitrary thickness to the paint to make it more realistic — say 0.1 inch. Then 22.9 square inches times 0.1 inches = 2.29 cubic inches. That's the quantity of (3D) paint needed to cover the (2D) area. Next, to extrapolate from **Figure 70** to the horn itself as portrayed in **Figure 71**, we can reuse our cylinder/half-silhouette technique (from page **241**). Thus we should multiply by a (dimensionless) factor of 2π, or approximately 6:

$$2.29 * 6 \approx 14 \text{ cubic inches of paint}$$

By our back-of-the-envelope calculation, that's the quantity needed to coat the surface of the horn out to b = 9,000,000,000, i.e., some nine billion inches off the right-hand edge of the paper. (Note that throughout this sequence we're using cubic inches where you might have expected square inches. The idea is to account for the thickness of the paint being applied to the area in question: From a distance, it seems like a 2D problem, but up close, it turns into a 3D problem. Why? Because that's how I choose to construct this variation on the theme: with a certain nod to 'realism'.)

Meanwhile, the quantity needed to fill the horn out to that same point (where b = 9,000,000,000) would be only 3.14159 (as calculated in Part I), still a mite shy of π, and predicted to stay less than π forever.

So far so good. The story is shaping up nicely in down-to-earth terms, expressed in quantities of paint that we can easily visualize: roughly 14 cu in versus 3 cu in. A samovar versus a tea cup? Something like that. Let's take a moment to try applying those numbers to a household funnel in the kitchen or garage. Suppose there is a certain funnel whose capacity I know to be 3 cu in., but my grade-school child claims s/he used up 14 cu in of paint to decorate it on the outside. I would be skeptical of that claim.

Why?

Most likely it's not that I have some specific equation in mind that relates the volume of a funnel to its surface area (like that business about ants and elephants and volume-to-surface-area ratios I was supposed to learn in biology). Rather, commonsense tells me, "*That* much paint for *this* funnel? Not possible!"

Back to Gabriel's Horn: By arbitrarily halting the process *down here* in its tracks, as it were, we've managed to obtain a paradoxical-seeming result, with the numbers 14 and 3 falling out of the rough calculation. We didn't need to feign an understanding of its ultimate state, *up there* beyond the clouds in the realm of ∞ or E. We're happy about all that, but...

Our reason for thinking '∞ versus π' looks odd seems too similar to our reason for thinking '14 versus 3' looks odd (here or in the kitchen/garage example): In all cases, it's a psychological reaction, the voice of commonsense. But can our commonsense be successfully extrapolated to something with such a peculiar shape as Gabriel's Horn, all the way out to b = 9,000,000,000 inches, never mind infinity? That's the nagging question that arises — does commonsense still hold out there?

In an effort to find out, we start to wonder about certain details of Gabriel's Horn: What *does* it actually look like at b = 9,000,000,000 inches to the right, and how does one apply a coat of paint whose thickness one-*tenth* of an inch (our arbitrary assumed value above) to an object whose circumference has shrunk to only a half dozen *nine-billionths* of an inch? And whatever thickness paint I might have chosen for the number-crunching exercise (presumably there are both thin and thick kinds of paint), this dilemma was bound to arise very soon. And the absurdity of this picture should tell us something is fundamentally wrong with the 'paint'-assisted version of the paradox (and this in turn might make us more skeptical of the underlying presumed paradox itself).

Where atomic scale is concerned, the aim in popular books on science is often to persuade us how really *really* small a proton is, relative to a whole hydrogen atom, for instance: "like a golf ball at the center of an airport," someone might write, or "like a grape at the center of a football stadium, whilst the electron spends most of its time where the stadium walls are"; that sort of thing. But here we encounter the opposite lesson: an awareness of how quickly one can find *himself* or *herself* right down there at the atomic scale, as it were, as the result of certain kinds of processes carried out to a logical conclusion. We may not encroach on any grapes, but we'll definitely be within shouting distance of the 'outer' stadium wall, let's say, in the Koch Machine thought experiment to follow, based arbitrarily on the diameter of a carbon atom.

But first, a few final words about paint: Rather than sharpen up the Gabriel's Horn paradox, paint can be used instead to *undo* it by the following logic: I instruct my paint crew as follows: "In order to be suitably matched to the surface it coats, the layer of paint you apply must grow thinner all the time." Thus, the quantity needed to coat the exterior turns out to be identical to the quantity needed for filling a given segment of the horn: the paint on the surface keeps getting thinner just as the quantity needed for filling the ever-narrowing stem of infinite length keeps diminishing. Since the two quantities diminish in concert, there never was a paradox. Much ado about nothing.

Just kidding! But you see the danger: This whole idea of slopping paint around or watching it dry turns out to be more trouble than it is worth. Eventually, it leads to an error of the apples-and-oranges type: How can *this* paint's thickness be the same as *that* paint's thickness, way out there where our surviving filament of 'horn' is proton-thin? Clearly it cannot be. The 'helpful' image fails. (Yet it appears not only in one of our 'popular' references, Clegg p. 241, but also in one of our text book references: Hughes-Hallett, p. 435, cited earlier.)

Koch's Snowflake and the Koch Machine Thought Experiment

Like π (which some believe is best interpreted as a random number *generator*, i.e., as an eternal *process* and not as an infinitely long *number*, which would be dumb), and like Gabriel's Horn, the Koch Snowflake is best thought of as a *process*, not a *thing*.

Imagine now a 'Koch Machine' that can grow itself like a crystal, progressing to the next level down (in smallness) at a rate of, say, one level per second, click click click. The first three of these 'clicks' I've portrayed in abbreviated form in **Figure 75** (with most of the picture implied, not filled in). Even without crunching the numbers, a glance at this fragmentary sketch of the Koch Machine at work might tell you intuitively that it couldn't endure for more than a dozen seconds, or so, before hitting the wall. By the 'wall', I don't mean we hit the edge of the picture. (To the contrary, it all happens within the confines of a magic circle, so to speak.) Rather, I refer to that place in the progression where the machine would be unable to grow its next crop of baby triangles because it couldn't find particles small enough for use as building blocks in their construction. This 'wall' is metaphorical but it is not fanciful: it's a very real barrier that must be encountered sooner or later.

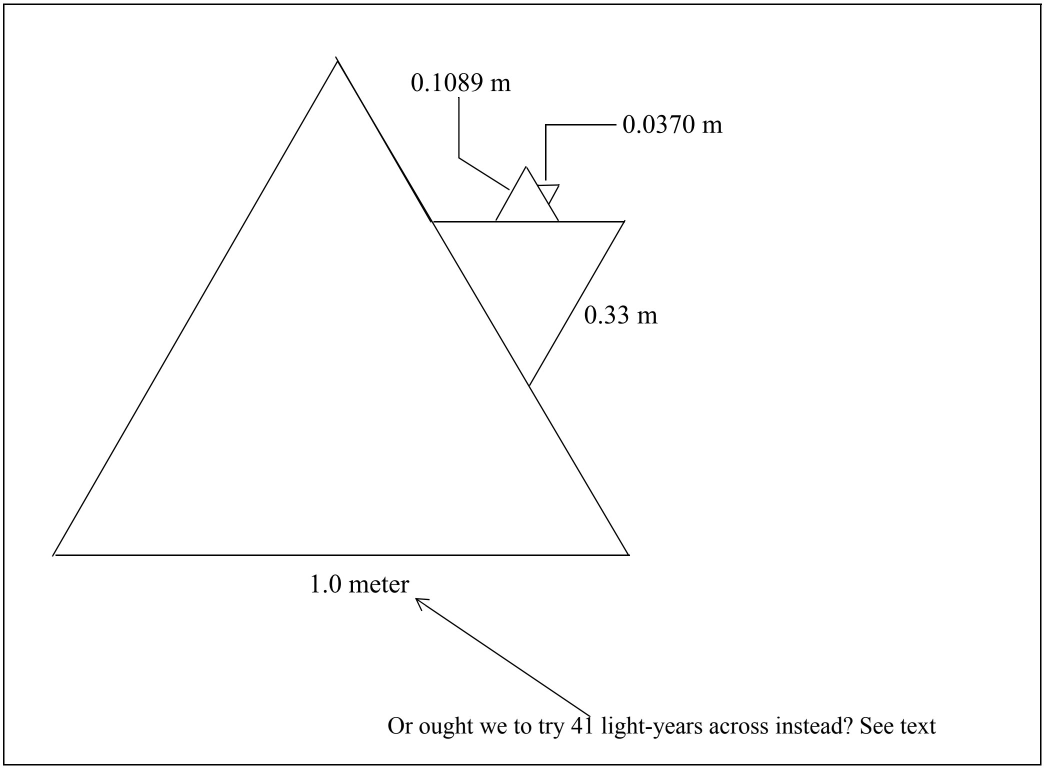


FIGURE 75: A Freeze-Frame Image of the Koch Machine in Action

Details regarding **Figure 75**: We show growth of the snowflake along one side only of three successive triangles. Naturally, the well-oiled Koch Machine would grow triangles on all three sides at once, so that 21 small triangles would be attached to the original large triangle at the moment of this particular 'freeze frame' rather than the three depicted in the figure (the ones with sides of 0.33 m, 0.1089 m, and 0.0370 m respectively). But the rest of our discussion would hold for that busier picture as well. Here I show only the essence of the machine's activity, opting to prune away much of the characteristic 'snowflake' shape.

Assuming the initial equilateral triangle measures 1 meter on a side, by my calculations, on the 20th level down in the snowflake, the Koch Machine will have reached the atomic scale already.(93) There it must come to an ignominious halt: only 20 clicks into it, and it's Game Over. So much for one's dream of infinity or eternity. Quite the anticlimax! (An aside: Presumably with nanotechnology one could actually build this critter and see it fail as just described.)

A Necessary Detour. Here we'll take a quick look at some *positive* implications of the Koch Machine's having halted so soon. The number 20 tells you that between you and any atom, there are only Twenty Degrees of Separation, by rough analogy with the film title, *Six Degrees of Separation*. Given that we are often told it is virtually impossible to have a visceral, intuitive understanding of objects down at the atomic scale, and given that I believe atoms are, however, the Only Game in Town(94), the number 20 is a very happy result. It suggests that the conventional view is unduly pessimistic. There *are* ways of 'communing' with something on the atomic level — just barely. Admittedly, this is tangential to the main topic of this appendix, but it had to be pointed out in passing, given the content and message of the book to which this appendix is attached, that message being: Wake up and realize that it's *all* about atoms; nothing else is real!

Back to the Koch Machine which crashed and burned already. What to do? Personally, I have no sentimental attachment to the Koch Snowflake. But for those who care, my suggestion would be to think a bit more boldly: Let the first triangle measure, say, 41 light-years on a side, instead of a measly meter as depicted in **Figure 75**. *Then* could we garner a vague notion of 'how eternity feels'? One can always hope. (Or, one could ignore the physical world and let the machine keep

93. To define 'atomic scale', take the following as an arbitrarily point of reference: the carbon atom's diameter, which is 2 * 77 picometers = 154 pm (as given in Kotz, p. 306 for example). Now set $1.0\text{m} * (1/3)^n$ = atomic diameter, which is to say $1.0\text{m} * (1/3)^n = 154$ pm, and solve for *n* to see how many iterations of Koch are needed to get all the way down to the 'sub-sub-basement'. But first, we need to take the log of both sides, and by the Log Law where 'log $[(1/3)^n]$' equates to 'n log (1/3)', perform a substitution: 1.0m * n log (1/3) = log [.000000000154m] From here on it's all arithmetic, as we solve the following for n:
1.0m * n(–0.4771) = –9.8124 n = –9.8124 / –0.4771 = 20.566.
Check: $(1/3)^{20.566} = 1.54 \times 10^{-10} = 154 \times 10^{-12}$ m or **154 pm**, which is where we began, with the diameter of a carbon atom. Now it is safe to round 20.566 off to **20.**

94. See main body of text, passim, but especially those subsections of the experiment called 'Avogadro's Number via Electrolysis' devoted to making scales, where the aim is get our hands dirty and 'make atoms real' (page 57).

doing its thing many notional layers *beneath* the subatomic scale. But most of us would find that image less appealing than the cosmic Koch arrangement just proposed.)

The Koch Snowflake as two-dimensional analogue to Gabriel's 3D Horn

Except for the quasi-juxtaposition of Koch's Snowflake and Gabriel's Horn in Clegg (pp. 231 and 240), the following idea would not have occurred to me: but when I look at the full-fledged Koch's Snowflake inscribed *in a circle* (Clegg p. 231), I find it easy to picture it as an Escheresque contraption, a kind of 2D sister to Gabriel's Horn, yanked inside-out and flattened as in a cartoon. Nothing earth-shaking *there*, just a fun image. However, on a more somber note, there is also *this* to take away from the Koch/Gabriel parallelism: Gabriel's Horn, if actually built (ha-ha), would encounter exactly the kind of scaling-down problem described above, hitting the wall early on, long before one had a chance to contemplate its playing out, in either an 'eternal' or 'infinite' manner. In fact, the deeper we get into this morass, the more it reminds me of that business about "How many angels can you fit on the head of a pin?" Not a good place to be.

Paradox Taxonomy and the Punch Line

As a point of reference, we begin with three Webster's definitions of paradox:

[i] A statement that is seemingly contradictory or opposed to common sense and yet is perhaps true.

[ii] A self-contradictory statement that at first seems true.

[iii] An argument that apparently derives self-contradictory conclusions by valid deduction from acceptable premises.

In our own context, I don't find those legally-tinctured dictionary definitions especially useful, so I've devised a few labels of my own for sorting out putative paradoxes. These will just be 'tags'; only the two flavors that I call 'Contemplative' and 'Challenge' are meant to be mutually exclusive.

Linguistic Paradoxes

This would be a paradox resulting from uses of the English language that are either [a] flawed (i.e., illogical or ignorant of the meanings of the words employed), or [b] excessively jargon-y, thus floating in a sort of self-induced haze.

When I first encountered the Gabriel's Horn Paradox several years back, my first suspicion was that it might be a Linguistic Paradox of type [b], turning on the words 'finite' and 'infinite' as insidiously bent to the 'professional' needs and fetishes of the Mathematics Priesthood. I still see a grain of truth in that angle, but it doesn't quite work as a primary line of attack because of the following subtlety: While it is true that the Priesthood maintains an abusive relation with those two words (see the pertinent entries in The Compleat Math-Speak Glossary below), it is not true that the Priesthood refers to the Gabriel's Horn function *as* a 'paradox' (at least in the calculus text books we surveyed in Part I we found no such case; to the contrary, a kind of quiet coyness or prudence about the elephant in the room). Therefore, disposing of the Gabriel's Horn *paradox* by classifying it as 'Linguistic' results in a hollow victory. No satisfaction there. (I'll try to make this point clearer in a moment.)

Contemplative Paradoxes

I believe it is fair to say that Koch's Snowflake provides us with a 'contemplative' type of paradox. There is nothing to debunk, no manipulation of logic to expose. No confrontational flavor. Rather, the snowflake simply *is*, in the way that the Mandelbrot Set *is* and the Coast of Norway *is*. So we look at it and wonder. (Except, as detailed above, there are ways to make the snowflake quickly 'fail' in its aspiration to be eternal, if one starts with too modest a scale, such as one meter on a side. By cold logic, a *physical* implementation of the Koch Snowflake can aspire to being eternal only if it begins with a triangle that measures infinity on one side. That's not paradoxical. That just makes your head hurt.)

Challenge Paradoxes

By contrast with Koch's Snowflake, the Zeno paradoxes challenge us and demand some sort of response: Does the arrow fly (or only freeze-frame)? Do we reach the wall or not? Where is the logical fallacy or 'illegal step' that will help us demystify the paradox? Likewise, an Escher stairway that seems to take its lizards both up and down in space would seem to fit this category. Likewise Gabriel's Horn, when it is spun as being 'both finite and infinite at once'.

So, *is* Gabriel's Horn a genuine paradox, or is it a case of: "This is just what the numbers do, so deal with it"?

No, it is not a paradox. I.e., I regard it as a 'challenge paradox' with an answer. It's a case of: "This is just what the numbers do. There is no mystery." Though there is the potential to produce good doses of puzzlement in the observer.

The punch line turns out to be: 'fill it completely'.

In Part I (on page 242), I used that phrase in an innocent-seeming role, as a loose metaphor for integrating a rotated solid to find its volume. It was just for adding variety to our exposition of the Gabriel's Horn *function*, not the paradox. The phrase is also used in popular accounts of the Gabriel's Horn paradox. But by now I hope I've persuaded the reader that it is more reasonable to think of Gabriel's Horn as a process than as a thing. And if it is a process in motion, lasting forever, how may one claim it is completely full, given that it is a moving target, so to speak? This line of questioning does not debunk the paradox per se, but it reveals a chink in the armor. It's a sign that all is not well, when we see the dubious claim of 'filled completely' scotch-taped to the castle wall. Note also that this is where we realize the concept of eternity is not just someone's fetish (mine, for instance, admittedly) but also a key ingredient in the correct formulation of the problem: So long as the horn is envisioned as a fixed, infinite *thing*, it may not seem entirely outlandish to play at 'filling it completely'. But as soon as you remind yourself (or understand for the first time) that this is a *process* growing its way into eternity, then 'fill it completely' is a non sequitur, indeed a laugh-out-loud absurdity.

Backing up a bit: How does the *non*-mathematician get this notion that he should 'fill it completely'? Because the *mathematician* (dealing only with the function, not typically the paradox per se), uses the term 'converge to a finite value, π'. That's how. And while appearing more sane and dignified than 'fill this growing process completely', the mathematician's verbiage is no less bizarre and symptomatic of sloppy thinking. Ultimately, it's the mathematician's version that must be blamed indirectly for the 'crime' of the paradox, even though the paradox makes most of its appearances 'in town', far beyond the walls of the ivory tower. (In this way, we have something like the link between a Mafia boss in the suburbs and one of his hit men downtown. Difficult to demonstrate, but you know with *certainty* that the link is there: Someone got hit; something spawned a paradox.)

Now for the disparity in quantities, which is the primary challenge to address. In that connection, let's revisit **Figure 72** on page 242. Like 'fill it completely', this was a visual aid to illustrate our integration of the horn's volume. In a note to the graphic, I remarked on the optical illusion whereby the widths of successive segments seem to increase when in fact I know I drew each of them as a copy of the same line (one that measures approximately 17 mm on the page). As it happens, we can now use the picture for a second purpose: To shed light on the paradox itself, by way of the optical illusion. Look at pairs of adjacent objects: wafers 1 and 2, wafers 2 and 3, wafers 3 and 4, or rather 'noodles' 3 and 4. In studying each such pair in isolation, the eye is trying to tell a story. The (valiantly *attempted*) story or fairy-tale is always the same, and it goes something like this: "The mass stayed the same, but the shape changed by stretching this doughlike substance out to the right." It's this 'stretched dough' assumption at the subconscious level that translates into a conscious notion that 'the width must be increasing'. But the linked assumptions of constant mass and increasing width are both wrong. The mass does not stay the same; to the contrary, it diminishes rapidly. Nor does the width increase; in fact, it is precisely the width that is the unvarying anchor. Once this mini-paradox begins to reveal itself, it becomes easier to see why the surface area in the main paradox outpaces the volume to such an extent. The one relentlessly multiplies, simply because 'it keeps on going', while the other tapers off so rapidly that it threatens to vanish. This is what I meant by saying, "This is just what the numbers do; there is no mystery." (And presumably it is this perspective that permits Salas, quoted on page 238 above, to say, "it *may* surprise you *somewhat*" [my italics] rather than "this is an astonishing paradox we've got here!")

On a technicality, then, mathematics escapes the charge of 'committing a paradox'. That great establishment is 'too good' to deal with such, even though as mentioned earlier it may still be the source of the tools used by others to cobble one together. In The Compleat Math-Speak Glossary, next, we can see those tools in context, as it were, meaning: on lurid display with all their associated brother and sister tools-of-the-trade. Not a pretty picture. As the Chinese say, `tíxiào-jiēfēi` 'cry laugh, both wrong', i.e., one doesn't know whether to laugh or cry.

The Compleat Math-Speak Glossary (MSG) compiled by Captain Flea-Hop of the Flash Infinity Spaceliner

Note: The following table is sequenced by a logical grouping of its terms in Column 1, not by a mechanized (alpha sort) routine.

TERM OR SYMBOL	ITS MEANING	MOTIVATION / REMARKS
approximate	Used for *'precise'*, as in "Yes, that answer is precise, with so many unsightly decimals straggling across the page; so I'll call it 'approximate' just to let it know how much I detest its hideousness, its failure to please Queen Mathematics. So there!"	Math-speak always means kinda the opposite of what you think. Thus, 'approximate' means 'precise'. Say it a few times until you're comfortable: 'approximate' (precise); 'approximate' (precise). See? Not so bad.
exact	*Rounded off* presumptuously to obtain a proxy symbol for something humans can't possibly comprehend but which Mathematics wishes to convey as something that *is* understood (π for example is 'exact'), and/or something one wishes to elevate to quasi-mystical or fabled status (**e** and ∞ come readily to mind, but **i** is not 'exact'; see below). (Meanwhile the actual processes in question live on, and their encapsulation in symbols is a lie and a distraction for anyone interested in knowing what really goes on in the universe: something messy.)	Similarly, 'exact' means 'approximated, rounded off'; the opposite of what it sounds like. Right where the whole business becomes most tedious and unruly, *that's* where the Mathematical Priest invokes a symbol such as ∞ or π to bestow upon the proceedings a paternalistic sense of Control and Reason and Tidiness and Closure. (But India has outfoxed them at their own game, with a wondrous phrase to make them scratch their heads: "Approximately and Exactly, sir!" See page 167.)
Limit	[1] A *Value Never Reached* (not **ever**, except see [2], next:) [2] A place where I can go if I damned well please: A *Value to which I Flea-Hop*.(1) Ha!	[1] The Limit is our religion, and we mathematicians are so-o-o cagey in its description... [2] ...except ultimately we're all just the whores of the Engineering Department.

TERM OR SYMBOL	ITS MEANING	MOTIVATION / REMARKS
∞	Kinda like the mirror image of a Limit. This is a *Hugeness Never Reached*. The implication is: "I *wanted* to find a Limit but couldn't. And to give you the particular flavor of how I failed to find a Limit, I'll going with ∞, but don't take this too seriously. It means nothing, really. Just another way of saying DNE, Does Not Exist." [Actually, Stewart's calculus text book is one of my favorites, but still I couldn't resist using his excruciatingly detailed explanation of what ∞ *isn't* as my source for the verbiage appearing above in this cell. By the vagaries of editing, the Stewart original wound up in the adjacent cell, where one may compare it directly.]	Is infinity a mere 'potentiality' (a notion that traces back to Aristotle, alive and well today)? Or are infinities real and burgeoning like rabbits (as suggested by Cantor, following in the footsteps of Galileo)? This is not a burning issue for me, since I say a pox on all their houses and let's replace infinity by eternity. But for the sake of completeness I mention this 'political aspect', as Wallace calls it. So, here are three examples of the assertion that '∞ does *not* represent a number' (which seems to hark back Aristotle's 'potentiality'). The first two passages quoted below take the following limit as their point of reference: $\lim_{x \to 0} 1/x^2 = \infty$, which can be generalized as: $\lim_{x \to a} f(x) = \infty$. 1. Hughes-Hallett, p. 53: "The symbol ∞ does not represent a number." 2. Stewart, p. 79: "This does not mean that we are regarding ∞ as a number. Nor does it mean that the limit exists. It simply expresses the particular way in which the limit does not exist: $1/x^2$ can be made as large as we like by taking x close enough to 0." 3. Salas, p. 204: "To say that as x--> ∞, f(x) --> ∞ is to say that, *as x increases without bound, f(x) becomes arbitrarily large*." (his italics) My comment on quotations 1, 2 and 3, immediately above: These three text book authors are clear regarding ∞ as a function's [*un*]limit, let's say. But all such authors that I've encountered throw their fastidious definitions to the wind when it comes to the chapter on Improper Integrals, where suddenly it is fine to state blithely, for instance, that: "the region below the graph of $f(x) = 1/x$, $x >= 1$ *has infinite area* " (Salas, p. 603, my italics). Here it would seem that infinity has suddenly been given the status of something *real*, no longer in the shade as "only a manner of speaking" (Gauss, cited in Clegg, p. 78). Now, isn't all this madness enough reason on its own to flee from Infinity into the arms of Eternity, and never mind all the other arguments I've tried to make?

TERM OR SYMBOL	ITS MEANING	MOTIVATION / REMARKS
finite	Now we're talkin'! This refers to an integration result for a function that properly converges. But 'converge' doesn't mean 'converge', of course, so look there next.	The math equivalent of a Happy Meal. This indicates that a Mathematical Happy Event has recently transpired somewhere on the page.
infinite	The term 'infinite' denotes 'the opposite of finite', that's all. It just means something *failed* to 'converge'. (Note that this has little to do with '∞', and recall that, in any event, "∞ does not represent a number!" so why do you care? You're confusing me.)	Not so awe-inspiring as the symbol '∞', but still impressive enough to keep those students on their toes.
converge	To approach very closely and *not* converge (repeat *not* converge *ever*) on a value. But it makes us so *happy* that we call it 'converge' anyway. The point being that it's so much better than *di*-verging. PLUS, it sets us up for the possibility of cheating later, with a good old flea-hop-onto-the-Limit (see entry for Limit)	Used in defining of 'finite' above, which is odd since the two terms seem nearly redundant. But maybe 'convergent' sounds marginally cooler? So in that case the two terms would not be *quite* redundant.
diverge	It did *not converge* (alack and alas), so that's why we say 'diverge', to indicate negation, see? But don't think for a moment this *means* 'diverge'. You and I both know there's nothing to diverge *from*, so you pose a silly question.	Similarly, the term 'divergent' seems almost redundant with 'infinite', but again, 'diverge' sounds perhaps cooler to say? (Try it: "finite, infinite, finite, infinite..." vs "converge, diverge, converge, diverge..." and see for yourself which is cooler. I vote for 'converge, diverge' even though the two terms don't mean what they say. But neither do 'finite, infinite' mean what *they* say, so there you go. Maybe Queen Mathematics keeps both pairs of terms swirling around in her toilet bowl together because she knows it's all bullshit anyway, at the end of the day. Time to flush.)
finite/infinite	Two sides of the same wrongheaded coin; a false dichotomy (Question in passing: If there's 'finite' and 'infinite' is there also 'finity' and 'infinity'?)	Sorry, we're not quite done with these two yet. To the practicing mathematician, 'finite' is just a place to flee from 'infinite' and vice versa, so the tendency is to never look at the two *together*. Glance at them side by side (as defined in mathematics), and you see their true colors, as a false dichotomy. It has to be a false *something* because each half of it was founded on a lie: One grows weary of a function that seems to plod too slowly toward infinity, so even though '∞ does not represent a number', one suspends that rule for expedience (it's 5:00 p.m., time for dinner) and calls the result 'infinite'. Similarly, a function is approaching its Limit in too tedious a fashion, so one trashes the idea of Limit and calls the value of the function its Limit (again because it's 5:00 p.m., etc.)

TERM OR SYMBOL	ITS MEANING	MOTIVATION / REMARKS
i	$\sqrt{-1}$ (root minus one)	By academic law, Ye Math-speak Lexicon must contain *one symbol* that doesn't mislead. *This is the one*! Savor the moment. Compare entry for 'inflection point' infra.
inflection point	This is the exact point where a curve ceases its concave-downing action and commences its concave-upping action. Or, the point vice versa.	By law, Ye Math-speak Lexicon must be anchored to *one term* that makes sense. *This is the one*! Savor the moment. Compare the entry for 'i' supra.
concave	Means 'concave', except when it means 'convex', called 'concave down' since otherwise you might think it was 'concave up', i.e., actual concave per the non-math dictionary. Slick, eh?	Motivated by simplicity? Good use of qualifiers 'up' and 'down' to reduce terminology clutter and conform with the little-known Terminology Reduction Act of 1991 (House Bill #314.218).
Aleph-null ($\aleph_0$)	Cantor's parlor game based on the power set concept.[2]	Paradoxically, this takes a finite time to comprehend (about 15 minutes) yet infinite time to explain to the world. Curious.
[Eternity]	--	Verboten ist das Ewigkeit! *Queen* Mathematics does *not* dirty her hands playing with something so *un*scientific sounding as Eternity! This 'isn't done'.

1. For an example of the flea-hop, as I call it, please refer to page **238** above. There we quoted the following from a calculus text book: "In fact, it is π" (in Salas, p. 603, where 'it' happens to be the volume of Gabriel's Horn, although Salas refrains from using that nickname). Now, in *fact*, the volume referred by Salas is a quantity that *never* reaches π. After all, that's the whole point of a limit: to *not* get there. But even Salas, whose book I generally admire very much, falls prey to the pervasive Looking-Glass zeitgeist, according to which, "Limits are limits except when I say they aren't limits." I.e., with his assertion about the volume *being* π, he has performed the dreaded flea-hop, suddenly blurring the line between [a] a function, and [b] its limit. In the eyes of Nature, that flea-hop is a kind of betrayal or blasphemy. Granted, there are other viewpoints to consider: If the flea-hop were *not* a permitted maneuver, the engineer would probably want to slit his/her wrists! For the flea-hop is, after all, a matter of pragmatism. But the ivory tower *mathematician*? What the heck is *he/she* doing teaching this flea-hop game to innocent students? There is no conceivable excuse for the practice, unless math departments everywhere long ago announced to the world that they are just whores of the engineering department. Did I miss the memo?
2. "He argued with himself about all things under heaven with that kind of wrong-headed lucidity which may be observed in some lunatics." Quoted from "An Outpost of Progress" in Samuel Hynes, ed., *The Collected Stories of Joseph Conrad* (1991), p. 59. "The scientists of today think deeply instead of clearly. One must be sane to think clearly, but one can think deeply and be quite insane," attributed to Nikola Tesla, *Modern Mechanics and Inventions* (1934).

Summary

In Chapter **V**, we introduced two processes that play out endlessly (leaves piling up, a rain drop falling). Both ideas come to us *from Nature*, but to complete the thought we have to turn them into thought experiments, requiring that the leaves pile up in an eternal forest and that the rain drop miss the earth and keep on going, so to say. Here in Appendix C, we've focused on two more processes that play out endlessly, but in this case they happen to be *human inventions*, i.e., not 'from Nature': Gabriel's Horn and Koch's Snowflake. Being human artifacts, these might seem relatively unimportant compared to an artifact of Nature. But I think they are worth studying not only for their intrinsic interest but because they are so closely analogous to the 'in Nature' examples, thus providing ways to further illuminate the latter — the ones we deem 'real', not imaginary.

The primary aim of this appendix has been to make the case for eternity as a substitute for infinity, in modeling certain situations in mathematics and the physical sciences. I hope the case was convincing. If not, one found 'value in the journey', I hope, as we had a glimpse of Twenty Degrees of Separation and felt less alienated perhaps from the atomic-scale (the only one that is *essential* to understanding the world, per my pro-atomic bias that colors the main text above).

As for the table that begins on page **259**, if it suggests that the emperor has no clothes, then so be it. I merely document what I see, with no apology for its absurdity.

Appendix D: The Fifty Years' Gibberish: So-Called Information Theory

There's a bit of conventional wisdom that says, "Don't stop to converse with a crazy person on the street-corner, or you'll look crazy too." (In a similar vein, the experimental physicist Larry Sulak once remarked: "...smart people don't put themselves into a situation where they have to understand something which is un-understandable." Quoted in Crease, p. 356.)

Now if we placed together my **Appendix D: The Fifty Years' Gibberish: So-Called Information Theory** and **Appendix E: Theory of Information**, I suppose we would have, in effect, 'a book on information theory'. It's just that I refuse to dignify the topic with something called 'a book'. To devote a book to 'Information Theory' would be to engage that proverbial crazy person on the street-corner in conversation, with dire consequences. Thus, I sneak up on the subject (which maintains a certain kind of limited 'importance' despite its toxicity), by writing hefty appendices in lieu of the literal 'book' once envisioned.

The first and most important thing for me to clarify this:
Our main topic is NOT Claude Shannon's mathematical theory of data communication, which is *also* known as 'Information Theory' (alas). The topic here is what I will call 'so-called Information Theory', a peculiar sort of ancillary non-subject that has lived its ghastly semi-parallel non-life in Liberal Arts for some fifty years already as I write, and simply will not die. The latter is attached like a barnacle to the former, even though logically they should have only a thin and subtle connection to one another.

Before I had immersed myself in the literature on so-called Information Theory, the story of the book-burning in ancient China would always make me feel slightly shocked and ill, whenever I was reminded of it, even though it happened so very long ago — circa 221 B.C. *After* I had absorbed the literature on so-called Information Theory, it became a no-brainer: I understood perfectly why the first emperor, Qín Shǐ Huáng Dì, felt that this was the only way to clear the slate and unite China: burn the books. Yes! I get it. That's how bad this field is.

If you are one who has already had your misgivings about it, you might want to stop here, the take-away being: "Okay, I was right. I think I'll stay away from that." However, if you are one who is immersed in its septic waters already, as I once was, *then* I would say, [1] my condolences, and [2] what follows is *required reading*: Why not spend a few minutes now sorting out some things (that defy sorting out!), rather than spend months or years at some later date trying to do it on your own? (Or, to continue the septic tank analogy: I'll show you how to escape and find a clean ocean instead.)

One way to look at so-called Information Theory is in terms of the 'war on drugs': How much of it is a Supply problem, how much a Demand problem? In the case of so-called Information Theory, the Supply was provided almost single-handedly by Norbert Wiener. On the Demand side, we have the whole Liberal Arts community to thank — and here I've been as guilty as anyone at times. As I write, the year is 2010. But I can remember as if it were yesterday when I first encountered the term 'information theory' and the name 'Norbert Wiener' in Leonard Meyer's *Music, The Arts and Ideas*, on pages 11 and 27 — back in 1967. The mental note was: "Now *that's* a vein to remember and to mine someday." For me, 'someday' turned out to be the period 2003-2005. In fact, one could say that *this* whole volume started out as a book about [so-called] Information Theory. But at a certain point of understanding, I had to admit that the field itself is bogus, for two reasons.

[1] It is rotten at the core because of the Fifty Years' Gibberish, to be reviewed shortly.

[2] Even without *that* mess to wade through, it would be a dubious subject because the universe is an intensely data-*hostile* place. Sure there is *some* data that is grist for the information mill, but in the big picture it must be recognized as an anthropocentric fetish, nothing more, with no bearing on How the Universe Works (or even on How the World Works, for that matter).

To traverse such a broad terrain — educating oneself on the rudiments of data communication theory, educating oneself on the *faux* subject of 'information theory', then coming to see how tiny and unimportant an *actual* theory of information would be — requires a huge expenditure of energy: many words for me to write, and for you to read. Is it worth the journey? I'm not sure, and for that reason I bury these issues in an appendix, and offer the following 'executive road map' to set the tone.

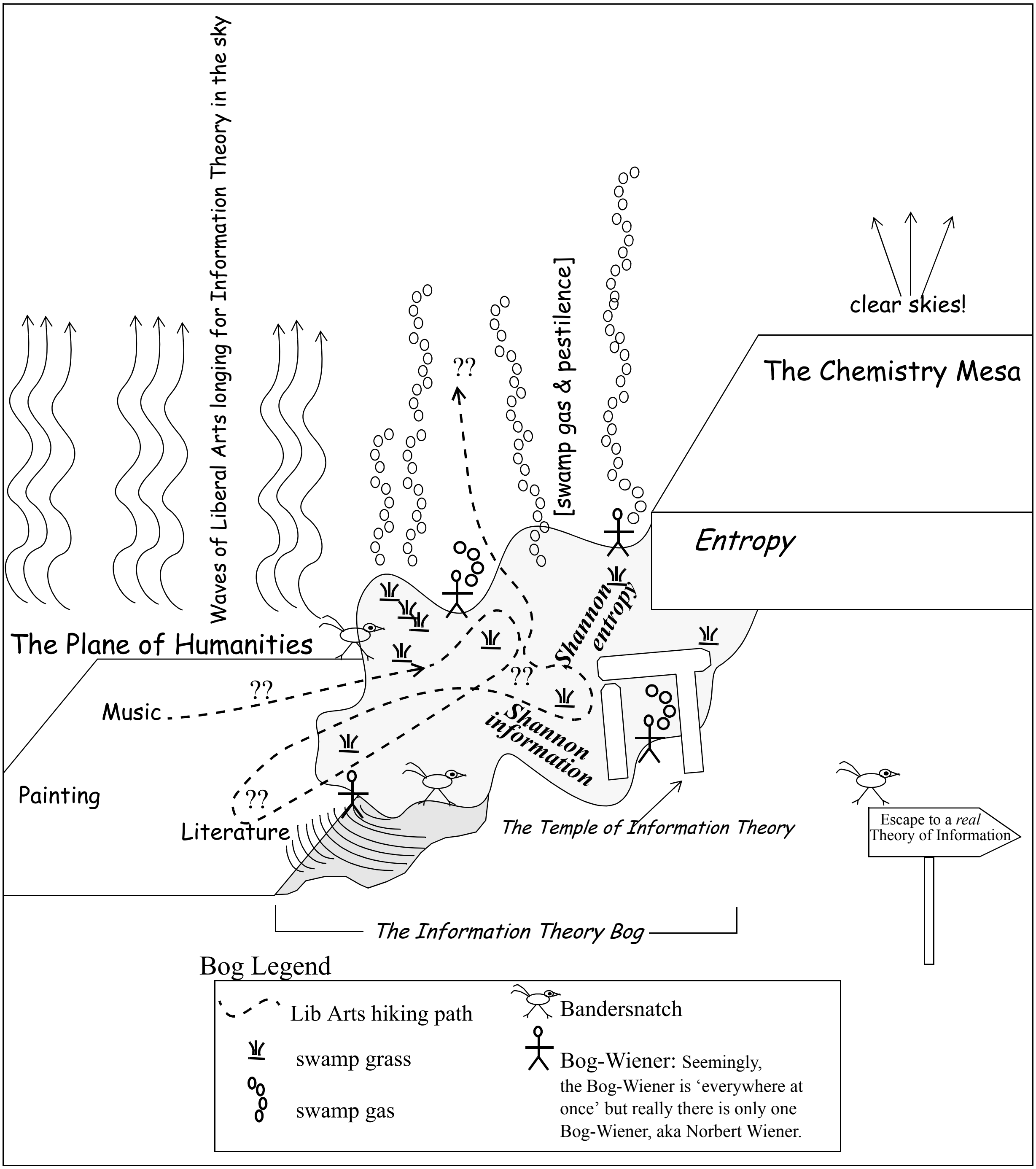


FIGURE 76: Weather Report with mixed message: Misty-Pestilential-Sunny

Figure 76 includes a stick figure identified as the 'Bog-Wiener'. Picture this denizen of the swamp alternately scaring off visitors with his Wunderkind ramblings into higher math, and turning friendly with a bear hug only to fill their ears with whispered nonsense.

Ultimately, Shannon must bear some of the blame as well, for having used the term 'information' loosely and the term 'entropy' unwisely. Mostly we blame Wiener, though, for making *public* and 'understandable' these terms that should have remained safely in Shannon's technical paper as elements in the semi-*private* language of a Bell Labs high priest, not stamped on the forehead of a buffoon at a cocktail party.

In **Figure 76**, the reader might note that while the Bog seems capable of tilting the temple and encroaching upon the Plane of Humanities, it does not sully the Chemistry Mesa. Rather, the Chemistry Mesa sits serenely atop it. Perhaps in a safely nonporous fashion?

Nomenclature

The overall nomenclature scheme for this Appendix (outside of this introductory section) takes the following form, with the four terms on the right supplanting the two on the left:

information → ***DERN (aka Shannon information)***
information → Information

entropy → ***Shannonentropy***
entropy → **Entropy**

FIGURE 77: Nomenclature overview

I will use this form...	...when I (or when the sources I'm referring to) intend the word 'information' in this sense:
DERN (aka Shannon information)	The **D**egree of **E**ncoding **R**ichness **N**eeded by a Signaling Alphabet to handle a given Message Source (in Information Theory, so-called)
Information	A person's knowledge of things or phenomena in the world, obtained from instruction, observation, life experience, aesthetic experience, self-study, or other investigation. In short, the common sense, generic definition of the word, which is very broad — even all-encompassing one might say. This is the object of our Theory of Information. Thus, we formulate the definition in terms of 'a person's knowledge', but couldn't most of this apply equally to a (dynamic) computer system or even to a (static) library or database? Also, out of habit we say '...phenomena in the world', but to retain credibility, a definition such as this one must eventually be extended to cover much more, including the solar system, the universe...

The following is an exception to the above rules: When quoting a classic in Information Theory (or when talking about the overall notation scheme itself in a 'metalanguage' mode), strict application of the convention would be inappropriate and counterproductive; therefore I revert to the plain form: 'information' or 'entropy' (i.e., the left side of **Figure 77**).

In connection with 'information', too, there is actually a 3-way distinction to be aware of, once we've acknowledged the word **δata**(95) as part of the picture. **Figure 78** summarizes this important subset of nomenclature issues:

95. Here I introduce another special typeface, the word 'data' spelled with lower-case delta. This will be used for the remainder of the appendix as a reminder to the reader and to myself that we are trying to buck the trend and make this important word *mean* something consistent!

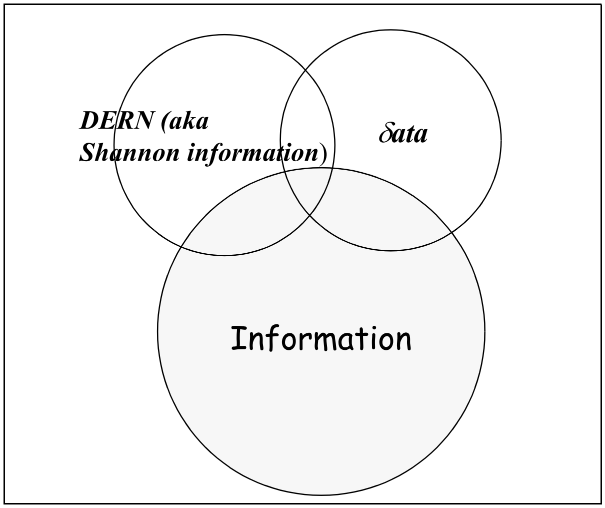


FIGURE 78: Schematic relationship of ***DERN (aka Shannon information)***, Information, and δ**ata**

Two abbreviations play a special role in this appendix (and the next):

- **TI** = **T**heory of **I**nformation.
  The abbreviation **TI** will be our way of referring to the main topic of this appendix, which is *not* 'Information Theory'!
- **TOES** = Theory of the Encoding/decoding of Signals (= Information Theory, so-called, aka Data Communication Theory aka the Mathematical Theory of Communication).
  Henceforth, instead of writing 'Information Theory' I will usually write '**TOES**' instead. This is an intentionally indirect designation, partly with a pedagogical aim (the name is more descriptive of the field) and mainly for the purpose of having a clear label for distinguishing that field from our own, **TI**.

The Idea of a Message Source (Rudiments of Data Communication Theory)

There is no way to approach the pseudo-subject of 'Information Theory' directly. Instead, we must begin with a real topic, Theory of Data Communication, for the sake of creating a context. (But like the skiff in a Buddhist parable, this Theory of Data Communication will ultimately have little to do with our main topic.)

The central idea in **TOES** is the Message Source. A typical Message Source would be English. All of it, I mean: the entire English language.

Or, a Message Source can be very small, so small that one would be inclined to call it a toy Message Source. Since 'the entire English language' is a moving target of mind-bending complexity, one is compelled to use a toy Message Source when trying out or demonstrating a new idea.

*What a Message Source is **NOT** is the speaker on the other end of a telephone connection. It might seem natural to you to regard that person as the 'source' of a 'message' entering your ear. But that would be a dead wrong interpretation of the term 'Message Source' as used in* **TOES**.

Instead, whenever you come across the term 'Message Source' in the literature, unless it has been qualified as being a 'model' (or 'toy' Message Source as I call it), you should assume it is a very *large* Message Source the author is talking about, and immediately translate it in your mind to something like 'the whole human gene pool', or 'the entire English language', or 'the entire history of occidental music'.

Don't **TOES** engineers care about that *one* hypothetical speaker on the other end of a telephone connection? (Isn't Bell Laboratories all about telephones communications between pairs of individuals?!) Yes, they certainly do, but in that circumstance the **TOES** theorist/engineer would regard himself as listening to or analyzing a miniscule *sample of* or *slice of* the great hulking Message Source in the sky. The Message Source is still the star of the show, not the little 'message' that happens to be coming across the telephone connection.

And if words like *sample* and *slice* make you wonder if we haven't entered the realm of statistics, you're absolutely right. **TOES** is best regarded as a specialized branch of Statistics, very far removed from Linguistics and Semantics, for example.

As our first toy Message Source, let's consider the gene pool of a brood of twelve chickens.[96] Here they are milling around in their yard:

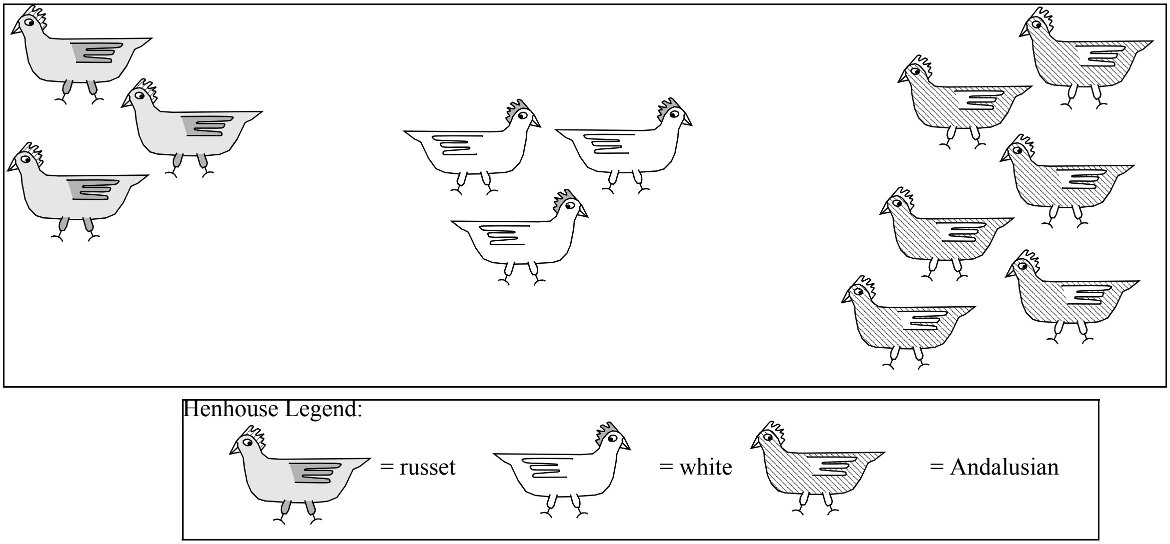


FIGURE 79: A Brood of Twelve

We can represent a sampled 'communication' from the gene pool of the brood, to us, by way of a Mystery Egg that someone found lying in one corner of the hen house:

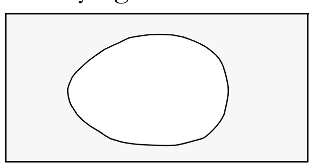


FIGURE 80: The Mystery Egg

What can we say *for sure* about the chick that will hatch from this egg? Nothing. (And we call it a mystery because we don't even know which hen laid it, let's say.) But even without hiring an expensive Statistician or **TOES** theorist to do some hand-waving and analysis of the situation, what *we* can do on our own is look back at **Figure 79** and say something to this effect:

> I see 3 russets, 3 whites and 6 Andalusians in my brood today. That's essentially the same mix I've observed through several generations of this brood. Accordingly, I'll predict the odds of this particular egg as follows: The hatchling that will emerge possesses a ¼ chance of having russet feathers, a ¼ chance of having white feathers, and a ½ chance of being of the Andalusian type, with greyish-blue feathers.

Notice how we understand intuitively, somewhere very deep in our bones, this idea of a gene pool shared by the twelve chickens.

96. Apology to the biologically literate reader: This will be a fanciful brood, based on graphical criteria, not meant to illustrate genuine barnyard genetics.

Curiously, this intuition is NOT readily transferred to the realm of **TOES**. *Here* it is obvious. In *that* realm it becomes obscure.

That's why I've taken you on this little detour within the detour, to the barnyard of all places: I'm I'm hoping to persuade you that you *already* have the concept of 'samples from a Message Source' in your head. The trick is not to lose it as we switch back to **TOES** proper. (From native intuition, none of us would take the Mystery Egg *itself* as the gene pool; we understand that it cannot possibly be anything more than a 'communication' to us that tells us something *about* the gene pool that resides in the brood of twelve chickens *collectively*. Nor would we claim that one russet chicken possessed, *as* a macroscopic entity, its own *separate* Poultry Plumage Probability Profile. But as we shall see later in this appendix, there are those who would take a single poem and apply **TOES** to it as though it were the Message Source, i.e., the entire English language or the entire realm of poetry.)

Note how we *automatically* understand that a Poultry Plumage Probability Profile such as ¼ + ¼ + ½ has a certain degree of complexity or 'richness' about it — more 'richness' than, say, the probability profile ½ + ½ for tossing coins and calling them heads or tails. This idea of 'richness' is another key concept in **TOES**, although its practitioners would never call it that, of course. More 'richness' in the Message Source implies the need for fancier kinds of encoding/decoding for a given piece of communication. And this in turn leads the layman to imagine that 'Information is being measured'; since the field is called Information Theory, after all. But that's not what they're measuring. What they're measuring is the 'richness' of their Signaling Alphabets, aka the *DERN (aka Shannon information)*. In a moment, we'll see exactly what 'richness' means in quantitative terms.

From the languor of a henhouse baking under the July sun, we turn now to the bustling milieu of an air-conditioned flower delivery service. Here is the skeleton of our next toy Message Source, a Flower Language with only eight words:

rose, carnation, mum, peony, camellia, iris, violet, vinca

In the next few pages there will be some math, but that doesn't mean anything heavy like fractal geometry or matrix algebra. Mostly it's simple arithmetic, with the letter sigma (Σ) thrown in for its aesthetic appeal — also for realism, so you won't think I've watered it down. True, much of Shannon's theory of communication will be *left out*, but the portion I do present is genuine.

Scenario. We own a flower delivery service. Orders are called in from various branch locations to the main store for processing and delivery. We offer only eight kinds of flower for sale (see **Table 7**), and no mixed bouquets. Still, sales are brisk, and to cut down on phone line expenses, we plan to install a computerized order-handling system, whereby our eight-word Flower Language (the Message Source in this example) will be encoded using a Signaling Alphabet suitable for high-speed communication. Typically, the latter will comprise two characters only, 0 and 1, treated *either* the familiar way as two binary digits *or* as two letters, hence the name 'alphabet' (a mind-bend that will be illustrated on **page 278**). But first we need some probabilities of occurrence, since this is all about Statistics:

$$\boxed{\sum p \bullet (\log_2 p)}$$

TABLE 7: The ***Shannonentropy*** of an 8-word Flower Language

Word to be transmitted in a message	The probability, *p*, of the word's occurrence	Logarithm of the probability: $log_2 p$	Product: $p \bullet log_2 p = ?$
rose	.30	-1.73	-0.519
carnation	.20	-2.32	-0.464
mum	.15	-2.73	-0.409
peony	.12	-3.05	-0.366
camellia	.09	-3.47	-0.312
iris	.06	-4.05	-0.243
violet	.06	-4.05	-0.243
vinca	.02	-5.64	-0.112
Totals:	**1.00**	n/a	-2.668 **say -2.66**

The probabilities in the second column (.30, .20...) are based on our records of past sales, let's say. (Although really, to create this table, I've just jotted down a jumble of eight decimal fractions that add up to 1.00. Any such laundry list of probabilities will do, the sole requirement being that they add up to the checksum of 1.00, as indicated at the foot of the column.)

Discussion of the third column: Because of a binary-digit assumption, we use base 2 logarithms.[97] In words, what the third column says, looking back in the direction of the second column, is this:

> To obtain .30, you must raise 2 to the minus 1.73rd power [$2^{-1.73} = 0.30$].
>
> To obtain .20, you must raise 2 to the minus 2.32nd power [$2^{-2.32} = 0.20$].

And so on.

In the fourth column, we use arithmetic to multiply column 2 times column 3 and obtain a product.

Working our way across and down to the lower-right corner of the table, we discover that "The *Shannonentropy* of our Flower Language is 2.66 bits."[98] This summing step for column 4 corresponds to the letter sigma (Σ**)** in the formula that floats (cheerily? darkly?) above **Table 7**.

"But *why* all of this?" you might be asking.

And there you would have me.

Except for my remark in passing about the reason for base 2 logarithms, all I claim to be explaining is the *what*, not the *why*. It's the Boltzmanns and the Shannons of the world who have the insight as to why one should push the probabilities of column 2 through a series of log-intensive computations to arrive at a measure of **Entropy** (Boltzmann) or a measure of *Shannonentropy* that is *useful*, not a mere artifact on the professor's busy chalkboard.[99]

---

97. In principle, the logarithms could be to any base, depending on the nature of the Signaling language contemplated for use. Accordingly, the formula is sometimes written this way: $\sum p_i \log_s p_i .. p_n \log_s p_n$ where subscript-*s* is a reminder that whatever the symbol-count is in the Signaling Alphabet, *that's* the base we must choose for all our logarithms. As it happens, though, it's almost always base 2 in this field because of the prevalence of binary encoding in the computer world; i.e., it's not the base used in a Common Logarithm (10) nor that used in a Natural Logarithm (e). From that standpoint, using the subscript-*s* seems slightly ivory-tower-esque. I prefer to use an explicit subscript-*2*.
98. Reminder: Although we're in base 2, this is *not* the familiar 'bit' of Computer Science.
99. For example, if you would like to see an explanation of *why* **S = klogW** forms a *bridge between* Classical **Entropy** and Statistical **Entropy** (kinetic theory of heat), see George Gamow (1961, 1988), p. 112. I think I follow his friendly, popular science explanation, but I'm not comfortable enough with it to quote it here, as though vouching for it from a basis of real, personal understanding.

So far, we've been looking at the left side only of Shannon's formula. The complete formula is usually written this way...

$$H = -\Sigma p_i \, log_2 \, p_i$$

...with the dot and parentheses of our earlier version only implied, and with the letter *H* introduced as a symbol to hold the result.

Are we done?

Almost. As soon as we explain this: How did it get to be a positive 2.66 in my summarizing statement above, while it's a negative 2.66 in the table itself? You'll notice that Shannon's formula for *H* contains a minus sign[(100)] before the summation symbol. Ultimately, after you work the numbers through, you'll find that the explicit minus sign on sigma, in conjunction with the implicit minus signs on the logarithms, creates a double-negative effect ('two negatives make a positive'), such that *H* on the left side winds up with a positive value.

Saying it another way, the effect of the minus sign is to reverse the negative numbers that come naturally out of a logarithmic function when the function is fed numbers between 0 and 1 — which any probability, *p*, must be by definition. Then, when it comes time to compare Average Length against *H* (as we will in **Table 8** below after a short detour to *The New Encyclopaedia Britannica*), both sides of the comparison will have positive values, and that's more convenient.

But individuals will vary in their personal definitions of 'convenient'. Take the case of the 'Information Theory' article in *The New Encyclopaedia Britannica* (2002). There we find Shannon's formula presented in this very unusual form (unusual for *it*, I mean, not in mathematics generally):

$$H = p_1 \, log_2 \, (1/p_1) + p_2 \, log_2 \, (1/p_2) + ... \, p_n \, log_2 \, (1/p_n)$$

But to what end? Might it be precisely to circumvent the double-negative business so that the values are all positive from the git-go? That's my best guess. Undeniably it does provide us with a positive number for each element of the series to be summed; hence, they sum to a value of *H* that is already positive, with no sign change required to make it that way. But is their unorthodox notation really worth all the fuss? The added clutter of all those one-over-*p* elements, of which the log is to

100. As presented in Pierce, p. 84, for example, or by Shannon himself: "We shall call $H = -\Sigma p_i \, log \, p_i$ the entropy of the set of probabilities $p_i, ..., p_n$" (Shannon, p. 11).

be taken, might solve one problem, but it creates another for us non-mathematician types: "*Is* this the famous Shannon entropy formula or *not*?" one might wonder as he/she thumbs frantically through the encyclopedia at the library, racing against time to complete an 8th grade term paper on 'Information Wizards of the 1940s'. That part *is* annoying, rather along the lines of "The path to Hell is paved with good intentions"; still, I have a soft spot in my heart for the $1/p_n$ version, clutter and all, for the following reason: It helps strengthen one's conviction that there's nothing metaphysical or magical or even intrinsic about Shannon's *minus* sigma and *negative* entropy; it's merely a notational *choice* that evaporates in another writer's presentation of the same formula. Logarithms with negative values are simply what occur when you happen to be taking the logarithms of small numbers (in-between 0 and 1, for example, which is the domain of all probabilities, *by definition*!): Push the right buttons[101] on your calculator, and out pop the logarithms with negative signs.

At any rate, here's what the number +2.66 tells us in the brass tacks world of **TOES**:

Short version: "2.66 is the ideal, our lower limit for Average Bits per Word when encoding the Flower Language."

Longer version: "If we are contemplating an encoding scheme that averages *more* than 2.66 [actual] bits per word for our Flower Language, there exist other encoding schemes to try that would give us more efficiency, so let's see if we can't discover one. Conversely, were we to try being heroes by discovering an encoding scheme that averaged *less* than 2.66 bits per word, that would be a wasted effort since there are *no* such encoding options, according to Shannon's theorem."

To see what this means in concrete terms, we will compare two encoding options for the eight-word Flower Language, first against each other (in **Table 8**), then against the limiting value of *H*, which we know in this instance is 2.66. (By the way, from here on it's pure arithmetic — no more logarithms to speak of.)

101. If you're wondering, "How do I even take logs to base 2 on a handheld calculator?" (which typically has keys for doing common logs and natural logs but not for logs to base 2), the trick is to divide one common log by another as follows: log x / log 2, where x is the number in question. If you understand *why* this gimmick works (division by the common log of 2), consider yourself blessed. If you can't quite get your arms around the logic, you might be consoled by the following bit of dialogue I recall from a TV show called "Moonlighting" (of 1990s vintage):

    "You know what's hard to understand?" queries Cybill Shepherd.

    "No, what, logarithms?" quips the Bruce Willis character.

TABLE 8: Two Encoding Options Compared

The Flower Language and its word-probabilities		Encoding Option A			Encoding Option B		
Word	*p*	Plain Binary *Code*	Num Digits in Code	Product of *p* times NumDigits	Weighted Binary *Code*	Num Digits in Code	Product of *p* times NumDigits
rose	.30	000	3	0.90	1	1	0.30
carnation	.20	001	3	0.60	001	3	0.60
mum	.15	010	3	0.45	010	3	0.45
peony	.12	011	3	0.36	011	3	0.36
camellia	.09	100	3	0.27	00000	5	0.45
iris	.06	101	3	0.18	00001	5	0.30
violet	.06	110	3	0.18	00010	5	0.30
vinca	.02	111	3	0.06	00011	5	0.10
Average Length in Digits (per Word Encoded):				**3.00**			**2.86**

Conclusions drawn from **Table 8** (as it relates back to **Table 7**):

Plain Binary Code (using the binary equivalent of decimal 0 through 7, one for each of the eight words) overshoots the ideal by this much:

```
Average Length          3.00
less Shannonentropy    -2.66
                        0.34 bits
```

Weighted Binary Code,[102] which takes into account the higher/lower probability of each word and adjusts its length accordingly, overshoots the ideal by this much:

```
Average Length          2.86
less Shannonentropy    -2.66
                        0.20 bits
```

102. What I'm calling 'Weighted Binary Code' is my impressionistic portrayal of an encoding technique known as Huffman Code; see Pierce, pp. 94-97 for a real example. The point to take away is that binary code is not something fixed and absolute; rather, it's a multipurpose tool that can be applied in many ways dependant on one's needs. Yes, all binary numbers are expressed in binary code, but not all binary code expresses binary numbers. In Encoding Option B, for example, we see '0' and '1' employed as a kind of miniature *alphabet* for building up the Signaling language; but this has nothing to do with the binary *counting* that characterizes Option A.

Thus, of the two schemes under consideration, the Weighted Binary Code of Option B comes closest to Shannon's limiting value (*H*) and is the more efficient encoding scheme to adopt.

Granted, the difference in Average Length as presented here (3.00 versus 2.86) looks miniscule; however, when extrapolated to a real Message Source and multiplied over thousands of monthly transactions in a business context, you can see how the numbers might become significant, translating into tangible dollar savings on one's total monthly 'connection' time.

Armed with your knowledge of the Flower Language, you can now return to the barnyard and try analyzing the chickens' communication needs like a real pro. Let's say the chickens in Henhouse A need to set up an efficient method of communicating news to Henhouse B. The news they wish to convey might be of a hatchling's feather-color as it emerges from an egg. **Table 9** shows the calculation of the *Shannonentropy* for any such an egg.

TABLE 9: Discovering the ***Shannonentropy*** of an egg

Word to be transmitted in a message	The probability, *p*, of the word's occurrence	Logarithm of the probability: $log_2 p$	Product: $p \cdot log_2 p = ?$
russet	.25	-2.00	-0.50
white	.25	-2.00	-0.50
Andalusian	.50	-1.00	-0.50
Totals:	**1.00**	n/a	**-1.50**

As explained earlier, the -1.50 will reported as a positive value thanks to the double-negative inherent in the H equation. Thus, H = +1.50. Next we would want to compare the relative virtues of various Signaling Alphabets available to the chickens, as they pride themselves on efficient clucking and are loathe to waste a syllable:

TABLE 10: Three bok-KAW-Encoding Options to Contemplate

A Henhouse Clucking Language and its word-probabilities		**Encoding Option A**		**Encoding Option B**		**Encoding Option C**	
Word	*p*	Fat Binary *Code*	Product of *p* times NumDigits	Thin Binary *Code*	Product of *p* times NumDigits	Thinner Binary *Code*	Product of *p* times NumDigits
russet	.25	000	0.75	00	0.50	0	0.25
white	.25	001	0.75	01	0.50	1	0.25
Andalusian	.50	111	1.50	11	1.00	01	1.00
Average Length:			**3.00**		**2.00**		**1.50**

Key to **Table 10**: 0 = 'bok', 1 = '*KAW!*'

(To save space, I've dispensed with the columns that were labeled 'Num Digits in Code' in **Table 8**. In **Table 10**, one can visually count the digits employed in one of the Binary Code columns, then multiply the count by the value in column *p* to verify the corresponding product that I've entered in Column 3, 5, or 7. Example: If 'russet' is encoded as '000' then the corresponding product is .25 * 3 = 0.75. If 'russet' is encoded as '00' then the corresponding product is .25 * 2 = 0.50. And so on, across the table, noting however that we allow a commingling of diverse 'word lengths' when it comes to Option C.)

How shall we evaluate the three options? This will be very similar to our comparison of the options in **Table 8**, except that this time I've provided three choices to consider:

Option B would be favored over Option A since Option B brings us closer to H = +1.5, the ideal or theoretical limit on communication efficiency as determined in **Table 9**. Conversely, with an average length of 2.00, Option B still falls short of the ideal by 0.50, and this might "inspire" us to continue the search for an even better encoding scheme. Option C shows one such scheme. Option C would be considered the best of the three, since its Average Length computation matches the *Shannonentropy* of 1.5 exactly.

More terms to define (or to revisit)

The measure called *Shannonentropy* is itself beyond reproach.(103) As we've seen it travels well, from communications satellites all the way down to a toy flower shop or imaginary

103. Or is it? Using a 'weighted' coding scheme like russet = 01, white = 0, Andalusian = 1 for Option C would bring us in still lower, for an Average Length of only 1.25. We would thus 'beat' the *Shannonentropy* of 1.50 by a significant margin. But that seems like Heresy, as the *Shannonentropy* is supposed to be the *absolute limit*. Therefore I decided against showing that version in **Table 10**, as it probably just means my logic or computation was flawed.

henhouse. But in its name and allied terminology there is great potential for confusion. Therefore, we will continue to build our vocabulary carefully, taking nothing for granted, and we will sometimes reiterate a definition to help get it nailed down. To round out the picture presented above, here is a formal, generalized definition of *Shannonentropy*:

> *A limit on the best (shortest) encoding scheme expressed as the average characters of S per character of M, where S is the Signaling Alphabet and M is the Message Alphabet.*(104)
>
> Or, in quantitative terms...
>
> $$H = -\sum p_i \log_s p_i \ldots p_n \log_s p_n$$
>
> ... which means: *H is the sum of the probabilities, p, of the Message alphabet computed via logarithms to the base, s, where s is the number of letters in the Signaling Alphabet* (as illustrated already by **Table 7**).

One might note a resemblance between our definition of *Shannonentropy* above and certain definitions that appear in dictionaries under the word 'information', e.g., *Webster's Third New International Dictionary* (1966):

> **in•for•ma•tion**
>
> **7**: a numerical quantity that measures the *uncertainty* in the outcome of an experiment to be performed <when an event occurs whose probability was *p*, the event is said to communicate an amount of [information] *log (1/p)*
> —W.F. Brown b. 1904> (emphasis added)

This standard way of defining *DERN (aka Shannon information)* focuses implicitly on the Message Source. Our preferred way of defining *DERN (aka Shannon information)* focuses explicitly on the Signaling Alphabet, not on the *Shannonentropy* of the Message Source:

> *the Degree of Encoding Richness Needed by a Signaling Alphabet*
> *to handle a given Message Source* (= DERN, repeated from page **269** above)

There are three reasons at least why our way is better:

1. It draws attention to the purpose for which engineers create such theories in the first place. The talk about 'measuring information' [so-called!] is only Part 1 of a two-part process. Once you've entered Part 2 of that process, all attention shifts to noise, error correction, and physical properties of the communication chan-

104. My definition is paraphrased and expanded from the definition found in the article on 'Information Theory' in *The New Encyclopedia Britannica* (2002), Vol. 21, p. 634: "The average character distribution in the message alphabet determines a *limit*, known as Shannon's entropy, on the best average (that is, shortest) attainable encoding scheme." Emphasis added.

nel itself. Never again does one think about the 'Message Source' unless there is reason to suspect a major error in that early part of the analysis, i.e., a failure to give proper mathematical representation to 'the entire English language'. Saying it another way: Part 1 is the means, Part 2 is the end. Yet Part 1 is what the dictionary definitions take as proxy for the whole. Part 1 by itself (represented above by **Table 7**) would just be an ivory tower game. Only when you add Part 2 (represented by **Table 8**) does it all begin to mean something to the electrical engineer, your friend at Bell Labs (of yore).

2. My definition saves **TOES** from being renamed as Ignorance Theory. The formula that lies at the very heart of the discipline is in fact a measure of ignorance, not knowledge. Moreover, it's a measure of ***δata***-ignorance, not Information-ignorance. My oddly worded definition of ***DERN (aka Shannon information)*** has method in its madness: It provides a sorely needed end-run for **TOES** practitioners, by throwing the weight of emphasis onto the Signaling Alphabet (which does contain some genuine ***δata*** of our own invention, if not actual Information), and away from the Message source which is, by definition, shrouded in x amount of mystery (= ignorance). This makes it just barely justifiable to say the field in question is 'Information Theory'.
3. My definition discourages the laity from trying to apply the term to their world. The lay person thinks he might know what the 'Message Source' is (i.e., the 'English language' in its totality), but he realizes instantly that he is on foreign ground when he sees a term like 'Signaling Alphabet'. Thus, mine is a less friendly definition at first glance, but in the long run it keeps us out of trouble.

Back to the formula for *H*: At this point, Shannon and his colleagues at Bell Labs are *done*.

The formula tells them what they need to know: how to decide if a proposed Signal Alphabet, S, and its encoding scheme are efficient, as measured (indirectly) against a given Message Source, M, *in its entirety*. (<== Hold that thought; we'll return to it on **page 285**.)

There the story should end, if you're thinking in terms of pure **TOES**.

Enter Professor Wiener.

In language that is alternately vague and tortured, he drags the term 'information' into the limelight (instead of playing it down as a technician's nonce tag, as he might have). In a much-quoted passage, the Bog-Wiener says:

> It is *possible* to *interpret* the information carried by a message as *essentially* the negative of its entropy..." — Wiener (1950), p. 21

I've added emphasis to three words above to point up the reptilian danger of all sentences uttered by Wiener when he is in this mode. He also tells us this:

> Our ordinary standards of value are quantities of gold, which is a particularly stable sort of matter. Information, on the other hand, cannot be conserved as easily, for...the amount of information communicated is related to the non-additive quantity known as entropy and differs from it [only] by its algebraic sign and a possible numerical factor. — Wiener (1950), p. 116

To the unwary, it might sound as though Wiener were saying this (switching over to my own nomenclature for the paraphrase): "Once you've scratched away the veneer of an algebraic sign change, the following two terms emerge as synonymous: '**Entropy**' and 'amount of **Information** communicated' " (which, in turn, is merely another name for *Shannonentropy*, he implies).

To the naïve reader, the phrase "amount of **Information** communicated" lends a false sense of familiarity to the topic. Thus, with that one sentence, Wiener simultaneously [a] opens the floodgates between the hard science realm of *Shannonentropy* and the 'soft' world of Liberal Arts *and* [b] destroys the necessary distinction between the **Entropy** of Statistical Mechanics and the *Shannonentropy* of **TOES**.

But a moment's reflection should reveal that *Shannonentropy* cannot possibly be equated with an *amount* of information-*[anything]*; rather, *Shannonentropy* is a highly abstract theoretical *limit*, as defined on page **270** through page **278** above.(105) Of course Wiener himself, being a professional mathematician, knows this better than anyone; but what he *knows* doesn't help a jot with what he *writes*, to be quoted ad nauseam for the next fifty years.

105. Coming at it from a different direction than mine (which is simple logic — just trying to make sense of this mess!), Kåhre confirms the point: "This result indicates that the Shannon entropy...is not a *measure* of information, but rather an upper *limit* H_B of the true information H_G." Kåhre, p. 220, emphasis added. Amen. There is a God after all.

Observing how the **TOES** practitioner employs *Shannonentropy* to measure the efficiency of a given Signaling/Encoding scheme relative to **M** (in its entirety), the Liberal Arts bystander begins to wonder if perhaps the *Shannonentropy* measure, when applied to specific slices of **M** (yielding "the entropy of great poems, the entropy of clichés," and so on), might serve as a convenient proxy for the **Information** content of these specific communications constituting tiny subsets of the language, **M**:

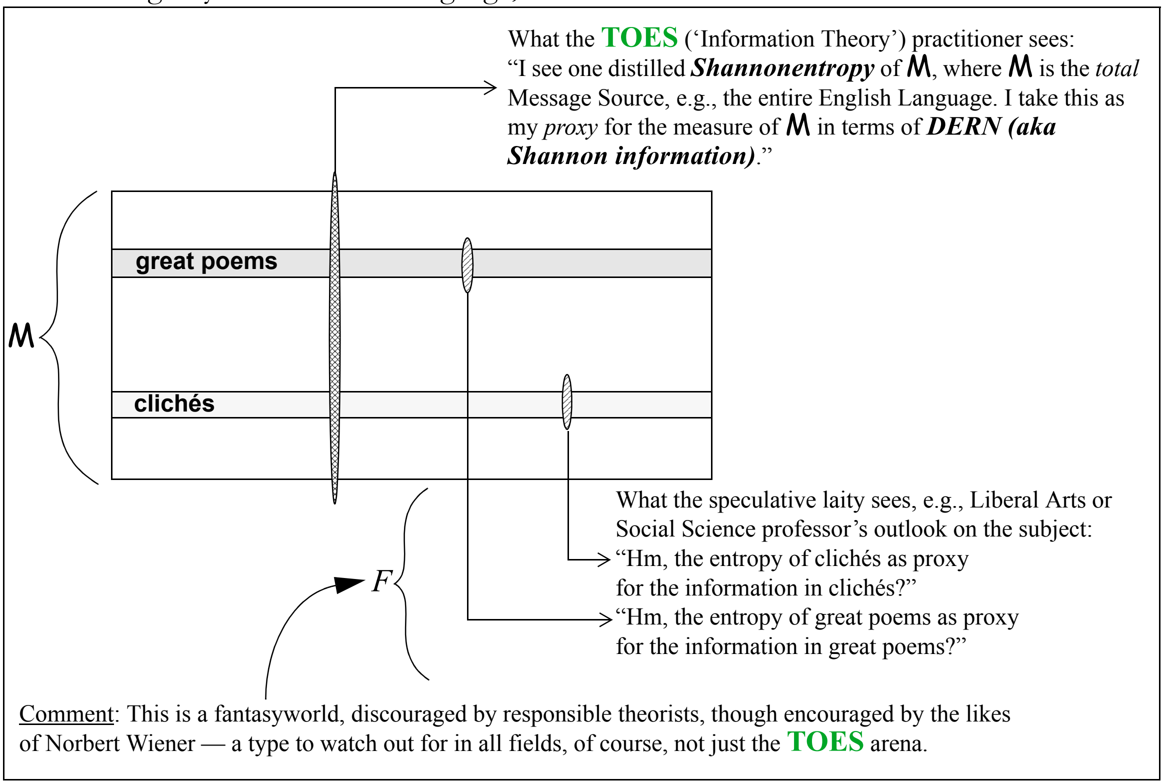


FIGURE 81: Real world of **TOES** contrasted with laity's fantasyworld version of it

The Liberal Arts train of thought (bracketed by '*F*' in **Figure 81**) is a predictable if rather pointless one. The mystery is why the theorists themselves should adopt the term "Information Theory" as if *they* were the ones treading so squishy and pseudoscientific a path into the marsh with no exit, in search of tools that might measure real **Information** as distinct from *DERN (aka Shannon information)*.

And yet, there it is, in the very next sentence after '...essentially the negative of its entropy', an engraved invitation from Professor Wiener to come to the Cambridge cocktail party and play in the academic sandbox:

> That is, the more probable the message, the less information it gives. Clichés, for example, are less illuminating than great poems. — Wiener (1950), p. 21

What is particularly exasperating about this latter half of the oft-quoted passage is that it actually makes perfect sense, *in the world of the arts*, where the focus implicitly *is* on Information, not on *DERN (aka Shannon information)*. But how did Professor Wiener transport himself all the way over to that side of the galaxy (lower part of **Figure 81**) in the space of one sentence? That's the question. In terms of **TOES**, it's a meaningless statement. The best one might hope for, if he were determined to salvage it as a Sacred Relic of the Cybernetics Saga, would be the following loose and charitable interpretation:

> Assume a toy Message source made up solely of clichés. This Message source would have less *Shannonentropy* than a Message Source comprised of the poetry of Poe. Accordingly, it would be easier to formulate a signaling scheme for clichés than for the poetry of Poe. Now, onward to the real thing...

Fine. But that leaves hanging the question of why Wiener made the non sequitur statement to begin with.(106) However it came about, I repeat — in terms of **TOES** — *the famous Wiener quote is meaningless.* Meanwhile, it *does* resonate with composers, with poets, with painters. *They* get the idea immediately. Or think they get it, which is the pity of it. For there's really nothing to get — back over the fence in the technical world (upper part of **Figure 81**) that Wiener *claims* to be representing at that moment, such that 'the public can understand it'.

From **page 282** you'll recall the phrase '**M**, *in its entirety*'. Here we pick that thread up again. We laity must remind ourselves continually that the **TOES** theorist is interested exclusively in the Whole Enchilada, not in any particular message that you or I might send. Here is the best description I've seen of how the **TOES** theorist views the world:

> [Shannon] looks at the probabilities of separate letters, or at small groups of letters; two letters (digrams) and three letters (trigrams). The 'grains' are arbitrary chunks

---

106. How *shall* we explain his shenanigans? Among the plausible causes are these: [a] he was too rushed or too overconfident to review his manuscript, [b] he was a sloppy thinker, or [c] he was arrogant, assuming the heathens would never fully comprehend his words anyway. Of the three, [c] seems most likely. It's as if I were to lecture on Electricity to a tribe of head-hunters in the Amazon, and I mumbled something about 'lamps in the house' and 'size AA batteries' all in one breath. Now there really are lamps in our houses, and we really do buy AA batteries, so I've uttered no falsehood; and yet, juxtaposing the two topics without comment *is* a kind of lie. In a lecture on Electricity in the circumstance described, perhaps I would gamble that I need not explain how unrelated they are? Who among the head-hunters would call me on it? For specific Wiener anecdotes (as distinct from my vague speculations, such as the one in this footnote), see Conway and Siegelman, *Dark Hero of the Information Age*.

> of text, stripped down to their bare statistical properties. This statistical approach smooths away the cultural intricacies of language, making it fit for a communications engineer, but not for a linguist... *The text is treated as an ideal gas of single letters*... hence the Shannon entropy equals the Boltzmann entropy H_B...
>
> Kåhre, p. 221, emphasis added

Even when the **TOES** theorist seems to be looking at 'one message', *he* values it purely as a statistical sample of (indicator of) the whole, caring not a whit about that individual message for its own sake, the way a Liberal Arts person instinctively would. Conversely, when a Liberal Arts person sees a **TOES** statement about "...great poems" (Wiener, 1950, p. 21), he/she will have a strong urge to misread it as a summarizing statement about the characteristics of *certain* great poems, as analyzed by the friendly **TOES** theorist down the hall; when in fact, **TOES** doesn't do that sort of thing. **TOES** deals only with statistical abstraction (upper part of **Figure 81**). This business of viewing 'one message' as a statistical sample (of the stew) versus the viewing of 'one message' as an artifact with aesthetic or semantic content is at the heart of all the misunderstandings between **TOES** and the laity.

To make matters worse, the occasional **TOES** theorist will make vague intimations (Wiener, 1950, p. 21) or even an explicit claim that the membrane between the two domains of **Figure 81** is, so to say, *porous*:

> ...it has been proposed that Shannon's entropy also applies to short messages, with the claim that it "actually corresponds pretty close[ly] to the usual idea of information among people in general"
>
> — S. Goldman (1953), quoted without comment in Kåhre, p. 105

One can forgive Goldman, writing in 1953 at the height of the first wave of the Cybernetic Mystique. Perhaps Goldman was overwhelmed by it all, as so many were. But one is surprised to see Kåhre introducing the quotation in such bland terms, as if it might actually make sense (when in fact it's just another symptom of the general malady whereby *DERN (aka Shannon information)* and **Information** are allowed to slop, mindlessly and obscenely, one into the other).

I believe that there exists *some* kind of connection between the two realms, but it is not an easy one to describe.

Stake through the heart

Fearful that I may not yet have persuaded the reader that something so prevalent in the literature as 'Shannon information' is a dangerous fallacy in need of having a stake driven through its heart *yesterday* if not sooner, here is one last perspective on the vexing topic. Thinking along the lines of the Henhouse Clucking Language that served us so well above (in **Table 9** and **Table 10**), we now imagine a pair of toy languages called Lint Count Language and Nuclear News Language.

TABLE 11: Stake through the Heart of Log as 'information measurement'

Lint Count Language	**Encoding Scheme**	**W**(1)	**Measure of Information**(2) **= $\log_2$ W**
zero pieces of lint in navel	00		
one piece of lint in navel	01		
two pieces of lint in navel	10		
many pieces of lint in navel	11	$2^2=4$	2

1. W = number of possible messages that can be encoded given the scheme proposed in Column 2. **TOES** borrows this notation convention from thermodynamics, where **$S = k\log_e W$**. See Appendix A: Entropy Survey.
2. This is what they all *say*, but I vehemently disagree that this is a measure of anything nearly so important-sounding as that. See text to discover what it really measures.

Nuclear News Language	**Encoding Scheme**	**W**	**Measure of Information = $\log_2$ W**
zero missiles coming in	11		
one missile coming in	10		
two missiles coming in	01		
many missiles coming in	00	$2^2=4$	2

What's wrong with this picture? The **TOES** theorist (of a certain ilk) will tell you that Column 4 contains the 'Measure of Information'. Aside from the obvious retorts of '*what* measure?' and '*what* information?' there are at least two other things wrong with such a statement.

First, the ever-popular Column 4 *itself* is a bogus construction, *regardless* of how one might later interpret it and label it. Why? Because it contains nothing new that we cannot see already in Column 3. Column 3 says in effect, "Given a binary encoding scheme (where n = 2, because we've chosen an alphabet consisting of the letters '0' and '1' only), and given the fact that we've chosen to limit our word length to two letters, the number of possible words we can build is two raised to the second power, which is four." (As a reminder that the encoding assignments are all quite arbitrary, I've varied their sequence, using '00, 01, 10, 11' in Column 2 for Lint Count Language and '11, 10, 01, 00' in Column 2 for Nuclear News Language.)

Next question, *still* looking at Column 3: "Have we covered all the possible messages that we wish to send, per the laundry list in Column 1 (the Message Source)?" Answer: "Yes, because there are four items in the laundry list and we have computed '4' as our answer in Column 3. The two numbers match. All is well."

Next question, *still* looking at fertile Column 3: "For Lint Count Language, I wonder what was our Degree of Encoding Richness Needed?" Answer: "The exponent '2' can be taken as a rough measure of DERN."

And for Nuclear News Language?

The answer would be the same: "*DERN (aka Shannon information)* is equal to 2."

Thus, Column 4 is superfluous, because the '2' in that column (whose proper name is DERN, not 'information-' anything) is precisely the '2' we were just talking about: *The exponent in Column 3*. But being superfluous is the least of the problems with Column 4. By now, I'll bet you (and your 4-year old reading along with you) will already have guessed what its other big problem is:

How does the **TOES** theorist get off saying that the 'information content' regarding lint in *his* navel is identical to the 'information content' regarding x number of nuclear warheads raining down on *my* roof?

Doesn't Column 4 contain the number '2' for both cases? Yes it does, but you and I know there is something rather different about ballistic missiles and lint. Then where could that pesky difference be hiding? The difference is in real **Information**, of course, the part of 'Information Theory' that the **TOES** theorist drops casually in the waste basket, all the while waving his cigar and pontificating at the cocktail party *as though* in the following there might be something profound said about semantic content:

"The measure of **Information** is the power to which 2 must be raised to match the number of 'word' combinations possible in the Signaling Alphabet that I've chosen for encoding the **δata** I shall transmit (or for decoding the **δata** you shall receive) 'from' a given Message Source."

Strip away the qualifying clauses, and the essence of the sentence above is this:

**** Information is a Power of Two ****

You have to ask yourself: Is a subculture based on the mantra "Information equals x where 2 to the x power equals C-sub-M-sub-thus-and-such" really one to endorse?

(A note of apology for the prevalence of 2's: I decided it would be the lesser of two evils if I kept the example simple and boring — though potentially confusing because of too many 2's in Columns 3 and 4 of **Table 11**. For an example that avoids this problem, see **Table 24 (Chicken Language Deluxe)** in **Appendix E: Theory of Information**.)

To conclude this section on a happier note, I'll quote a passage from *Quantum Reality*:

> Seen from outside — the human point of view — these obligatory conjugal relations look like "uncertainties." From the inside — the [particle's] point of view — they feel like "realms of possibility," the basic inalienable estate of every [particle] in the universe. — Nick Herbert, pp. 110-111

This passage occurs in Herbert's second pass through Heisenbergian uncertainty, seen no longer in the light of measurement limitations (pp. 67-70), rather in the attractive light of intrinsic quantum wave-attributes (pp. 109-111). Change only a few words, and the quoted passage works for **TOES** as well. One can read it as a general description of how a signal (something on the 'outside') relates to its Message Source, the latter conceived an abstraction, distilled from all that resides on the 'inside' of the language. Viewed from inside, the language is ripe with 'possibilities' for the sender, thus the concomitant 'uncertainties' that might plague a distant receiver. The **TOES** practitioner, being only a voyeur and having no control over the Message Source, must focus on such uncertainties and worry about correct deciphering of signals. The artist, by contrast, has much to say about the make-up of the Message Source (if he is an influential artist, that is). Thus, she has the luxury of focusing on the possibilities instead, or even playing the outside and inside of the Message Source against each other.

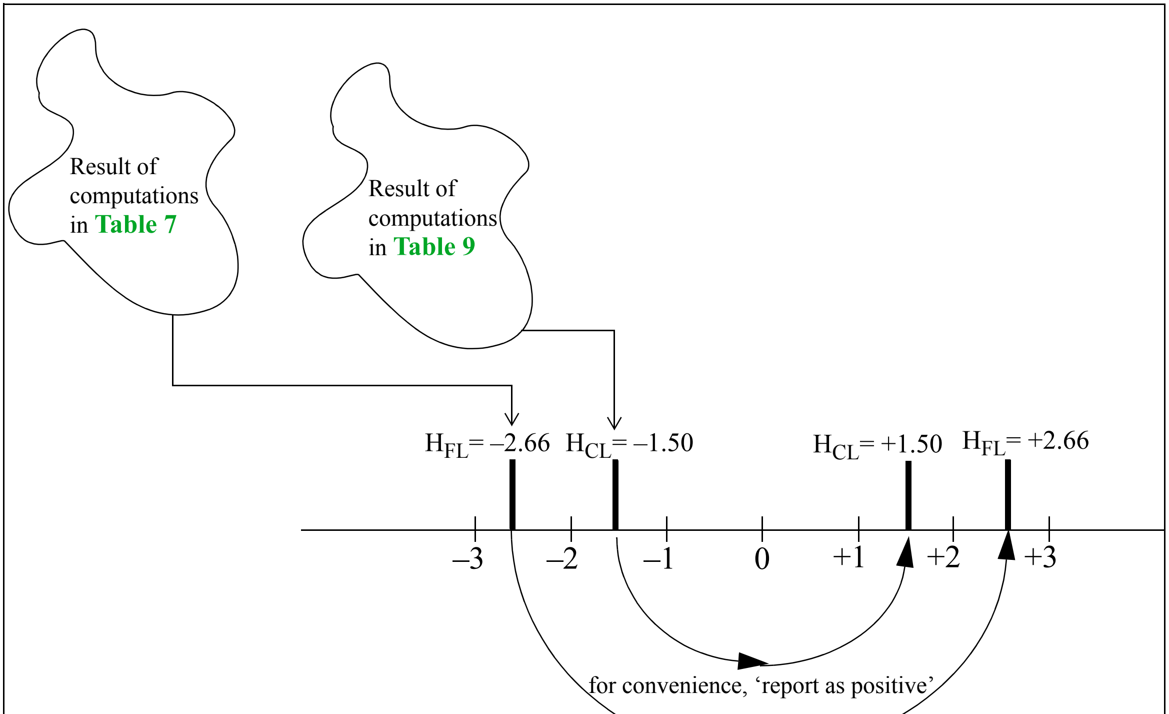
"Just a sign change" – Norbert Wiener

Recall that following the presentation of **Table 7** on **page 274**, we performed a sign change, thus converting – 2.66 to H = + 2.66, which was a more useful way to talk about the value in connection with **Table 8**. (Similarly for **Table 9**, we first computed –1.5, but then converted it to H = +1.5 for the ensuing computations in connection with **Table 10**.) Such a technique is not unique to **TOES**.

For example, in Kinetics the rates of reaction, of production and of consumption are all reported as positive, *by convention*. Similarly, in deriving pH from a H^+ concentration, the computation is pH = – { log($[H^+]$) }. The effect of this is to transform a logarithm that carries a negative sign into a pH that carries a positive sign (usually implicit: without a literal plus sign). Same impetus. There's nothing mystical or ontological at play here; it's all about established *conventions*, and the workaday *convenience* of dealing with positive values instead of negative ones.

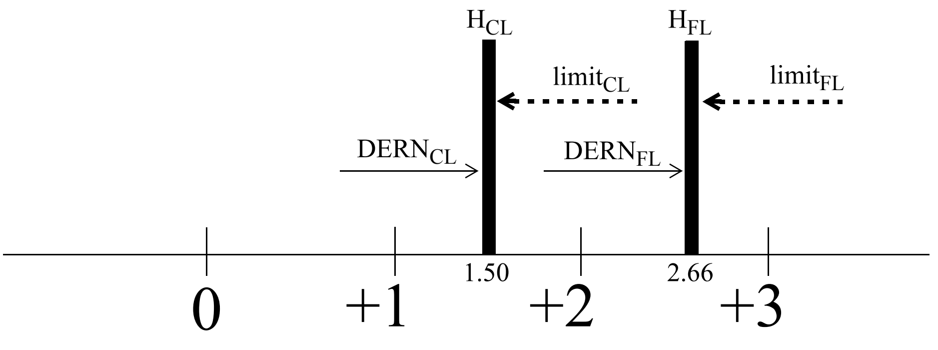
In **Figure 82**, we have a reason for bringing to the forefront this business of 'reporting as positive' which follows on the computation of H in **Table 7** and **Table 9**.

In **Figure 83** we leave behind the negative arm of the number line and zoom in on the positive one, where we discover that we can learn something by viewing a given value of H from both the left side and right side (literally and figuratively speaking).



Key:
H_{FL} = ***Shannonentropy*** of Flower Language, a toy Message Source
H_{CL} = ***Shannonentropy*** of Chicken Language, a toy Message Source

FIGURE 82: Report negative as positive (for notational convenience)



Key:
H = the ***Shannonentropy*** (qualified by subscript CL or FL below)
DERN = 'Degree of Encoding Richness Needed' for a given Message Source
limit = lower limit of efficiency for an encoding scheme (the ideal to strive for)
subscript **CL** = Chicken Language is the Message Source: {russet, white, Andalusian}
subscript **FL** = Flower Language is the Message Source: {rose, carnation, mum, peony, etc.}; see **Table 7**.

FIGURE 83: H from the left, H from the right (for two values of H)

Approached from the left, the values H_{CH} and H_{FL} can be read as relative measures of

Degree of Encoding Richness Needed (DERN). If we wish to create an encoding scheme for communicating things in 'Flower Language', that scheme must clearly be *richer* in its features than an encoding scheme designed only to handle 'Chicken Language'. In qualitative terms, we can see this already simply by glancing at the leftmost column in **Table 7** and that in **Table 9**. The added advantage of H is that it quantifies this difference. And were real Message Sources involved in lieu of our toy Message Sources, you can imagine how this ability to quantify such differences would suddenly become a necessity, not just a luxury or amusement (as it is in **Figure 83**).

There's more to learn from **Figure 83**. Approached from the right, the values H_{CH} and H_{FL} tell a different story (dashed arrows). Viewed this way, H_{CH} says in effect, "In creating your encoding scheme, try for an Average Length of 1.5 bits per 'word'. If you're much in excess of that value, your scheme is inefficient and you should try a new one that comes closer to 1.5. Conversely, 1.5 is the theoretical lower limit for *any* encoding scheme you might ever devise, so don't waste your time trying to get your Average Length lower than that value." And so forth for H_{FL}: it's a limit when read from the right side.

Shannon & Wiener

Here is one way to analyze the contrasting viewpoints of Shannon and Wiener. They are both dealing with the number line shown in **Figure 83**, but with this crucial difference: Shannon is looking at it in the right-to-left direction, with an interest in discovering encoding limits for a given Message Source, whereas Wiener is looking at it in the left-to-right direction, and talking about it to non-engineers, and claiming to see **Information** where really there is only *DERN (aka Shannon information)*.

For easy reference, here is a compendium of passages from Wiener that touch on **TOES**:

> Just as entropy is a measure of disorganization, the information carried by a set of messages is a measure of organization. In fact, it is possible to *interpret* the information carried by a message as *essentially* the negative of its entropy, and the negative logarithm of its probability. That is, the more probable the message, the less information it gives. Clichés, for example, are less illuminating than great poems. — Wiener (1950), p. 21 (emphasis added)

> ...the amount of information communicated is related to the non-additive quantity known as entropy and differs from it *by its algebraic sign* and a possible numerical

factor. — Wiener (1950), p. 116 (emphasis added)

...[the] amount of information, being the negative logarithm of a quantity which we may consider as a probability, is *essentially a negative entropy.*
Wiener (1948), p. 64 (emphasis added); see also p. 11 and p. 62

The notion of the amount of information attaches itself very naturally to a classical notion in statistical mechanics: that of entropy. Just as the amount of information *in a system* is a measure of its degree of organization, so the entropy *of a system* is a measure of its degree of disorganization; and the one is *simply the negative* of the other. — Wiener (1948), p. 11 (emphasis added)(107)

Next, we take his most famous sentence(108) and tether its jumble of vaguenesses to solid objects on the ground; please refer to **Figure 84**.

107. A note about Danchin's *The Delphic Boat*. Generally, Ms. Quayle's translation from French to English seems fine (although I confess I haven't looked at the original); however, I couldn't help noticing one peculiarity in a putative quotation from Wiener:
"...the notion of quantity of information relates naturally to a classical notion of statistical mechanics, that of entropy. Just as the quantity of information of a system is a measure of its degree of organization, the entropy of a system is a measure of its degree of disorganization."
We see the above passage attributed to "Wiener, *Cybernetics*", sans page reference, in Danchin, p. 199 (where the footnote points to p. 344). And yes, it looks plausibly Wieneresque. But Wiener never wrote that. My best guess: The passage above was translated from Wiener (1948, p. 11) into Danchin's French, and thence to Quayle's English, without anyone having consulted the Wiener original to see if it still matched. And it is just too wonderful that the topic at hand is none other than our good friend **Entropy**. Borges would love it. (Or, for that matter, gene mutations come to mind as well.)

108. Most famous in the confused demimonde of Cybernetics, that is to say. Elsewhere, in other fields, he has made solid contributions (e.g. the Wiener-Hopf integral), which remain unsullied by the discussion here.

The favorite quotation Wiener (1950) page 21	Translated from Wiener-ese into concrete terms
"Just as *entropy*	This sounds like **Entropy** at first, but soon we see he means ***Shannonentropy*** (H), e.g., a value such as our 1.5 for Chicken Language, pertaining to 12 chickens collectively per **Table 9** on **page 279**.
is a measure of disorganization,	
the *information* carried by a	***DERN (aka Shannon information)*** (Note: At first the subject was the ***Shannonentropy*** of the Message Source, but now the subject has switched to 'messages', i.e., to data communication events.)
set of messages is	
a measure of *organization*.	I disagree. It is not a "measure of organization"; it's more like a Degree of Encoding Richness Needed (DERN). The latter implies no judgment about the embedded semantic content. Whether the word 'its' refers to 'message' or back to 'information,' the whole sentence is *gibberish*. Only a *Message Source* can have a ***Shannonentropy***, *not* a message and *not* the **Information** carried in that message, so it doesn't matter whether his phantasmagoric entropy is 'negative' or 'positive'.
In fact,	
it is possible to interpret the *information*	
carried by a *message* as essentially	
the *negative of its entropy*,	Excerpt from **Table 9**, with a new column added to show negatives 'reported as positive' (by putting minus before log which is negative: two negatives make a positive):
and [as] the *negative logarithm*	
of its *probability*.	
That is, the *more probable* the message	Suppose a certain henhouse message is decoded to mean, 'She's an Andalusian!' That would carry less **Information** (semantic content) than the following message: 'She's a russet!' Why? Simply because there are numerous Andalusians (50% => '+1') and fewer russets (25% => '+2'), so the table reads: '1 < 2'
the *less information* it gives.	
Clichés, for example, are less	Again, a message stating 'Andalusian!' is less illuminating than 'russet!' because p=0.50 for the one (the 'cliché') and p=0.25 for the other (the 'poem'). BUT, notice how we've drifted from the realm of ***DERN (aka Shannon information)*** into that of **Information** (= stuff with semantic content = What the chickens are actually *saying* to one another), and with no warning from Wiener.
illuminating than great *poems*."	
[italics added to clarify where the targets are for translation]	

Poultry Type	p	log of p	– [log of p]
russet	.25	– 2	+ 2
white	.25	– 2	+ 2
Andalusian	.50	– 1	+ 1

FIGURE 84: A translation exercise from hell

If you read the annotated passage in **Figure 84** (previous page) alongside **Figure 82** (**page 291**), you can see that Wiener has taken something that is relatively straightforward (a computation of H, as in **Table 9**) and natural (reporting negative values as positive, which everyone does all the time for convenience, as explained on **page 289**), and twisted it like a pretzel, making it sound almost hopelessly abstruse and 'deep' and possibly even mystical or vaguely metaphysical, when really it's *all 7th grade arithmetic on a number line*!

Negative entropy and all that

While proposing that the *Shannonentropy* might be morphed into – H, Wiener is likely thinking about Schrödinger's negative **Entropy**, '–S'. This notion Schrödinger arrives at by the cuteness of S = klogW ==> – S=klog 1/W (Schrödinger, 1944, p. 73).(109) This dubious and unnecessary departure from standard **Entropy** notation(110) earned Schrödinger some sharp criticism from his colleagues. Whereupon Schrödinger (in a second-edition addendum to his Chapter 6: Order, Disorder and Entropy) credits the idea to Boltzmann! As though to say, "Well, how bad can it be? This negative **Entropy** is really a notion of the great Boltzmann himself, not *my* idea, you see. I'm merely playing with it" (see Schrödinger, p. 74 for his own words of attempted vindication).

As for Wiener, he makes reference to *neither* Schrödinger *nor* Boltzmann in this regard — it's just that I think it likely he was influenced by one or both of them. And if he were called out on the idea, one can easily imagine him brushing it all aside as "an idea of Schrödinger's upon which I had formulated some personal conjectures to share with my public," just as Schrödinger was silent about Boltzmann until criticized.

By the way, even George Gamow, who usually has a clearer head, goes on for a whole page about 'negative entropy' and photosynthesis (Gamow, 1947, p. 230). However, just like Wiener, he fails to mention the connection back to Schrödinger or Boltzmann. But the idea is so unique and so gratuitous, confusing rather than clarifying the whole idea of entropy and photosynthesis, that one prefers to imagine

109. Note in passing that this is just the opposite of the case where the author of an 'Information Theory' article for *The New Encyclopaedia Britannica* used the $1/p_n$ notation to make an unwanted minus sign turn positive ahead of the game! See **page 276** above.
110. Ostensibly his concern is to 'reconcile' the 2nd Law with Life, meaning photosynthesis in particular. But no such fancy explanation is required. See Penrose, p. 317 for example.

a line of influence rather than having to postulate that Boltzmann, Schrödinger, Gamow and Wiener were all struck independently by the same goofy idea, one that would be ultimately discredited for the pseudoscientific-sounding thing it was.

"Just a sign change"

Gradually the fog lifts and one perceives that the phrase "just a sign change" can mean three very different things which I've labeled [a], [b] and [c]:

[a] It can refer to the necessity of just *getting the bloody thing right* (!), as when navigating 'Result = Final – Initial' in chemistry, which often involves multiple layers of sign changes. According to one analysis, it was on this point that L. Szilard fatefully stumbled, thus rendering questionable the work of his many followers over the next 70 years, as they leaned too trustingly on a thin reed.(111)

[b] It can be an allusion to the humdrum workaday practice of 'reporting negative as positive', as explained on **page 289** above. See also **page 276** in connection with $1/p_n$. (Well, it's humdrum *if* you're in a context such as pH, where you're less likely to trip over [a], that is!)

[c] It can lend a sententious tone to a discussion, introducing intimations of the quasi-ontological or the semi-mystical, as if to say, "If we can think out of the box, perhaps we are only one sign-change away from discovering something great." An example of this mode would be Schrödinger's work at reconciling **Entropy** to Life via '–S' (**page 295** above).

And which of these three modes might Wiener be in, with his "simply the negative of..." or "[only] by its algebraic sign"?(112) To me it feels as though Wiener meant it in *no* particular way, taking sign change rather as a kind of intellectual toy to bat around. Call it mode **[d]** if you like.

Do you begin to inkle what a grandly absurd circus act we have before us?

One ghost clown plays with an algebraic sign as though it were a chew-toy.

Another solemnly manipulates the sign on the *left* side of the **Entropy** equation

111. For the correction, see Corning and Kline, pp. 481-482: Appendix A: "A Theoretically Significant Sign Error in Szilard's Seminal 1929 Paper on Maxwell's Demon." See also Orly Shenker's remarks on Landauer's Dissipation Thesis, as she questions the **POI** premise of S = klog 2 from several other directions.

112. Wiener, 1948, p. 11; Wiener, 1950, p. 116.

(tsk-tsk!), hoping to explain the Mystery of Life (in a regime where no mystery exists).

Another clown (the sad one) fails to check his work for sign and logic errors, in a context where the sign *does* matter, and where his whole argument might (legitimately) have turned *on* it. Oops! (Was that a banana peel?)

It would be funny if it wasn't so maddening — a half-century and more during which scholars of various stripes have all peered dutifully at the resultant runes, trying to find sense where none exists: in a few moldy peanut shells scattered across the floor of a disused circus tent. That's what they (I) have been putting under the glass.

It seems appropriate to let the filmmaker Claude Chabrol have the last word on this early and dubious chapter in the supposed book of 'Cybernetics'. In explaining how he picks his themes (typically depressing stories about the doings of especially unpleasant and inept people), he has been quoted to this effect:

> Folly is infinitely more intriguing than intelligence.
> Intelligence has its limits, whereas folly has none.
>
> *La bêtise est infiniment plus fascinante que l'intelligence.*
> *L'intelligence, elle, a ses limites tandis que la bêtise n'en a pas.*
>
> — Claude Chabrol

Source: http://www.actustar.com/biographies/chagrolclaude.html, my translation

Appendix E: Theory of Information

Suppose you wanted to develop a *real* Theory of Information. Personally I would not recommend such an endeavor because, as discussed in **Chapter III** already, the universe is not just data-*neutral*, the universe is data-*hostile*. And once you take that knowledge to heart, the supposed glamour or importance of contributing to the Information Age should wilt like so many petunias in the gardens of Nagasaki. Still, there are those few who *will* pursue the field, and to those queer folk I address this Appendix. I will talk about certain things that are not widely understood by the earthling, but must be integrated into any such undertaking.

Prologue: How *δ*ata becomes Information

We've seen in **Appendix D: The Fifty Years' Gibberish: So-Called Information Theory** that there is great potential for confusion *within* the word 'information' because most authors blithely let it run the gamut, if not quite from the absurd to the sublime, then at least from *DERN* to **Information** (as defined on page **269**). There is also a problem along the *boundary* of the word 'information' as it overlaps vaguely with that of the word '**δata**' (as shown impressionistically in **Figure 78** on page **270**).
Here is an example of ***δata***:

7607

Next, assume we are told by someone that the useful **Information** corresponding to that snippet of *δata* is this...

760.7 mmHg

...or 760.7 millimeters of mercury, a barometric reading close to standard atmospheric pressure at sea level.

Well, that seems fairly straightforward: For convenience of writing and/or reduction of keyboarding errors, it would appear that someone opted to remove temporarily the decimal point. Similarly, for the sake of saving disk space or data communication time, they also chose to drop the units, *mmHg*. All of this was deemed 'obvious' in the local context, we surmise. And it is easy enough to restore such missing pieces on demand, as we just demonstrated.

And yet, I'm going to dwell at some length on this *δata*/Information distinction that could be taught in about ten minutes to a Fourth Grade child. Why? Because in conversation and writing, even where 'technical people' are involved, the distinction — easy though it may be *in principal* — is rarely honored in practice. Instead, people use the words 'data' and 'information' in a vague, half-asleep, semi-interchangeable way, as though one had never heard of something called the Information Age.

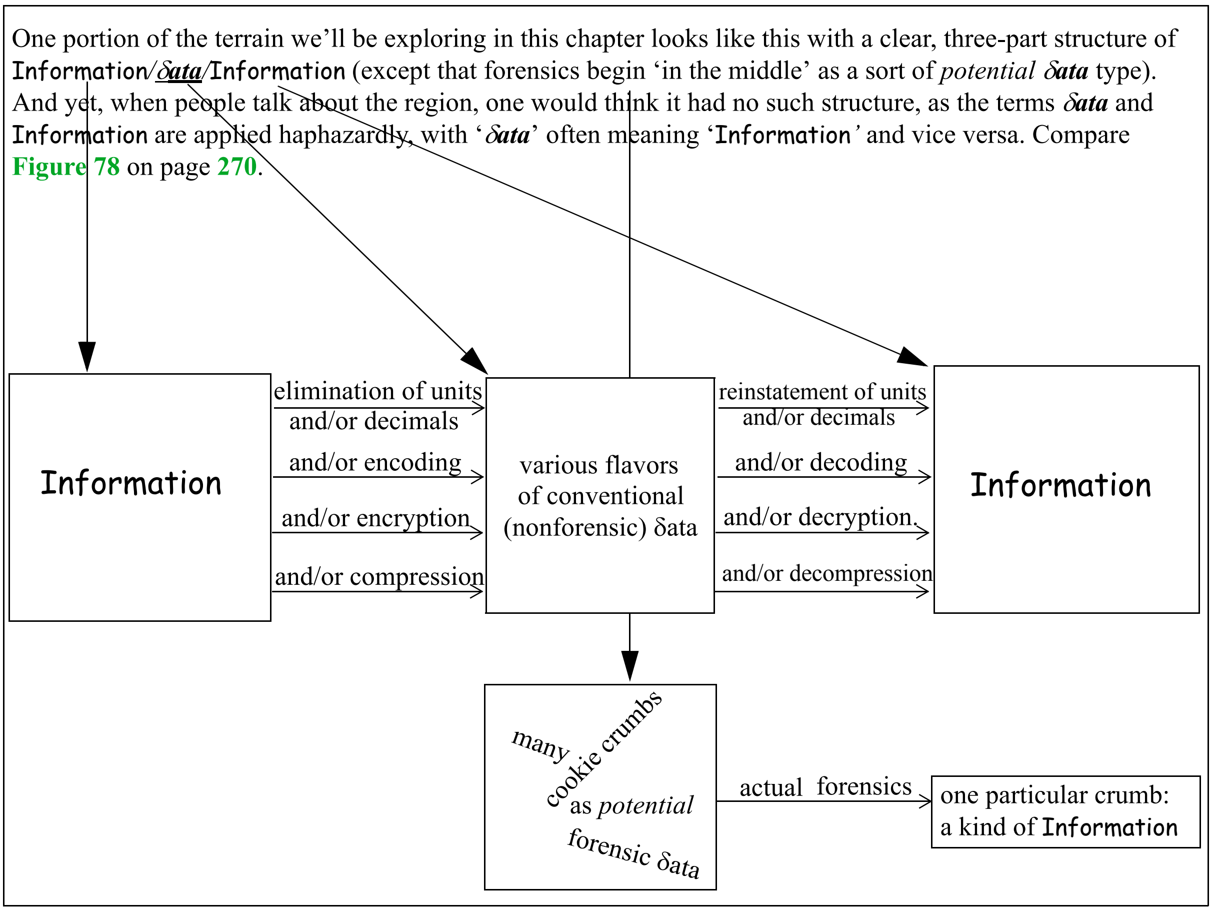


FIGURE 85: The Path from Information to δata and back to Information

Aggravating though the casual use of '*δata*' and "Information" might be to some of us (who would rather keep things tidy, along the lines indicated in Figure 85), one can think of scenarios that might partially explain the unfortunate status of these two words. Consider an

EKG strip that contains a series of acronyms such as VS = Ventricular Sense, VP = Ventricular Pace, and so on. For one who knows *only* these acronym definitions, the stuff on the EKG strip is still, arguably, 'just *δata*', which this person may or may not interpret successfully later, after the fact. For a nurse or doctor who has been trained in cardiology, the same string of abbreviations is directly 'readable' as useful information, telling a story, possibly a dramatic one, about the patient's heart. Here, the line between *δata* and Information is genuinely blurred, through no fault of the humans trying to navigate it. This doesn't make the idea of *δata*/Information distinction any less valid or useful, it just means care is sometimes required in applying it. To the one person, the EKG strip *is δata* (i.e., a string of runes that might easily be recited though without much comprehension). To the other, thanks to his or her advanced training in the topic, it really *is* Information already (i.e., its translation, up from the binary realm inside the computer chip, is already complete from this second person's perspective). One may have heard the joking about certain Computer Science types who 'think in hex' (or even in binary), meaning they can read directly a kind of computer output that others would find cryptic, requiring hours of tedious translation effort to reveal what it says in terms of familiar Arabic numerals or English alphabetical text, as the case might be. There too, one man's *δata* is another's Information, although it is happening at a lower level than in the EKG example.

And what might *metaδata* be? Its name notwithstanding, I would classify *metaδata* as a subtype of Information: it is a special kind of Information about *δata*. For an example, see **Table 16** on page **308**.

(The term *metaδata* is a misnomer, by the way, at least in my judgment. In Linguistics, the term *metalanguage* has been around for decades and it has a legitimate and useful role to play in describing 'language about language' — the special vocabulary that arises naturally in a foreign-language classroom, for example; thus, one finds an article entitled "Chinese Classroom Metalanguage" in *Journal of the Chinese Language Teachers Association*, February, 1978. But somewhere along the way the Linguistics term *metalanguage* seems to have spawned the term *metaδata* in Computer Science, as if to say one possesses '*δata* about *δata*', which doesn't make much sense. The Computer Science sister word may have a nice snappy sound to it, but alas it is not descriptive. A better name for it would have been *data attribute* or *data annotation* or *bridge information* — because it consists of [partial] Information, such as 'millimeters of mercury', capable of building a bridge from the *δata* back to

[full] Information. To me, the attempted allusion to Linguistics is subtly off the mark. But now that I've had my say, I'll follow the crowd and use the term *metaδata* as they do. However, later on I'll also propose the term meta-Information, for expressing relationships similar to those between metalanguage and language in Linguistics.)

For the record, here are some typical Webster-ish definitions of the word *δata*:

1. Factual information [as distinct from wished-for information, as in "Let's look at the marketing data and start dealing with the realities of this product line before it fails."]
2. Information *output* [emphasis added]
3. Information in numerical form that can be digitally transmitted or processed [i.e., the *input* to a program, I would say]

All the dictionary definitions I've seen are confused and deficient. They carry no hint that to those in the computer field the whole point about *δata* is that it might, in certain scenarios, *not* be Information, might even have lost its ephemeral link to the real world of meaning, forever. Granted that computer professionals, in conversation, do no better than the general public in keeping the two *words* clearly separated; still the two *ideas* are worth pursuing. Still, with or without an untainted pair of words for talking about it, the underlying *δata*/Information distinction is real.

Road map for the section on *δata* and Information

In Part One, we present an example involving bare names and numbers (**Table 13**), and we show how the simple reinstatement of a column heading, *cm* (which might have been present in early paper-and-pencil sketches of the table, we'll pretend), turns it from useless *δata* [back] into useful Information (**Table 14**). Alternatively, the addition of a *metaδata* column likewise restores the Information value of the numeric column (**Table 16**). Both methods work.

In Part Two, we put the first eight notes (notionally the whole score) of Bach's *Brandenburg Concerto No. 5* into column 2 of table, and pose certain questions about the value of [a] adding a heading to column 2 versus [b] adding column 3 as *metaδata* or *meta-*Information.

Part Three is built around **Table 20 (Novels and meta-Information)**, where each cell in column 2 contains, notionally, an entire novel. Here, the point of the rightmost column is not to turn the contents of column 2 *into* Information; rather, the role of column 3 (the *meta*-Information) is to summarize column 2 along certain axes and to illuminate additional attributes that might be hidden between the lines of the Information.

In Part Four, we revisit the nomenclature for a moment, now with the focus on '*δata*' vs. '*raw δata*'.

On page **304**, **Table 12** provides another kind of preview. This table is meant to be suggestive only, not self-explanatory. Each of its components will be discussed later in turn:

TABLE 12: **Chapter** Preview

δata type and sample thereof	metaδata for translation back to Information	metaInformation for understanding	Criminology and Forensics
Literary ‘δata’:[1] “I have just returned from a visit to my landlord — the solitary neighbor that I shall be troubled with.”	NA	Fiction by E. Brontë Subtext: a first-tier novelist.[2]	NA
Musical δata:[3] 1133 55$\overline{11}$	Violin part for a concerto in D major. “Oh, so it *means*: 	Music by J.S. Bach: Subtext: a first-tier composer.	NA
Conventional Numeric δata:[4] 7607	Assume 1 decimal and units of mmHg. “Oh, so it *means* 760.7 mmHg.”	Context: Atmospheric pressure is 760 mmHg at sea level.[5]	NA
Potential forensic δata: some cookie crumbs of various indeterminate sizes scattered about haphazardly	NA	NA	Detective work that brings *the* significant crumb[6] into the limelight.
Self-Oblivionating δata: 99.99% of all δata simply vanishes, as though thumbing its nose at our much vaunted ‘Information Age’.	NA	NA	NA

1. The quotes around ‘**δata**’ are explained on **page 316**.
2. If your impressions of Emily Brontë come from Hollywood movie renditions of *Wuthering Heights* (or from PBS for that matter), you may be puzzled by my reference to her as first-tier. What one must do is *read* the book (or better yet, listen to it read by the incomparable team of Michael Page and Laural Merlington, whose unabridged recording is available via www.brillianceaudio.com). Then read Paglia, pp. 439-459, then reread Brontë.
3. I’ve represented the notes first in numeric form, by way of pointing up their δata-nature in column 1, then as conventional notes, to suggest their transformation to Information in column 2. These are the opening notes of Bach’s *Brandenburg Concerto No. 5*.
4. Rows 3 and 4 of this table correspond roughly to the two rows in **Figure 85** (**page 300**).
5. But for an alien reader light-years away, it still might not be comprehensible until augmented along these lines: “760 mm of mercury in a **J**-shaped siphon-barometer, open on the short arm of the ‘**J**’, this being the amount of the liquid metal that can be pushed up into (and balanced within) its long arm by the atmosphere at sea-level on Earth, the third planet from Sol, on a day deemed ‘nice’ by Earthlings.”
6. Compare the role of teacup number 61803 in **Figure 95**.

Part One: δata on a mystery disk

At a garage sale, I come across a stack of diskettes from a bygone era, ignominiously held together by a yellowing rubber-band ready to break, the whole package priced at "50¢ OR BEST OFFER," let's say. I offer 25¢ for the lot of them, and the antique database application is mine, including a few diskettes whose labels, written carefully with a blue felt-tip pen, suggest that they might contain database *tables* of some kind. At home, I pop one such diskette into my oldest PC in the attic (the only one that can read such a relic from the dawn of the Information Age) and I see this:

This mystery table has no caption and no column headings.

TABLE 13: ???

Ahab, Courtney	176
Barber, Samuel A.	152
Carter, Elliot	160
Delaney, Patricia	171
Foss, Lucas	151?
Kupka, Joseph	175
Lemming, Bernie	---
Steinway, Leonard B.	171
etc	etc

Am I looking at some kind of useful **Information**? Or is it merely inscrutable *δata*? That's the question.

Because there is no context, no *meta***δata** (i.e., no annotations *to* the *δata*), no unit of measure (like '176 cm', '152 cm'...), no heading for column 2 (such as 'cm' or 'USA Area Code' or 'Checking Account Suffix'), what I'm looking at is *just* **δata**.

Relative to what its value would be if column 2 carried a heading, the value of this sphinxlike table is quite low. For all I know, I may never find a way to turn it (back) into useful **Information**. Never is a long time to languish as 'just **δata**', but this is a real possibility.

You've just seen an illustration of how the terms 'information' and 'data' *might* have been used over the past fifty-odd years to actually mean something. Sadly, such usage (recommended by authors of books about Data Base Management Systems back in the 1980s) never caught on, not even among computer professionals, much less in other areas. Instead, we have "Get me the data-sheet on chlorine spills" or

"Tell me what the radar data says", and so on — any number of cases where someone is requesting Information in a time-sensitive life-or-death situation but they're calling it δata. Conversely, someone might say, "What information did we glean from Voyager?" But the one sure thing about stuff recently obtained by telemetry from a space probe is that it's *not* (yet) Information — not by a long shot. Storage space is precious on any such aerospace project. So you leave out decimal places, you leave off the units, and you ruthlessly compress what is left. To elicit the Information that hides behind all that gibberish (all that **δata**), you run it through a suite of conversion programs back on earth, where it is understood that a decompressed blob of digits in *this* part of the telemetry contains an implied decimal before every group of, say, five digits, and the differently blobbed digits in *that* part of the telemetry contains implied pairs of, say, measurements in whole centimeters; and so forth.

The road from the **δata** back to Information is tortuous and error-prone.(113) Example: circa 2002 came a red-faced correction from astronomers about the Color of the Universe. Seems it was not a pretty turquoise shade after all, but only a kind of nondescript brown. They had gathered no storehouse of Information about the Color of the Universe, only reams of sphinxlike **δata** to pore over. And they had pored wrong. (And for my money, not only the initial statement but also the 'corrected' statement is suspect.)

The toy values that I've thrown into **Table 13** depict a relatively easy case of orphaned **δata**, severed from any context. Given a slightly larger sample of such paired names and numbers (say thirty of them instead of eight), and time enough to do comparisons against a few commercial databases, we could make an educated guess about the general nature of the values in column 2. We might conclude, for example: "They are not area codes; they are not weight in pounds; more likely, they denote the person's height in centimeters."

113. This will give you the flavor: "[Systems] used in sending data back from deep-space missions...make use of sophisticated error correction, including convolutional coding and decoding using the Viterbi algorithm." Pierce, p. 196.

TABLE 14: Height in Centimeters

	cm
Ahab, Courtney	176
Barber, Samuel A.	152
Carter, Elliot	160
Delaney, Patricia	171
Foss, Lucas	151?
Kupka, Joseph	175
Lemming, Bernie	---
Steinway, Leonard B.	171
etc	etc

Then, by the simple act of adding 'cm' as a heading over the numbers, we transmute them from **δata** into **Information** (see **Table 14**). Perhaps these individuals constitute a control group for a study of osteoporosis patients? Something like that.(114)

All of this is by way of saying that in the world as we know it, **δata** swims in a rich and teeming Ocean of Context. Thus, we can often let meaning take care of itself, in the following sense:

Let's say I'm a clerk at a hospital. Someone provides me the runes of **Table 13**. I attach them to an e-mail that I send to a doctor outside the hospital. The doctor recognizes the names and turns the numerical column into a set of heights expressed in centimeters (because they are in fact part of an osteoporosis study). To me it is only (inscrutable) **δata**, but upon receipt by the doctor it is instantaneously transformed into **Information**, as depicted in **Table 14**. And, potentially, the same transformation can be repeated for the sake of *anyone*, if only the doctor makes explicit on paper the heading for column 2 (which is already in her head, based on context): *cm*.

There is another way that the **δata** of the mystery table (**Table 13**) might have been turned into **Information**. Somewhere in the stack of garage-sale disks, suppose I found another table that contained the same set of names (Ahab through Steinway),

114. However, we might observe later that the digits '8' and '9' never occur in our sample. Could this mean that the whole thing was done in octal (which uses only the digits 01234567), not decimal? Really we should consider what the raw **δata** would look like if decrypted on that tentative assumption, just to be sure. Thus, under the octal presumption, 176 really means 126; 152 really means 106; and so on.

now associated with a set of comments or attributes. See **Table 15**.

TABLE 15: Comments for merging with **Table 13**

Ahab, Courtney	height in cm
Barber, Samuel A.	height in cm
Carter, Elliot	height in cm
Delaney, Patricia	height in cm
Foss, Lucas	stood hunched over
Kupka, Joseph	height in cm
Lemming, Bernie	withdrew from the study
Steinway, Leonard B.	height in cm
etc	etc

In this case, simply by merging **Table 13** with **Table 15**, we can turn the δ**ata** into **Information** on a row-by-row basis with no need for column headings:

TABLE 16: The δ**ata** married up with its respective *meta*δ**ata**

Ahab, Courtney	176	height in cm
Barber, Samuel A.	152	height in cm
Carter, Elliot	160	height in cm
Delaney, Patricia	171	height in cm
Foss, Lucas	151?	stood hunched over
Kupka, Joseph	175	height in cm
Lemming, Bernie	---	withdrew from the study
Steinway, Leonard B.	171	height in cm
etc	etc	etc

Table 16 illustrates one kind of *meta*δ**ata** — explanatory text placed in a field (or in many fields) of Comments or Attributes that go 'beyond' the δ**ata** itself; hence the prefix *meta*. The purpose of the *meta*δ**ata** is to explain what the δ**ata** is; or what its rationale is; or how reliable it is; or why it fails to appear in a given row; and so on. Note that the columns still lack headings, but in this case we don't care since each row explains itself fully. In fact, one may make the argument that **Table 16** is better than **Table 14** since it lets one know why there was bad δ**ata** ('151?') for Foss (because he stood hunched over) and why there was the missing δ**ata** ('---') for Lemming (because he withdrew from the study before we got around to measuring him). We've given up the efficiency of a concise '*cm*' as our column heading, but we've gained the ability to explain any irregular item in detail, if need be. That's the trade-off.

Here's another example of the δ**ata** / **Information** contrast. Consider the following row of **δata** that lies somewhere between the Murky and the Incomprehensible:

```
Smote,LaPleyel,Heathmett,1,3,0,Brad,Mary,Jake,
Betty,John,Jillian,Thomas,Pip,Sylvia,Dee
```

What could it possibly be? Feed it as input to the right computer program, and in a blink you can see several thousand rows of such **δata** [Level 2](115) transformed into something like **Table 17**, now quite coherent as [Level 3] **Information**:

TABLE 17: Families, Sorted by Number of Children

Surname	Number of Children	Given Names: Adult 1, Adult 2, Child 1, Child 2...
Heathmett	0	Sylvia, Dee
Smote	1	Brad, Mary, Jake
LaPleyel	3	Betty, John, Jillian, Thomas, Pip
etc	etc	etc

How wonderful that a simple column heading like '*cm*' in **Table 14**, or '*Number of Children*' in **Table 17**, can bring about such an alchemical transformation!

Finding the right heading — might this be the Key to Everything? In Parts Two and Three of this discussion, we will try applying the same principle to increasingly complex structures in music and literature to see if the idea holds up. (Or, in terms of the present example, we might make the following observations already: Yes, **Table 17** brings forth the *general* idea that we're looking at a representation of families and the number of children in each. But only a human reader will pick up the nuance that Sylvia and Dee seem to comprise a 'nontraditional' family, and only an acquaintance or neighbor will really know some of the personalities behind the names, e.g., the neuroses and eccentricities of Betty LaPleyel, which leap to mind every time we see her name in print. Shouldn't there be a way to flag these as successively 'higher' kinds of **Information**?)

115. In this section, in anticipation of 'L1, L2, L3...' in **Figure 94**, I've begun using labels to suggest gradations of value: **δata** = Level 2 (because Level 1 was used up already by Potential Forensic **δata**, a lower type); various kinds of **Information** = Level 3 or higher, as warranted.

Part Two: Musical δata and Information

Let's say an extraterrestrial comes looking for signs of intelligent life on earth. After noting that something called *Brandenburg Concerto No. 5* had been published as a pocket score umpteen times on earth, she might take 10 seconds to teach herself Earthling Music Notation, then read the score, then mentally convert it to tabular form for further evaluation. At that juncture, it might look like **Table 18** (inside the extraterrestrial's head), where we've shown the first two beats of the Bach composition as numerals in lieu of notes. (This numeric notation system works nicely for attempting an extraterrestrial's view of the music, but it is by no means limited to that use: Such a system is in fact used to teach singing in grade school classes the world over, though it is less popular in the USA than abroad. The overline on '1' denotes the higher octave. A snippet of the actual score was given in **Table 12** on **page 304**.)

TABLE 18: Johann Sebastian Bach: δ**ata** or **Information**?

Violin	1133 55$\overline{1}\overline{1}$
Viola	3___ 3_
Cello	1___ 1_

Earlier, in connection with **Table 13** and **Table 17**, we noted the near-alchemical effect of adding a simple column heading to an otherwise inscrutable set of numeric values. Viewing **Table 18** from that perspective, please tell me what magical headings could transmute *its* lead into gold?

Alternatively, the extraterrestrial might have converted the score into the following graceless looking solfa that she hummed in her little green throat (nervously, since she is busy and has better things to be doing just now, like recharging the atomics that power her flying saucer):

do-do mi-mi sol-sol DO-DO

It doesn't matter. Either way, I have the same question:

What *then*?

How would she discover the useful **Information** engraved *by BACH for* Posterity, human or otherwise, *in* the Important Mile-High Runes of *1133 5511*?

From the viewpoint of an extraterrestrial, **Table 18** might look very similar to

Table 13 — just a column of names (this time instruments instead of people, but would she know or care?) associated with numeric **δata** in column 2. Or, would the extraterrestrial be smart enough or polite enough to see it just as the musicians do on Earth: as **Information** par excellence? (For a closely related discussion that I noticed some years after drafting the above section, see "An Unlikely UFO" in Hofstadter, p. 162.)

My fear is that the hypothetical extraterrestrial would see it only as **δata** since, for that matter, many of our own earthlings see it that way and would only scoff at the meta-**Information** 'first-tier composer' as shown in **Table 12** (**page 304**) because their musical taste is narrow. In an uncharacteristically dark moment, even Douglas Hofstadter acknowledged this aspect of music:

> To some, this art [of Escher's] will perhaps appear "merely mathematical" — but then, to some, the sublimely powerful fugues of J.S. Bach sound like nothing but a sewing machine mechanically clicking and clacking away.
>
> — Douglas Hofstadter, in his Foreword to Schattschneider, *M.C. Escher*, p. viii

Exactly. There's the rub.

And why does all this matter? Because the reputation of Earth pretty much hinges on this hypothetical moment of communication or miscommunication, doesn't it? When it's all said and done, Bach is basically all we've got to make the argument that we were something more than outsized viruses who encased our gene-bags in zippered trousers, and talked ad nauseam about our favorite TV shows, all the way until we blew ourselves up or the sun blinked out.)

If you would prefer a visual example, consider the pattern '0010100000100001011...' which is the upper left-hand corner of a bit map representation of the Mona Lisa — some of the Mona Lisa's **δata**, in other words, as distinct from the **Information** content of 'the Mona Lisa' as understood by so many millions of you earthlings. How exciting will that be to an extraterrestrial? Enough to make it want to keep going until the whole image is represented?

The point of such examples is this: When we step back a bit from the process of data communication, we see that the **δata**-*only* view of the **TOES**[116] theorists is greatly simplified from reality: For most of the **δata** that they endeavor to communicate as 'information', the only reason it works (i.e., the only reason it is

116. TOES = Theory of the Encoding/decoding of Signals. Defined in **Appendix D: The Fifty Years' Gibberish: So-Called Information Theory** on page **270**.

deemed 'successful' or 'of value') is context — a context such that **Information** is created at the receiving end, outside the blitz of encode/decode activities that comprise the 'data communication' event itself. (In this connection, see also **Context is everything: The Teacups in Tableaux A, B, C** on **page 353**f.)

Shannon was well aware of the distinction.(117) His clear thinking and respect for the distinction notwithstanding, he found himself running out of words, though; and for that reason alone, he chose to employ the word '*information*' in a figurative sense sometimes, to avoid phraseology that would have been ungainly. That's my hypothesis.(118) Unfortunately, his usage has been slavishly imitated and perpetuated by others, some of whom have only a woolly notion of the *DERN (aka Shannon information)*/**Information** distinction and the *δata*/**Information** distinction.

Continuing with **Table 18**, note that within its elusive **Information** content, there are several layers to consider:

Level 1: One must 'know music' in a general way.

Level 2: One must 'know the kinds of music' (such as Javanese gamelan; occidental classical; heavy metal; Moon Pie Kazoo; and so on.)

Level 3: Finally, to actually 'get it', one must in some sense 'know Bach', specifically.

Level 4: And to really *really* get it, perhaps one must be Glenn Gould — someone of that caliber.

The piece we've sampled in **Table 18**, Bach's *Brandenburg Concerto No. 5*, is the one that music lovers (including yours truly) always rate highest in those concert lobby polls about "If you were allowed to take only *one* piece of music to a desert island, which one would it be?" With or without that supporting statistic, it is arguably one of the most fantastic and enduring pieces ever composed; *and yet*, to our beetle-browed space alien, we fear that it says just this...

`do-do mi-mi sol-sol DO-DO`

...which isn't all that different from the melodic contour of "On Top of Old Smo-o-o-[key]..."

Well, *that* certainly doesn't look very original or inspired! It could be a warm-up

117. "These semantic aspects of communication are irrelevant to the engineering problem." Shannon, p. 1.
118. Supported by remarks in Kåhre, p. 2.

exercise for students in middle school choir. Will the space alien even bother listening to measure 2 and beyond? Will she *get* it?

Or, if you prefer, consider the first few bars of "Thunderstruck", as written and performed by Angus Young of *AC/DC*. Same problem. In a cold objective **δata**-only description, here is what we get: Some noodling on the guitar, to this effect: `ti-sol-la-sol` in alternation with `DO-sol-la-sol`. That's only slightly more complex (i.e., it has only slightly more *DERN (aka Shannon information)*) than the opening of the Bach piece; I'm guessing that our impatient space alien might still be underwhelmed, even by the "broadly based appeal" of *AC/DC*. How to convey to her the **Information** that makes Angus *Angus* or makes Bach *Bach*?

A musical example such as the *Brandenburg Concerto No. 5* places us in-between the two cases identified in **Figure 85** (**page 300**) as potential forensic **δata** and conventional **δata** (in computers and communication). When presented with the score of a composer (especially if it is a composer who lived long ago), one is forced to skip the left column and start at the middle column with a kind of **δata** whose original transformation *from* (musical) **Information** is relatively unknown or inaccessible. One proceeds toward the right column anyway, hoping he can turn the **δata** into **Information** *anyway*. When you look at it this way, it's quite a remarkable process (see **Figure 86**).

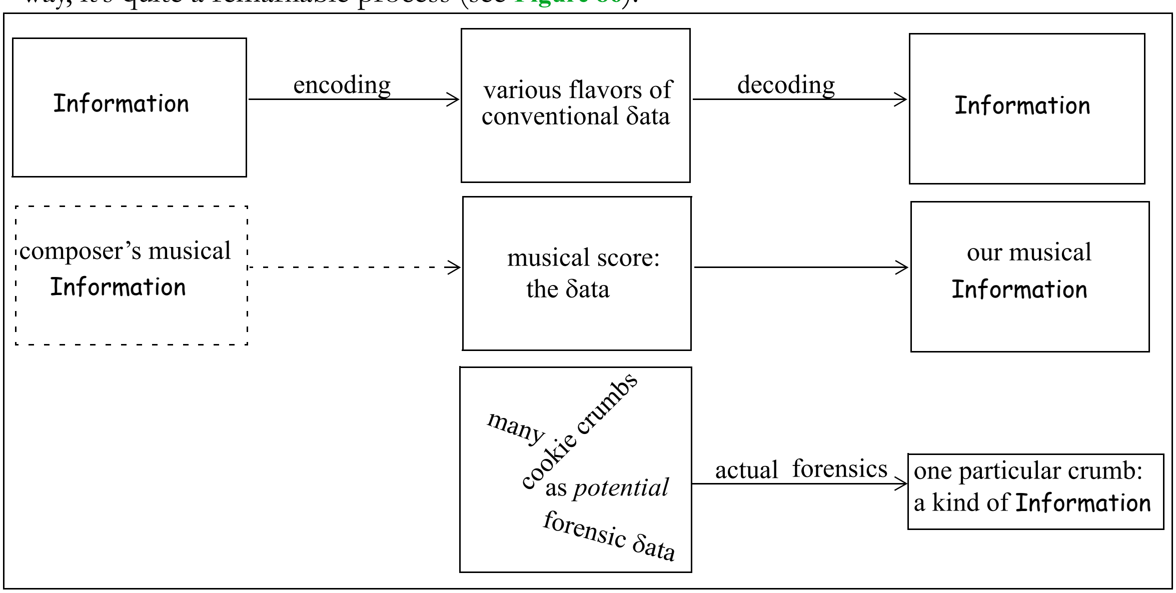


FIGURE 86: Decoding artistic δ**ata**

Remarkable that anyone can claim to 'read Brontë' or 'listen to Bach' and feel that he or she is in receipt of the message or, say, 75% in receipt of the *intended* message from this dead white female genius or dead white male genius.

Back to **Table 18** for another look. For starters, we would have to consider the way a violin is bowed (as opposed to how it feels to mouth '`do-do mi-mi sol-sol DO-DO`'); or, switching to the *AC/DC* example, we would want to consider the way Angus Young struts and grimaces and grins while delivering that endless eternal line of virtuosity on his guitar. That sort of thing. And of course little of this can be supplied merely by finding the right headings to add to the columns of **Table 18**. About the specifics of *that* exercise I was just kidding; but in *principal*, it's still true. That's the daunting realization. Just as **Table 13** needed a column heading like '*cm*' (**Table 14**) or a *meta*δ**ata** column (**Table 16**) to turn it into **Information**, so **Table 18** needs something like that — it's just that the 'something' is not forthcoming, as indicated in **Table 19**. Viewed one way, **Table 19** is like a variation on **Table 13**; viewed another way, it's a variation on **Table 20**, requiring not *meta*δ**ata** but *meta*-**Information** in the rightmost column:

TABLE 19: In search of helpful column headings for the Bach δ**ata**

Instrument[1]	**??** Well, whatever it is, we see now that there's "lots more where that cam from", all equally good:	*...but is it metaδata* or *meta*-**Information** that our hypothetical alien visitor needs in this column?
`Violin`	1133 $55\overline{11}$ $7\overline{1}76$ 5432 1133 $55\overline{11}$ $\overline{2}$_5_ etc	??
`Viola`	3___ 3_ 2_1_ 2_7_ 1_5_ 1_3_ 7_1_ 2_7_ etc	??
`Cello`	1___ 1_ 5_6_ 7_5_ 3_2_ 3_1_ 5_6_ 7_5_ etc	??

1. Note to Space Aliens: These are all *string* instruments of the Baroque Period, played with a *bow*, which makes them sound really different and incomparably *better* than if one were simply to sing the phrase as `do-do mi-mi sol-sol DO-DO tiDOtila solfamire do-do mi-mi sol-sol DO-DO RE_ la_`. Do you see? (Really? How do I know? Does the color red 'mean' the same to you and me?)

As it stands, it might fall flat. One fears that it will prove to be an embarrassment to bipeds everywhere. Not a Bach masterpiece, replete with crucial **Information** about our splendid species, just some stupid-looking δ**ata** that we'd best hide from the space alien lest she conclude that we're not very with-it.

That's the pessimistic view. A more optimistic view goes like this: the barn swallow is able to build its nest anywhere it finds two of our structures — say a barn and its attached hen house — forming a right angle. The result of its labor is a sort of inverted pyramid of dry mud that floats in the corner with "no visible means of support"; paused on the tundra, beneath the moon, a trio of wolves will sing in three-part harmony; whenever a certain diminutive species of octopus(119) sallies forth from her grotto, she carries in her curled fist a bouquet of Portuguese Man-of-War sting nettles to warn off enemies; and so on. In all these cases, although I am a higher animal looking 'down' upon the culture of an alledgedly lower animal of the air, land or sea, I *think* I understand the culture, and certainly I admire and *appreciate* it, the genetic chasm notwithstanding. So far so good. But an extraterrestrial would not have the benefit of all the genes I *share* with a barn swallow, a wolf, a Tremoctopus. That's where I begin to worry about the potential for grotesque miscommunication.

Is Information 'about' something?

Jan Kåhre cites a definition of the word 'information' from the *Oxford Advanced Learner's Dictionary of Current English* (1974) in support of his idea that Information must be *about* something. This in turn leads to his notation scheme **inf(B@A)**. This means 'the information B gives about A', which he then employs in various mathematical formulas throughout the book (see Kåhre, pp. 3, 486, and *passim*). Earlier when I wrote "Not a Bach masterpiece, replete with crucial Information about our splendid species," I was being sarcastic, so that doesn't count as an 'about' relation. If Bach and Beethoven have value, it's precisely in their ability to show one something far, far *beyond* his pathetic species, not because these composers "celebrate the human potential" or "exemplify humanity at its best", as the Liberal Arts folks and Pulitzer prize committees would pompously have it. The point of such music is precisely to create a kind of Information, but the music is not 'about' anything other than itself.

If it was clear to everyone what Bach is 'about', then they would be confident of their ability to make it understandable even to a dullard with no particular aptitude for music or even to someone 'too smart' to get it, such as a hypothetical extraterrestrial. But people have no such confidence. The music is just about itself,

119. The Tremoctopus, two inches long, and powered by copper-based blood. See Michael Chester, *Water Monsters* (Grosset & Dunlap 1973), pp. 29-37.

and that's difficult to explain to one with unsympathetic ears.

Part Three: Literary 'δata' and meta-Information

We begin by placing **δata** in quotes. This acknowledges the commonsense notion that literature is already Information, not in need of a **δata**/Information conversion. But then reading and comprehending a novel by Conrad or Dickens is not for everyone, and we can acknowledge the space between a dull mechanical 'reading' and an actual engagement with such an author by introducing the term *meta*-Information. I use the term *meta*-Information in a very broad sense to include not only statements about a work of literature (or music or painting) but anything the reader brings along with him by way of past education.

At first glance, it may seem that my so-called *meta*-Information about the five novels listed in **Table 20** is simply a kind of literary criticism given a different name.(120) If you bear with me, I hope to persuade you that this is something new — that it really is an extension of the topics introduced earlier, and thus a way of entering a new intellectual domain. (In terms of the Level 1, Level 2, Level 3... scheme that was introduced in **Part One: δata on a mystery disk**, we are now looking at a Level 3 / Level 4 contrast. Later we'll need these levels as a navigation tool. Here I introduce the idea only in passing.)

120. And, "Why must you use such an ungainly term as *meta*-Information?" one might ask. Candidly, in a more relaxed context, I would just label the columns **δata** and *meta***δata**, and be done with it. But in an attempt to practice (here) what I preach (elsewhere in these pages), I've worked through the logic and concluded that the relationship between column 2 and column 3 in **Table 20** is of a higher order than it was in **Table 16**, hence the new headings to acknowledge this fact. And if the column 3 heading lacks aesthetic appeal, so be it.

TABLE 20: Novels and *meta*-Information

Author, Title[1]	The text as Information (imagine that a whole novel is placed in each cell)[2]	column 3: *meta*-Information
Arthur C. Clarke *2001: A Space Odyssey*	"The drought had lasted now for ten million years, and the reign of the terrible lizards... ...For though he was master of the world, he was not quite sure what to do next. But he would think of something." [297 p.]	moderate to poor coherence; uneven word-sense; zero web-sense[3]
Emily Brontë *Wuthering Heights*	"I have just returned from a visit to my landlord — the solitary neighbor that I shall be troubled with... ...and wondered how anyone could ever imagine unquiet slumbers for the sleepers in that quiet earth." [372 p.]	very high coherence; good word-sense, too; web-sense assumed[4]
Stephen King (as "Bachman") *The Regulators*	"Poplar Street/3:45 P.M./July 15, 1996 Summer's here. Not *just* summer, either, not this year, but the apotheosis of summer... ...And a sense, almost, of coming home." [466 + 9 p.]	very high coherence; good word-sense, too; web-sense assumed[4]
Joseph Conrad *Victory*	"There is, as every schoolboy knows in this scientific age, a very close chemical relation between coal and diamonds... ...and then murmured with placid sadness: 'Nothing!' " [385 p.]	strong web-sense; strong word-sense and high coherence assumed[4]
V. S.Naipaul *A Bend in the River*	"The world is what it is; men who are nothing, who allow themselves to become nothing, have no place in it... ...The searchlight, while it was on, had shown thousands, white in the white light." [278 p.]	strong web-sense; strong word-sense and high coherence assumed[4]

1. For publication details, see **Literature Cited** on page **457**.
2. Here we've used a symbolic approach, copying in the opening and concluding lines only, for each of the five novels. This way of looking at novels — each as a single object — is less theoretical or fanciful than it might seem at first glance. A professional writer/reader/editor of novels does in fact endeavor to hold the entire novel in his/her head at once. As though it were a single, complex object of contemplation. Depending on one's success at managing the text from that height, the resulting work might rank as passable or possibly a candidate for greatness (if other things fall into place).
3. I explain my terms *word-sense*, *web-sense*, and *coherence*, on **page 318-324** following this table.
4. Once we get beyond the problematical work of Clarke, the four the remaining novelists in the table have all three attributes strongly in evidence: *coherence, word-sense*, *web-sense*. It's just a question of which criterion for excellence we tend to notice more. For Brontë and King, one assumes (and finds) good *word-sense* and *web-sense*, but *coherence* is the attribute that I tend to notice — because the dizzying complexity of Brontë's storytelling frame must make it especially difficult for her to be coherent; because the sheer volume of output from King makes it all the more surprising that he can be steadily coherent in every novel. Moving on to the very highest grade of writer, for a Conrad or a Naipaul one assumes (and finds) strong *word-sense* and high *coherence*, of course; but when studying an author of such Olympian rank, one is even more interested in noting evidence of his *web-sense*, this being the most advanced and difficult of my three proposed criteria for excellence.

There comes a moment of awakening from the fog of adolescence when we realize why the English Composition teacher doesn't like to see constructions such as this in our papers: "What happens when that happens is..." or "The unemployment rate is employed as..."

Sometimes it is surprisingly difficult to wring these mindless kinds of resonance (that aren't truly resonant) out of a given sentence, but at least one understands the principle: it's embarrassing, it looks silly when you let a word mindlessly repeat itself within the very same sentence. But if you think that's difficult, consider the challenge faced by the professional writer of fiction, where the same principle is extended over the length of a novel, never mind if the text is 500 pages long. The principle still holds: word repetitions there may be, but they had better occur rarely and with full consciousness of the writer, and with a purpose the reader can discern. Otherwise, the reader feels cheated. The author was asleep.

I call this *word-sense*. If the writer is good, he/she will have a keen sense of which words and images and phrases have been 'used up' already, and will assiduously avoid revisiting any of them *unless* aiming for a special effect. To one who doesn't write, this degree of control over a 500-page manuscript may sound incredible, suggesting supernatural ability, but it's a fact — it is part of what makes a writer a *writer*: even in a long novel, the writer has an Olympian knowledge of *what is there*, just as you and I know what streets and stores exist or don't exist in our town. So should the reader strive for some approximation of this view, by the way; otherwise, if one experiences the book the way one does farmland as seen from the window of a speeding train, he has not really experienced the book along with the author as intended.

To take an extreme example of how this works, consider the words 'enchanted' and 'placid' in the novel, *Victory*, by Joseph Conrad. Always, the word 'enchanted' is associated with the protagonist, Axel Heist. Even more noticeably, the word 'placid' is fairly glued-on to poor old Davidson, if not as the root word 'placid' then as a derived word, 'placidity' or 'placidly', for a total of sixteen occurrences, half of them falling in Chapter 5, and one of them on display in the final sentence of the novel. Like a Wagner Leitmotiv, the word 'placid' becomes synonymous with Davidson: If you spot the word 'placid' in the text, then Davidson is sure to be nearby; conversely, if you see Davidson coming along the wharf, the word 'placid' is sure to follow, like his faithful dog. Thus, between the covers of *Victory*, the two adjectives *enchanted* and *placid* are both 'spoken for'. They are 'married', if you like, to specific nouns, as surely as certain atoms bind with other atoms to form molecules, based on their valences: 'enchanted Heist', 'placid Davidson'.

Saying it another way: the two adjectives are willfully removed from the writer's own palette, and are thus not available for use elsewhere in the novel.(121) (There are so many specialized occurrences of 'placid', one might even argue that Conrad was heavy-handed about the device. But that's a matter for the critics to ponder. Here we are trying to stay focused on the **TOES** facet of novel-writing. I'll just say in passing that I regard *Victory* as a novel that is generally *under*rated. It's a relatively unknown work that contains some of Conrad's greatest writing, granted that the portrayal of Davidson might be deemed quirky or overdone.)

Here is another example of repetition, in a different configuration and with a different purpose and effect: When V.S. Naipaul uses a rose-petal simile on p. 184 of *The Enigma of Arrival*, and again on p. 293 of the same novel, I'll stake my life on a bet that he did it for an effect and with full consciousness. How can I be so sure of this? I'm aware of the danger of a circular argument, but I have to say: Because repetition of this kind is so rare in Naipaul; that's why. The fact that repetition is so assiduously avoided everywhere else suggests that when it is allowed, it means something.(122)

What about the little words? Surely they constitute an exception? Yes, there are some obvious 'noise' words such as *the* or *a* that are not part of the unwritten law alluded to above. But even those small words are managed stringently by a professional writer, only in a different dimension. Although many speakers of English as a Second Language seem to disbelieve the magic, the choice of *the* versus *a* or of '*the hat*' versus '*her hat*' can have a dramatic impact on the meaning of a sentence. So, of course, those words too are managed with great care, although it's not a question of "Should I allow a repetition [yet] of that word?" Rather, the question is "Which word works best in this sentence — *a*, *the* or the possessive?"

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121. The one exception being when "the placidity of [a] domestic cat dozing" is attributed to Ricardo, the gambler (Part II, Chapter VII, p. 139). Now, which is more likely: That Conrad fell asleep at the switch? Or that he made a calculated decision to let the word do double-duty this way, in violation of the unspoken law, because he felt that he 'needed' it that badly for painting his picture of Ricardo? From the way I've constructed and slanted the two-part question, you can see that I believe in the latter explanation. Writers like Clarke fall asleep at the switch. Writers of the Conrad caliber do not. So you seek an alternative explanation when the rules are violated.
122. In this instance, it's what I would call a 'rhythmic' repetition (with minimal story-line impact), invoking a slight flavor of Robbe-Grillet — something like that. Whatever it was, if you know much about Naipaul (and great writers in general), you'll understand why I'm so certain that he did it on purpose.

Another exception to the rule of no repetition is what I call 'artistic insurance-policy redundancy'.

To see how a work is progressing, the writer must test and retest each new draft with his *word-sense* (which answers the question: "*What* words are in the text?"), and also with his *web-sense*. This term answers the question "*How* do they all interact with one another?" It's as if, to a good fiction writer, every single word has its own 'molecular weight' within a given opus, and it is placed just so for the sake of keeping the whole structure balanced — just as a sculptor would manage the balance of a mobile made from metals of many different densities and shapes and sizes, except that in a novel the pieces are invisible and the notional 'mobile' is fabulously complex.

Clearly, *word-sense* and *web-sense* are closely related. Only for the sake of analyzing good and bad writers along a gradient is it useful sometimes to separate the two closely related senses, since a mediocre writer might have reasonably good *word-sense* but not have the talent for *web-sense*. With regard to a top-notch writer, the distinction is less interesting since both are liable to be present at full strength.

Novel-writing as the n-factorial craft

Suppose you want to play mad scientist or alchemist with 4 vials of colorful but unknown elixirs, trying out all possible combinations, two-by-two, to see if there might be a reaction. You can prepare for the experiment by setting up a table this way...

	A	B	C	D
A				
B				
C				
D				

...where shading designates a cell you won't use because (a) it would create a redundant combination, or (b) it would represent the nonevent of having mixed a given chemical with itself (AA, BB...). The blank cells are the ones you'll actually use to record the results of six combinations, each in turn: AB, AC, AD, BC, BD, and CD. For larger numbers of chemicals to test, two by two, is there a general rule for determining how many combinations there will be (i.e., how many unshaded cells there will be in a given table)?

Yes, it is called the Combination Rule, comprised of three factorials...

$$\frac{n!}{(n-k)!\,k!}$$

...where *n* is the number of chemicals on your palette, and *k* is set equal to 2 since you intend to mix only pairs of chemicals (not trios or quartets of them, which would be stoopid and dangerous). Trying out the statisticians' formula on the above example, we get the following: 4x3x2x1 / (2x1)(2x1) = 24/4 = 6, which matches the number of unshaded cells in the grid we constructed by brute force.

For 10 vials we calculate the number of unshaded cells in the resultant 10 by 10 grid as 362880/40320(2) = 45 pairs of elixirs to test. And so on. (We'll soon be dealing with a very large grid, hence the need to start thinking about a formula.)

What other sorts of creative activity have intensive cross-indexing — explicit or implicit — that might be suggestive of this 'n-factorial relation' (as the math geek would call it, with a gleam in his eye)? Two come immediately to mind: poetry composition and computer programming.

In a poem, one is aware that every word interacts potentially with every other word. So the number of two-word combinations that is implicitly managed or sensed in the 45-word stanza at the top of **page 374** (to take a random example), must be 43!/(41!2!) = 905.

In computer programming, an innocent-seeming tug over 'here' on one thread will cause vaguely expected though not precisely known trouble over 'there', as an undesirable side-effect of one's attempted fix or enhancement or 'maintenance' of the code. In short, fixing one bug often seems to induce a new bug to present its ugly face. This is far from being a literal n-factorial situation, but it definitely has that *feel* about it, as though anything potentially can have a side-effect on anything.

What is not so well-known, except to the very talented people who actually produce such works, is that certain novels are also n-factorial — just like poems, but now with a literally astronomical number of word-pairs to manage — as though delicately balanced in the notional 'mobile' mentioned earlier, as it floats inside the writer's mind (and — to an extent — inside the reader's mind, too, the author is entitled to hope). With writers of the caliber of Conrad, Brontë, and Naipaul, one can sense complete control of the mobile. Since every word has its own special weight and personality in the author's mind, if ever it is repeated within the 300, 400, 500... pages of the novel, it will be repeated for a well-considered reason. (We will allow an exception for mundane words such as 'the' and 'a' — maybe. We can only say 'maybe' because sometimes the difference between choosing 'the' or 'a' as the article has earth-shaking consequences — a concept that some speakers of English as a Second Language stubbornly resist for decades. A Russian will never stumble here, by the way, preferring to drop *all* articles from his sentences and thus escape the nuance!) Think of gravity as an analogy: Everything has its gravitational pull on everything else; it's just that for small objects the *g*-force is imperceptible among mortals. Just so the words of a novel.

Who verifies that the mobile is built correctly? In the world of software development, at least we have feedback in the form of compile-time warnings; runtime errors; the squawking of a disgruntled user when perfection is not attained on the computer screen; and so on. With novels, there is no analogous processes or tool to fall back on. Nor in the early stages would one want to foist his or her draft on a reader merely to 'debug' it a bit; that would be uncouth. Thus, not only is the complexity greater than what we deal with in the computer world, but the method of dealing with that complexity is *also* more onerous: In solitude, the writer solves it all in his or her head. (Doesn't a word processor help? For consistency-checking and for overuse-checking [see remarks on 'ebon' on **page 328**], it brings the novel *somewhat* closer to the realm of nonfiction writing. But in the latter, one may assign numbers and labels and tags and then mechanistically cross-reference them all in a variety of ways. In fiction, on the other hand, you are not allowed to make any of that visible, so the overall burden is not reduced all that much by using a word processor. Examples of the kind of excellence I have in mind would be the ingeniously convoluted time-line in Brontë's perfect novel, *Wuthering Heights*, and the fine 'molecular weights' that are in evidence everywhere in Conrad and Naipaul. Contemporary masters of the craft include Josephine Hart, Ian McEwan, and Stephen King.)

There are some good reasons why this n-factorial facet of novel-writing is not widely recognized or appreciated. First, consider the legions of second-, third-, and fourth-tier writers who are quite incapable of keeping all that in their heads and then knowing what to do with it (or believing that anyone is watching or caring what they do with it). Their work dilutes the overall impression one forms of *what a novel is*, leading one to assume incorrectly that poetry holds the franchise on n-factorial rigor and the implied subtleties while prose is *necessarily* lacking in such (because it is 'obviously impossible' to attain in prose).

At the other extreme, we have the case of Henry James, apparently the first to articulate a principle close to n-factorial, but also one who, indirectly, gave it simultaneously a bad name. James said each point in the web of the novel should contain every other.(123) Meanwhile, James is also the one who characterized Russian novels as "loose, baggy monsters."(124) Put those two quotes together, plus the fact that James' writing comes across to many as fussy, boxy, mechanistic, stultifying — tending toward the antithesis of what novel-writing is all about, viz. the formulation of a loose, broad imitation of the world in all its complexity and 'messiness' — and you can see how James is not the one you want as the sole proponent of "each point containing every other." If any of the real novelists such as Brontë or Dickens or Eliot or Hardy or Conrad or Naipaul had articulated this idea that I call *web-sense*, not as a prescription (ugh!) but as an *observation on* the writing of his or her peer, that would have been good for the craft. But for James to have articulated it only leads to trouble, on account of his anti-Russian bias and his schoolmarm fussiness and his prescriptive bent, all of which undermine his authority.

Here's the take-away: Don't associate *web-sense* or the n-factorial idea only with Henry James. It's part of what every topflight writer *must do*, if not by second nature, then by a great effort. It is a de facto nonnegotiable requirement of being in the game.

At the same time, one should be aware of how *outré* my claim (their talent) is, mathematically. We'll return for one last look at the Combination Rule. For argument's sake, let's say only 100 words occurring in a 50,000 word novel are the 'important ones', liable to be noticed and tracked with special care, as described above. Feed the number '100' to the Combination Rule, and what comes out is 4945,

123. Indirect quote in Briggs & Peat, *Looking Glass Universe*, p. 275. Hence, my derived term 'web-sense' above, which is intended as a direct reference to James, while the n-factorial idea actually goes beyond what James stated to a higher level of rigor, by taking the words themselves as the primary currency, in lieu of 'points' in the novel.

124. This is the better known of the two Henry James quotes. It appears in John Gardner, p. 184, for instance.

say five thousand. But of course a novel of 50,000 words has far more of these hypothesized 'important words' than our stingy 100, so the actual number of word-pairs juggled by the author is almost beyond belief. I chose the relatively small value '100' for the calculation above only to prevent the two factorials, top and bottom, from bleeding out to infinity and thus halting the computation before we got to the division step.

We return to **Table 20**, perhaps with a new respect for what is represented by column 2, and a better understanding of *why* I would do that crazy thing of placing a whole novel notionally 'in a cell', as though it were an object. Now we understand that it *is* an object: the fabulously complex mobile-of-words in the author's head, managed with n-factorial rigor (*if* the author is good).

Playing Devil's Advocate, here's a counter argument, a rationale for getting rid of the *meta*-Information that I entered as column 3 of that table: "Whatever magic Naipaul performed at the level of the Gestalt of his 278-page novel, *A Bend in the River*, it's there already, by definition, *in* the [plain] δ**ata**[(125)] — isn't it? It must be. So why do we need *meta*-anything to 'talk about it'?" Point taken. Surely it *is* there. *In* the very δ**ata**, so to say. But in a million other novels, there is no such skillful Gestalt, born of a keen *web-sense*. And for one who happened to have partaken mostly of those million other novels of inferior construction, and not yet many good novels, how would he know to even to expect such a structure? That's the argument in favor of the meta-Information column for pointing out the degree of web-sense, as promised by the analyst (me) to the prospective reader (you). Although, admittedly, we've just stumbled along the edge of a rather disturbing philosophical cliff. The Devil's viewpoint will come back to haunt us anew, after we've had the grand tour of the Borges Video Emporium (page **332** f.) and have had time to ruminate on its vast blood-chilling merchandise display.

Another criterion for good fiction is what I call *coherence*. The best way to understand what I mean by *coherence* is to compare a case where it is noticeably deficient with a case where it occurs in spades. Not to castigate the fellow, but another's mistakes

125. Why do I say δ**ata** when I mean Information? That's how language works. The force of convention is strong — so much so that in this section about the δ**ata** / Information distinction, I break my own rule. Turning this 'problem' into an 'opportunity': What better way to illustrate the depth of the problem, the constant battle one must wage to get the nomenclature right?

often provide the best material for learning, and the fellow I've chosen to teach this lesson is Arthur C. Clarke.

Commercially successful after his collaboration(126) with Stanley Kubrick on *2001: A Space Odyssey*, if not before, Clarke is obviously no slouch of a writer. Nevertheless, if we remove him from that pedestal for a moment and judge his book by normal standards, it comes across as decidedly second-tier. Through all its editions and printings during the period 1968 through 2000, neither Clarke nor his editors ever bothered to read *2001* as one complete 'object'; otherwise, they would have noticed immediately the disagreement between "twenty feet underground" on p. 99 versus "thirty feet deep" on p. 209 and fixed it. There is only one monolith on the moon, and it was excavated only once. Why does its pit have two different depths between the covers of the same short novel? Just for starters, that's an insult to the reader. And it destroys the reader's suspension of disbelief and reminds him that it is, after all, only an artificially contrived 'piece of imaginative writing'.

But here's the subtlety: It's not so much the discrepancy itself that disturbs the reader (who really cares if the bloody pit is twenty or thirty feet deep? surely I don't — split the difference and make it twenty-five feet deep for all I care); rather, it's what the oversight *implies*: that the book has never been 'held in one head' — not by its author, not by an editor. (Evidence that an author has done this — held the whole text in his or her head at one time during its invention, at least for a moment if not for days or weeks — may not be among the stated reasons that a book is judged good, but there is a close correlation between an author's ability to do this and the overall quality of a novel.)

The discrepancy can be likened to the proverbial cockroach in a restaurant: you see only one, but you infer that in the floorboards of the kitchen it has many brothers and sisters. We see the glaringly obvious point about the size of the excavation pit missed by both the author and umpteen editors, and we suspect that many problems of a more subtle but important nature went likewise undetected by them.

126. In passing, there's an interesting story here: Perhaps uniquely among well-known book-movie pairs, the novel in this case cannot be described as a simple inspiration *for* or novelization *of* the screenplay. Rather, from the "Forward to the Millennial Edition," we learn that it was a thoroughly collaborative effort, with the novel only slightly ahead of the screenplay at first; then "...toward the end novel and screenplay were being written simultaneously, with feedback in both directions." Clarke, pp. vii-viii.

Take the case of Chapter 13: 'The Slow Dawn'. The central idea of this chapter is *poetic*, harking back to the acorn from which grew the oak:(127) A sun-powered monolith greets the lunar dawn with an electronic shriek after a slumber lasting three million years. How can you not like that? But its translation into *narrative* form is an embarrassing mess, reminiscent of a preteen's first attempt to write a story.

Forgetting the book *2001*, for a moment, here are the bare facts of the case that Clarke is trying to present:

As the moon circles the earth, an astronaut residing somewhere on the earth-facing hemisphere of the moon would experience a kind of pseudo day and pseudo night comprised of 14 days each. The lunar 'night' would be ameliorated by earthlight. The start of lunar 'night' might be named lunar 'dusk'; the start of lunar 'day' might be named lunar 'dawn'. We may estimate the lunar dawn's duration as about three earth days. Please refer to **Figure 87**.

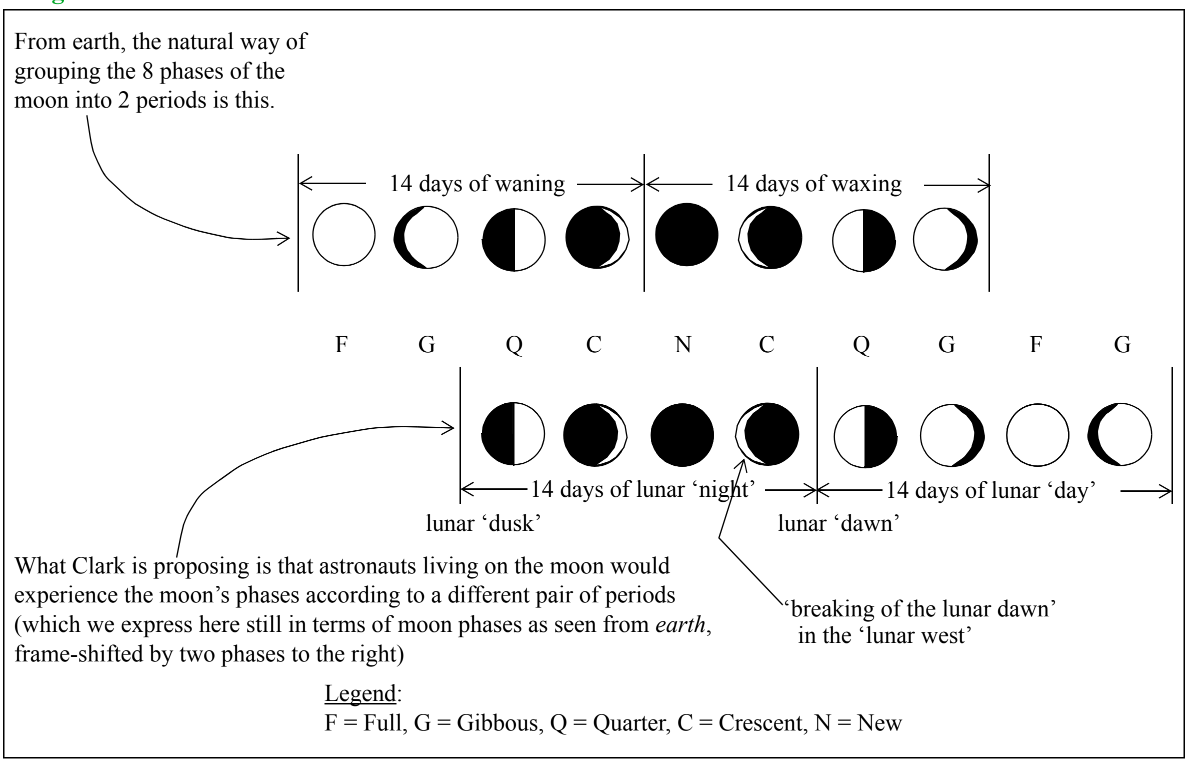


FIGURE 87: Our 8 phases of the moon, mapped to lunar 'day' and lunar 'night'

Chapter 13 ('The Slow Dawn') occurs at the point I've labeled 'breaking of the lunar dawn', otherwise known as the waxing crescent, down here on earth (as distinct from the waning crescent). Perhaps one needn't go so far as to make pictures, as I have in **Figure 87**, but any

127. This is the author's characterization of the relation between his story, "The Sentinel" (1948), and its flowering in his 1968 novel (Clark, p. xii).

self-respecting writer would offer more than just a few mumbled words about the 'lunar night' and 'lunar dawn' when introducing such a complex idea. And that's only the first of several problems in Chapter 13.

Indirectly, we are given to understand that all the excavation activities must have been carried out during an instance of lunar 'night', not during a period of lunar 'day'. (Otherwise, the monolith would already have been 'awakened' by the sunlight and the game would be up, wouldn't it?) But *why* would the workers have scheduled their excavation during the lunar 'night'? The author might have said something like this, for example: "'Toiling by 'night' under a bank of Klieg lamps, they would incur a huge lighting expense but escape the worry of direct sunlight and its damaging radiation." But Clarke is silent on this point.

Moreover, *why* would Dr. Heywood Floyd *et al.* happen to show up at that precise moment, for the breaking of *the* lunar 'dawn'? Certainly it was not because they knew in advance how important it was for the monolith to greet the rising sun with a five-part electronic shriek after three million years in the dark cold ground. Not at all. The whole thing was an utter surprise to them — even traumatic to the point of death, one might speculate, for those cringing and off-kilter earthlings we see portrayed in Kubrick's version. (Although, Dr. Heywood Floyd does reappear in Chapter 30 of the book, so in that version of the story, at least, we can assume that no one was mortally wounded by the alien emanations.)

Why are they there at *that* particular moment? Because it is the Destiny of Humankind? Because the extraterrestrials 'made them do it' — made them assemble in the dark like so many unthinking zombies for their photo op at just the right moment? Why?

There's a difference between "presenting mysteries on purpose for the reader to ponder" and just being a goof who doesn't know how to tell a story. Nothing is set up or explained by Clarke. Not the mechanics of lunar 'night and day', nor what is meant by the lunar 'dawn' (which, as we see from **Figure 87**, is not intuitive); not the workers' rationale for doing a nighttime excavation; not the rationale for everyone trooping down into the pit, *en masse,* just in time for the ebon slab's shriek.

I, for one, refuse to say "Gee, cool," like a good Sci Fi zombie-fan, and move along loyally to the next adventure. I am willing to say the film version is excellent thanks to Kubrick's skill: He either addresses an issue visually (shows the actual 'dawn') or glides right past it (gives the audience no time to wonder why the excavation was done by lunar 'night', such that everything would click in such a hunky-dory way). Movie makers try this sleight-of-hand routinely, hoping it will count as 'movie magic' (not as 'bungling of the story-line' which it is, more often than not). For the film version of *2001*, it all just barely works somehow, thanks to movie magic, and one is willing to play along. But where the book is concerned, there is no such magic, and I want a box office refund, so to speak.

We can't quite tell if Clarke's Chapter 13 is murky through ineptitude or murky on purpose. If he recognized how weak his story-line was and wanted to hide it, he would have had his motive for fudging the chapter and making it murky on purpose. Either way, we've been sold a bill of goods. Thanks to his bungling of Chapter 13, one cannot rate the novel overall as having more than moderate *coherence*.

What about *word-sense*? Here and there, Clarke seems to exhibit a real flare for language, I'll admit, a genuine appreciation for words. For example, how many authors would think to put the color 'salmon' or 'scarlet' in the plural? Clarke does, and the effect is memorable in his description of the Jovian colors (p. 139). And he seems to play nicely with the word 'bow' applying it first to the lunar sunrise ("a thin bow of unbearable incandescence," p. 97); later to Saturn, seen as a crescent ("Now it was a delicate bow," p. 251); and also as an allusion, it seems, hiding in David Bowman's name. (Anyway, I'll give him the benefit of the doubt and assume a deliberate connection there.) So far, all this holds out the promise of an author with *word-sense*.

Then we notice that he uses the word 'ebon' half a dozen times in this 297-page book, mostly in the vicinity of pp. 91-98 ("ebon lunar sky"; "ebon blackness"; "ebon surface"; "ebon slab"), also on p. 265 ("infinite ebon walls"). When any adjective or noun is repeated in a novel, it had better be for a reason. (That's one of the several implications of 'the novel as n-factorial craft', described earlier in this section.) And when that repeated word is a quirky, archaic adjective like 'ebon' (glossed in one dictionary as definition #15 under 'ebony') all the more so. If one were asked to imitate Milton, the word might come in handy: "Eve forsaken under the ebon welkin"; or, again, if one were engaged in a parody of H.P. Lovecraft, it would fit right in: "In the elder time of Hrnogh Tower, upon whose ebon incline the basking basilisk Blasphemers did group themselves egregiously of an eventide..." But a Sci Fi writer has no business using the word even once, never mind half a dozen times in a short novel. Put Clarke's mindless peppering of the novel with 'ebon' together with his sloppiness about the pit dimensions and his vagueness about the macro- and micro-timing of the monolith's awakening, and one can see that he's just what we expect from the Sci Fi ghetto generally: an uneven writer, a dabbler. No artist.

By contrast, in the prolific outpouring of novels from Stephen King, we read descriptions of scenes whose complexity often rivals[(128)] that of the lunar dawn in *2001*, and always King makes it *clear*, and always he gets it *right*. There are no slipups, no internal contradictions between the covers of a novel by Stephen King. He will insult neither himself nor the reader that way.

The man is *awake*.

He's *on it*, to use a dancers' term, with respect to the beat.

Regardless of what one might think of King's story-lines or his ethos (it seems that many English professor types write him off as a hack), one must acknowledge that he offers the reader a never-ending stream of high *coherence*, in book after lengthy book. And on that physical basis alone, he counts as a sort of phenomenon or World Wonder or oracle to behold. For most people, *coherence* doesn't just happen; even for a three-page term paper, it tends to be an agonizing state that we wrestle the text into after an hour or more of hard work. As we've seen from the Clarke example, just being smart and earnest and wanting to write a novel isn't good enough. To be coherent into the bargain takes a small miracle. If one lacks a Mozartian gift (the likely explanation for a King or a Dickens), then one must summon a Herculean effort to the task (as I would imagine the case for Naipaul and Conrad).

If I seem to dwell at inordinate length on the *coherence* issue, it's by way of pointing out that 'just getting the facts right' is a surprisingly difficult part of writing; yet the qualities that really matter — the ones I call *word-sense* and *web-sense*, which characterize the masters such as Brontë and Conrad — must be built on top of that foundation. There's no point trying to show off your *word-sense* if you don't even

128. For example, the transitions in King's *Rose Madder* from the familiar places 'here' to the fantastic places 'there', through the looking-glass portal of a landscape painting, are arguably more challenging to describe since the scenes are phantasmagoric, not even real. But he never falters. With his writing skill and his enthusiasm, he *makes* them real for the reader.

have a backdrop of *coherence* to act as its foil.

Part Four: Raw δata revisited

We'll conclude this discussion with a few more notes on nomenclature. You may have noticed that I used the term 'raw **δata**' in footnote **114** on **page 307**. Does the addition of the modifier 'raw' help one make the desired distinction between **δata** and **Information**? No, that doesn't help either, I'm sorry to report. Here's why: I write Program A. I take the output from Program A and feed it into Program B:

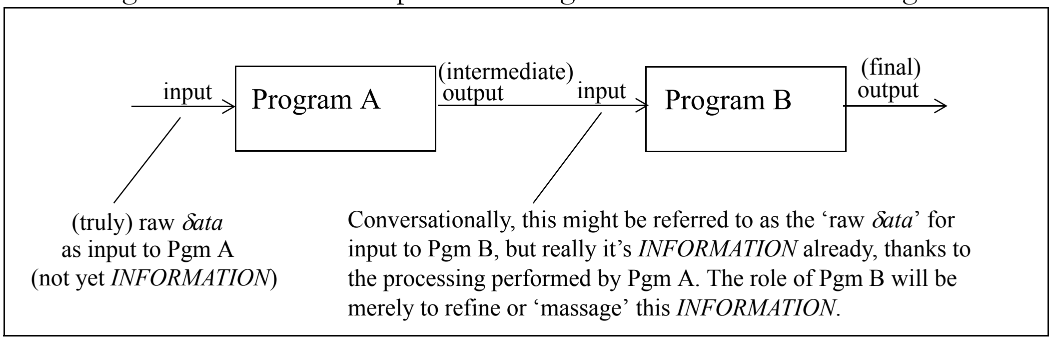


FIGURE 88: When 'raw **δata**' isn't

It's the output from Program B that I regard as my finished product, the 'deliverable' to my client. Conversationally, I might refer to the output from Program A as my 'raw **δata**' not because it is actually 'raw' (in the problematic sense that we've seen illustrated in **Table 13**, for example) but only because it isn't yet *fully* processed by the suite of programs, not yet the finished product that will come out the other side of Program B. To the contrary, the output from Program A may be chock full of perfectly good **Information** already. The **Information** is in an arrangement my client doesn't like, though, so I've written Program B to massage it some more, to match his or her requirements — as *though* it were mere **δata**, still waiting to be transformed into something useful. Thus, the potential for using these terms to refer to an (actual) 'raw **δata**/[good] **δata**' distinction is, once again, tainted by our haphazard usage and lack of respect for the language.

Stepping back for a bit of perspective, the problem with *raw* **δata** and **δata** seems like the **δata**/**Information** problem all over again, at the next level down. Yes, there are such distinctions in reality; but when we look around for the two words that would seemingly be best suited for tagging such a distinction, it turns out we've ruined them long ago through sloppy use. Both the words 'data' and 'information' exist at the level of cocktail party chatter; they are just about useless until stringently defined in a particular context. (Also, as we'll see later, there are circumstances where the **δata**/Information concept fails us and new vocabulary must be invented; see "Definition of '*crumb*' as a technical term" on **page 368**.)

It gets worse. Shannon is careful to label his work as A Mathematical Theory of *Communication* (as in **δata** communication), and he says on page 1 that he doesn't deal with *meaning*. But others usually refer to his work as the foundation of Information Theory (as though it did somehow touch on meaning). Now it's true that Shannon himself uses the *word* 'information' extensively in his paper. But in many of those instances, the word '**δata**' would have worked as well or better. All of this only confirms my earlier point that the words 'data' and 'information' are often used interchangeably — even by one such as Shannon, who is otherwise so meticulous in his word choice. But I digress. The main thing I wanted to point out was that 'data' vs. 'information' is only one point of confusion; meanwhile, in another dimension, there is also this business about 'communication theory' vs. 'information theory' — another pair of terms that *might* have been devised to label an important distinction (between something low-level and technical vs. something high-level and philosophical and possibly technical in the future), but the opportunity was squandered. Instead, the terms are used interchangeably. Or, rather, the one term has supplanted the other, which now is remembered chiefly when we see it in Shannon's title.

Library Science in the University of Borges & Poundstone

Now we conduct a thought experiment that blends the imagery of Jorge Luis Borges (1941) and that of William Poundstone (1985). In the work that I allude to, Poundstone saw himself doing an update of "Gamow's playful idea of a universal printing press."[(129)] But for my money, his vision of a Universal Video Library is, above all, an (unwitting) update of Borges' *The Library of Babel (La Biblioteca de Babel*).

129. See Poundstone (1985), pp. 91-97, where he alludes to George Gamow (1947), pp. 11-14, also to Maxwell's Demon, whom we are to imagine transported to the Information Age, now earning his keep as a Video Librarian. Poundstone, a mathematical Wunderkind, seems not to be familiar with Borges, who might be described as a literary figure with keen mathematical sense and a Daliesque appreciation of the Absurd. Not quite Poundstone's cup of tea? And since Borges' fantasy of *Babel* precedes Poundstone by some forty-odd years, there can be no question of influence in that direction either. At any rate, in this appendix we bring their two spirits together and find them fully compatible if not quite kindred.

For that reason, I use both 'Poundstone' and 'Borges' in the name of this thought experiment.

Here is Poundstone's point of departure:

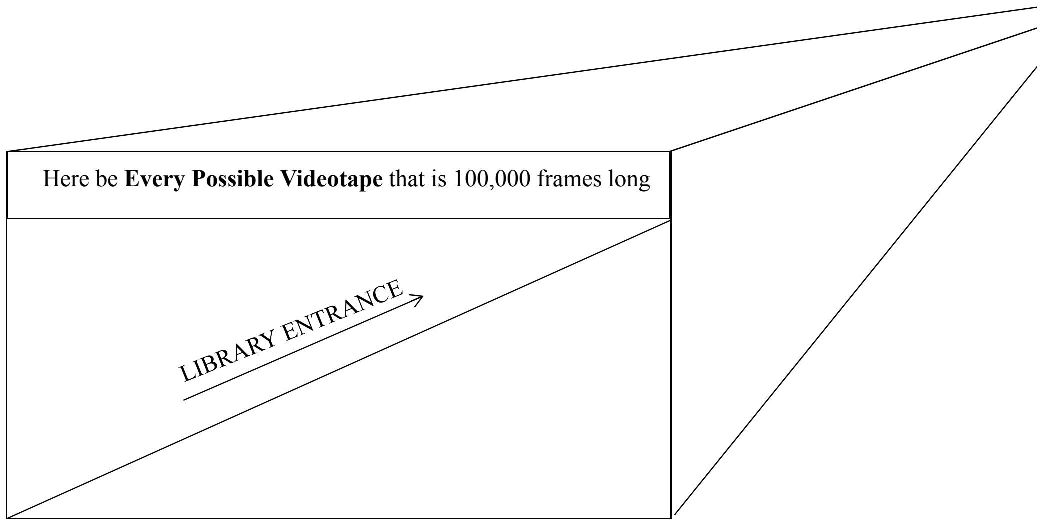


FIGURE 89: Poundstone's Universal Video Library

Why 100,000 frames per video? There's no particular magic in that — it's just a round number that Poundstone adopts for illustrative purposes, a number he equates to a modest 56 minutes of running time per video.

"An unfortunate length," you might remark, "since it excludes almost every video of a movie — where the standard length is something on the order of 100 to 110 minutes."

Not to worry. If the Video Librarian can locate the right *pair* of 56-minute videos, he'll come back to you with Part 1 and Part 2 of a 112-minute movie, right? Simple though it is, the idea may elude one at first, not least because intuitively one balks, suspecting that this 'if' might be the Mother of all if's.

Undaunted by a vision of the stars blinking out before the hapless Video Librarian returns from the stacks with Part 2 of our movie selection, we forge bravely ahead to consider not one but two *kinds* of Borges Video Emporium (hereafter *BVE*), one of them raw and unsorted, the other Pre-sorted. (Why Borges? The overall shape and style of Figures **90** and **92** below I owe to Poundstone. Their ancestor is his video snow diagram; Poundstone, p. 96. At the same time, I regard Borges as the Patron Saint and unrivaled maestro of this peculiar domain; therefore, for an amalgamated Borges + Poundstone version, I would have to imagine the name Borges on the marquee: *The Borges Video Emporium*.)

Why 'Pre'-sorted? Because no conceivable combination of human resources — physical and intellectual — could sort the *BVE* after the fact, but we are free to conceive of some godlike or extraterrestrial being who might possess the power to build one for you already sorted. For convenience, we'll give her a name, **e** for entity, as we'll be calling on her services repeatedly in this appendix. (Come to that, even an unsorted *BVE* could not be created without some such 'outside help', *plus* an assumption that the Cosmos we know is not the 'real' one, only a projection from elsewhere where more atoms and more space and more time are on tap — enough to allow completion of such a grand project. But this anticipates a theme to follow.)

Before embarking on a tour of one *BVE* or the other, let's try to do a rough comparison of how the two versions would look placed side by side in a god's-eye view:

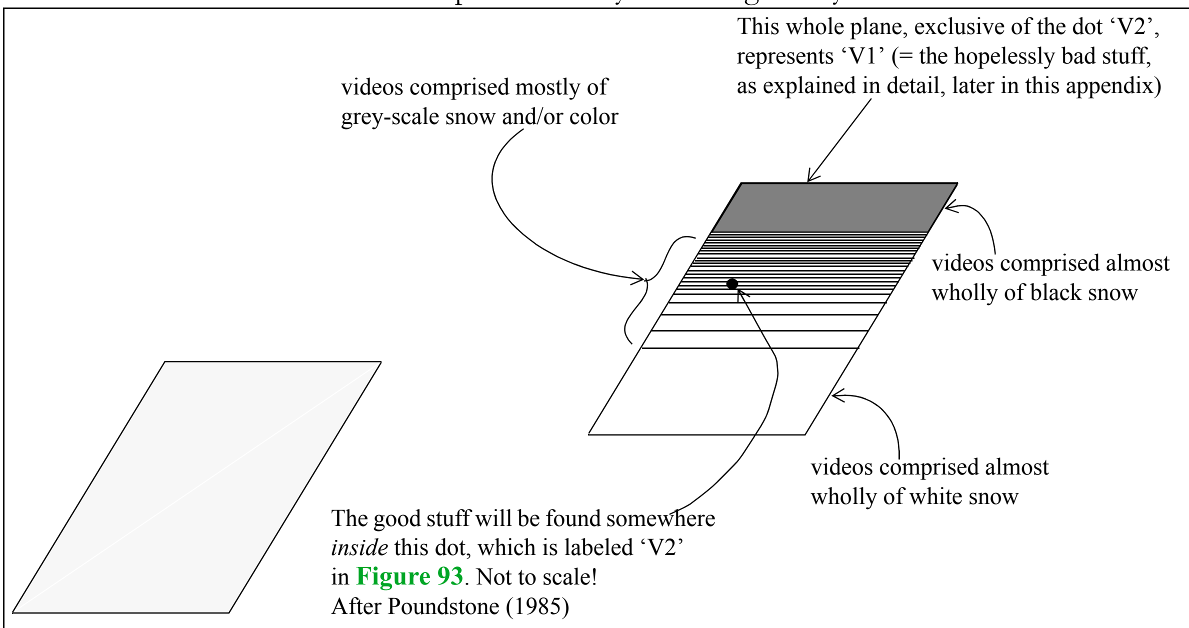


Figure 90a: Unsorted *BVE*: utter Chaos (but is it *indeterminate* Chaos? see **page 357**)

Figure 90b: Pre-sorted *BVE* (but have we Time enough to traverse it?)

FIGURE 90: Unsorted *BVE* contrasted with Pre-sorted *BVE*

Implicitly, both the unsorted *BVE* and Pre-sorted *BVE* must contain oodles of 'good stuff' — it's just that in the one, the good stuff hides like specks of gold dust under the Sahara (**Figure 90**a), while in the other, it is concentrated in a 'dot' (**Figure 90**b).

We said we would be calling on the entity, **e**, with some frequency in this appendix, to provide 'outside help'. Question: In creating the 'good stuff' for earthlings, would the entity, **e**, need to understand how earthlings think and feel? (And similarly, in creating the 'good stuff' for Martians, would she need to understand Martians?)

Answer: Being a deity, she might possess that level of understanding, but it would absolutely *not* be required for doing the job at hand, the creation of an Emporium with all possible videos.

That's why the concept is eerie and unsettling. Once her task has been defined (whether by you or by the deity herself), a totally blind and mechanistic entity, **e**, who has never been near an earthling and frankly doesn't give a rip about you *will* in fact make that 56-minute video all about you and your relatives on the Fourth of July in Sheboygan, Wisconsin. (And that other 56-minute video... and that other one... and one that's mostly about your family but has a two-minute interruption that appears to be excerpted from a speech by Camille Paglia, except it's Lilly Tomlin's face grafted onto Paglia's body, and she's wearing some kind of telephone operator headset gizmo, revelling in her [Tomlin's] Ernestine persona — oh well, toss *that* one (or keep it for a curio? decisions, decisions, is this what they mean by 'information overload'?)... and that other one that looks very much like a home movie of your family by the backyard swimming pool, except time is running backwards and little Jakey undives from the water up to the diving board, so toss that one too, and keep searching for something... 'good', whatever that means.

Upon her completion of the *BVE*, perhaps one's Grail would be *The Enigma of Arrival* that isn't really *the* opus by V.S. Naipaul, only a counterfeit cooked up by our indefatigable entity, **e**, on High. Or is 'counterfeit' too harsh? If not a counterfeit, what is it? And where does V.S. Naipaul, the man, now fit into the picture? Is he not detached from and superfluous to the opus we thought was 'his'? What shall become of his highly regarded 'web-sense' (**page 319** above), the Gestalt of yore?

Does the sense of horror begin to touch you? The story of the Emporium might even be regarded as the ultimate horror story. Except (as in Lovecraft), it's also rather droll when tilted a certain way: think *www.videowasteland.com* 'cubed', in the hyperbole of engineering jargon. Or perhaps the cold machine logic of this Naipaul-not-needed domain — call it N^3 — will put you in mind of the Turing machine: the Anything Machine that Turing watched in his mind (with horrified fascination?) as it replicated, in principle, all that a human might ever do, if only one could feed the little beast a long enough piece of ticker tape to read, from here to Eternity. (Is there a way to experience viscerally this notion of human-looking artifacts emerging gradually from a mist of cold machine logic? Yes, for that purpose

I recommend looking at "The Series of Approximations to English" in Shannon, p. 7, which is repeated in full, with a seventh example added, in Cover & Thomas, pp. 134-135. Even without the first clue about the mathematical underpinnings of a 'Markov approximation', one can definitely get the gist of the technique and appreciate its results, which might strike one as droll or as eerie, depending on the mood of the moment.)

So much for the comparison (**Figure 90**). Now we're ready to have a look at the Pre-Sorted Emporium. Let's listen to Pedro, the barker and proprietor, who stands proudly at the entrance:

Step right up to the Borges Video *Em*-porium — for movies like you never find.
Bring the family *too*, and something for everybody — it's waiting for *you*.
En-joy our extensive slek-shin in an opulent warehouse-style-galleria with class and central air that measures 'bout ten to the *five-nine-nine-nine-eight-four Light Years* long (divided by five): "If Borges Doan Got It, Doan Nobody *Got* It," ...and you can boogie to the bank on that one, *muchacho*. Step right up to the Borges Video *Em*-porium — for movies like you never find (more titles than videowasteland-dot-com, convenient location for your lunchtime Perú-zal). Bring a neighbor *too*, and something for everybody — it's waiting for *you*. Your own *pre*-customized video of *purse*-nil vindication, even *that* you might find, just like the great man say: ¡Jorge! ¡Luis! ¡Borges! (And for flea market prices, whad I say?)
Step right up to the...

What does he mean about $10^{599,984}$ Light Years long? Surely that's a gross overstatement, even after it's been "divided by five". We weren't born yesterday; we know how reliable these carnival barker types are! Or, could this one possibly be telling the truth for once? Let's find out. Standing on the big shoulders of Poundstone (pp. 90-99) we make certain assumptions, then see where they lead:

- Assumption 1: Each video will be 100,000 frames long (10^5 is Poundstone's nice round number as explained earlier, roughly corresponding to a duration per video of 56 minutes).
- Assumption 2: 10 pixel states (mainly for encoding color, also a modest sound track).
- Assumption 3: 10^6 pixels as the density of the video screen; a modest degree of resolution, no?

Computation:

- From Assumptions 2 and 3, it follows that there are $10^{1,000,000}$ possible configurations of the video screen: the number of pixel states raised to the power of their density (kind of like working out how many different license plate numbers there can be in the State of Kansas from AAA111 to ZZZ999).
- The total number of videos in the Emporium will have to be the product of Number of Frames per Video times Possible Configurations per Screen or $10^5 \times 10^{1,000,000} = ?$

Let's imagine an arrangement where the videos simply 'tile' the whole immense floor, with say $10^{400,005}$ videos across the width of the Emporium and $10^{600,000}$ videos down its length.[130]

In other words, this Emporium has no shelves: all video cassettes lie unceremoniously under foot as the customer browses.

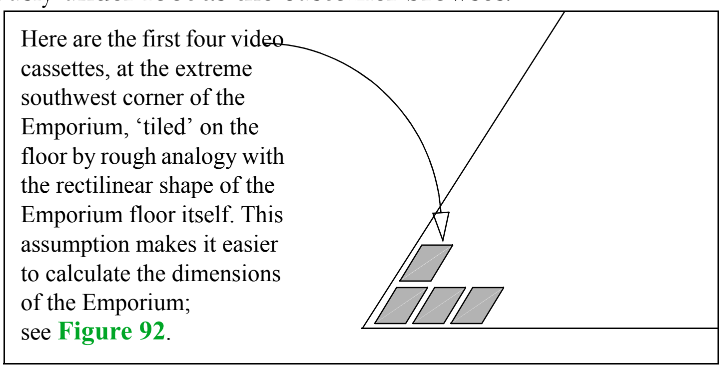


FIGURE 91: 'Tiling' of the videocassettes on Emporium floor

130. Our original number, $10^5 \times 10^{1,000,000}$ videos, is the same as saying $10^{400,005} \times 10^{600,000}$ videos. Bear with me, and in a page or two you'll see why I've rearranged the exponents this way: it's merely in response to an aesthetic urge, to roughly match the rectilinear shape of the Emporium as depicted in Figures **90**, **92** and **93**. (Whereas, if I stuck with the original $10^5 \times 10^{1,000,000}$ scheme and tried to make a rectangle out of that, it would have been about 6 miles wide and $10^{999,984}$ Light Years long — unpleasing proportions for the layout of a store, as any Emporium Floor Manager will testify in my defense.)

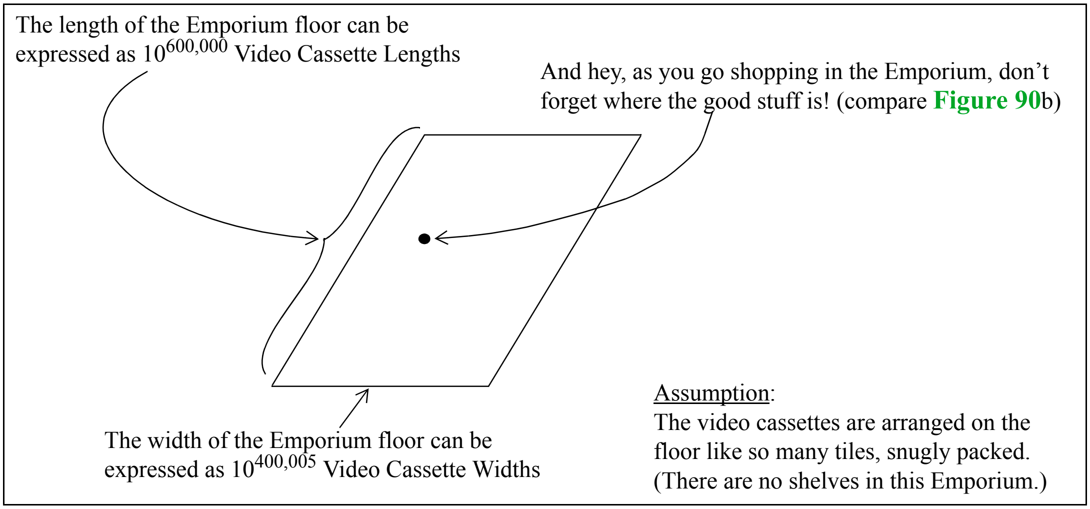


FIGURE 92: *BVE* dimensions expressed as 'Video Cassette Widths'

One more assumption then we can finish our calculation:

Assumption 4: Each video cassette measures 10 cm wide by 19 cm long. (These are standard VHS dimensions, similar to those for the width and height of a Kraft Macaroni & Cheese box, a 'technology' that will surely long outlive that of the VHS video cassette!)

So, the breadth of the Emporium floor would be:

$10^{400,005}$ cassettes x 10 cm per Video Cassette Width
= $10^{400,006}$ cm = **$10^{400,004}$ m**

And the length of the Emporium floor would be:

$10^{600,000}$ cassettes x 19 cm per Video Cassette Length
=19 x $10^{600,000}$ cm=**0.19 x 10600,000 m**

Well, meters are nice. But that still has the look of "lots and lots of [something]." Let's try to make it slightly more meaningful or dramatic, at least. With some help from *Webster's* we recall that 1 Light Year is 6 million million miles or 9.46 trillion kilometers. For convenience (and since these numbers are so darned big *anyway*) let's round that up to a tidy 10^{16} m and call that a Light Year. Fair enough?

Now, if we divide our provisional $10^{400,004}$ m by 10^{16} m per Light Year, the meters cancel out and we should be left with an answer expressed in Light Years. In terms of exponent arithmetic, that means subtracting 16 from 400,004 and subtracting 16 from 600,000 to arrive at this:

$$10^{399,988} \text{ Light Years wide by } 10^{599,984} \text{ Light Years long}$$

Hm, those numbers are still inconceivably large. And worse yet, one of them matches what the barker said: "...'bout ten to the *five-nine-nine-nine-eight-four Light Years* long," he said.

Finally, we round 0.19 up to 0.20 or one fifth, and that must be why the barker added in an undertone, "divided by five" — as if that really makes much difference. Aside: We suspect that this is one reason your pocket protector types all love to talk about "orders of magnitude" — in recognition of the situation where dividing by five or not dividing by five is quite the nonevent, the bedrock number itself being still such a behemoth. In other words, bringing it closer to home, "Would you like a billion dollars next year, or would you settle for a fifth of a billion dollars right now, sir?"

With stock like that to manage, how do you suppose Pedro stays in business, rather than getting lost in oblivion or being burned in effigy by disgruntled patrons who see him empty-handed? I know what I'd do if I were Pedro. I'd fake it, by stocking the front of the store with *copies* of the movies most likely to be requested, all within a 20-minute search as I vanished behind a curtain, playing Wizard of the Emporium. Thus, I would never sell items from the Emporium itself, only operate the business by way of an elaborate proxy, using copies of popular movies. And my customers, ever hungering to find something for nothing (the American religion), would mostly be innocent and unsuspecting: most would accept my services as a true video 'value'. Business would boom. It would be a win-win situation.

Let's assume Pedro does it that way. Then he retires.

After his demise, no one figures out Pedro's trick for making a go of the business. A few would-be Emporium Floor Managers get lost in oblivion. A few others get burned in effigy. Finally, the storefront is boarded up.

Centuries pass.

One day Cyndi Cyborg arrives on the scene. Half-human half-machine, she has the strength, stamina and navigational wherewithal to chance a genuine tour of the *BVE*. Terminator-like, she uses her fist to reopen the boarded up façade, in preparation for her eons-long trek, in search of El Dorado.

She'll want to be equipped with a tool for sorting and recognizing various distinctive areas of the library stacks. To that end, an urchin gathers into one place the somewhat scattered ideas of Mr. Poundstone,[131] and proffers them to Cyndi as a handy, four-tier taxonomy, as set out in **Table 21**. The paparazzi snap a picture of her titanium fingers pinching the paper delicately as she accepts the ragamuffin's gift.

131. Poundstone, pp. 96-98.

TABLE 21: Poundstone's Taxonomy

My Tag	Poundstone's category (page 96)	Poundstone's category (page 98)	Comments
R3	n/a	the Good segregated from the Bad	Videos in class R3 possess aesthetic value or some other facet of 'interest' as a key attribute. Question: Do the videos in this class require 'something extra', such as *meta***data**, to be defined and created? Often I believe they do. (In other words, just writing out the score of Bach's *Brandenburg Concerto No. 5* isn't quite good enough.) But see text, where I explain the other viewpoint that makes *meta***data** irrelevant.
R2	figurative	meaningful (plausible) movies and shows, including all their disfigured cousins(1)	Videos in class R2 require `Information` to be faithfully created (in the image of '**e**' or whomsoever).
R1(2)	abstract	structured	Videos assigned to class R1 are those that require *DERN (aka Shannon information)* to be properly defined and created.
V1	video snow Note that this includes three subcategories: pure white, pure black, mixed black & white 'snow'	unstructured	Videos assigned to class V1 are those that require only *raw* **δata** to be defined; but what is 'raw **δata**' exactly? Informally, even this lowest level is referred to often as containing 'information'.

1. Included here are all the hideously disfigured cases, such as: most of *Citizen Kane* intact, but with the final glimpse of Rosebud supplanted by a snippet from a Julia Child's cooking show; every witticism of a Marx Brothers film cruelly replaced by a San Diego weather report snippet; and so on. And you thought *you* had a good definition of 'obscenity'!
2. My ring, R1, is the first ring inside the dot 'V2' that is exploded in **Figure 93** below; this is the same dot 'V2' that was introduced in **Figure 90** already.

Table 21 is to be read from bottom to top, which takes us through a nested series of Rings (tagged as R1, R2, R3), from the 'bad' toward the 'good'. Likewise its companion, **Table 22**, where we augment Poundstone's scheme to encompass Borges' Library (by assuming a subset of tapes that contain only video text, no video images).

TABLE 22: Legend for **Figure 93** (the Borges Video Emporium)

R7	Somewhere within R7 are all the best books of the Library of Babel, including, as an incredibly special bonus, *your* own Book of Vindication. Not that there would have been time or resources to emboss your initials in gold leaf on the spine. But it *would* exist, and in ever so many versions, of course: There would be an edition with 1 typo, an edition with 2 typos...an edition where 66.665% of the words contained typos... *En aquel tiempo se habló mucho de las Vindicaciones: libros de apología...*(1) (Borges, p. 92) *No hay, en la vasta Biblioteca, dos libros idénticos.*(2) (Borges, p. 91)
R6	More Library of Babel: All possible books in earthling dead languages, in earthling pseudo languages and in Lovecraftian demontongues, and the books that suffer 'too many typos' (say with typos in 66.666% or more of the words? You decide) *...lenguas pretéritas o remotas*(3) (Borges, p. 90)
R5	video text, good and bad, for earthlings only. This is where the Borges Library of Babel begins, in video text form, with heaps of textual 'snow' (i.e., the videotext equivalent of regular video snow). As with the Emporium overall, we assume — unlike Borges — that someone was kind enough to sort the Library of Babel.
R4	video text: Beginning with R4, we are in a subset of videos where there are no pictures, only screens full of text, rolling by at, say, 10 seconds per screen, to allow time for reading. However, caveat emptor: R4 contains only *non*-earthling videotext.
R3	The 'good videos' for Earthlings and 'good videos' for Martians and... Within V4, all videos are *visually* 'good', but this category includes both good and bad video*text* (= V5). For details on V1, R1, R2, R3, see **Table 21**.
R2	figurative (for Earthlings and Martians and...)
R1	abstract (pure abstract and video snow/abstract hybrids)
V2	The dot 'V2' that is exploded in **Figure 93** is the same dot 'V2' that was introduced in **Figure 90**. We now break it down in terms of seven rings, labeled R1 through R7.
V1	V1 we define as everything except the dot, V2. V1 is occupied by various kinds of 'video snow' defined broadly to encompass all-white, all-black, and black-and-white (the latter being your normal video snow), and with the occasional relief of a red or blue pixel allowed into the mix, the colored pixels representing no more than, say, 1% of the total per tape. Clearly, the exact boundary of the V2 dot is arbitrary and subjective (but of little particular interest, compared to the divisions within V2, labeled R1 through R7).

1. At that time, there was much talk of the Vindications: books of apology.... What does Borges mean by a Book of Vindication? It's just what it sounds like: A detailed biography (Cyndi's, mine, yours...) rationalizing all of one's actions of a lifetime, showing why "My Way" was the right way, and absolving one of all embarrassment, sin, folly....
2. *There are not, in the vast Library, two identical books*.
3. ...extinct or remote languages

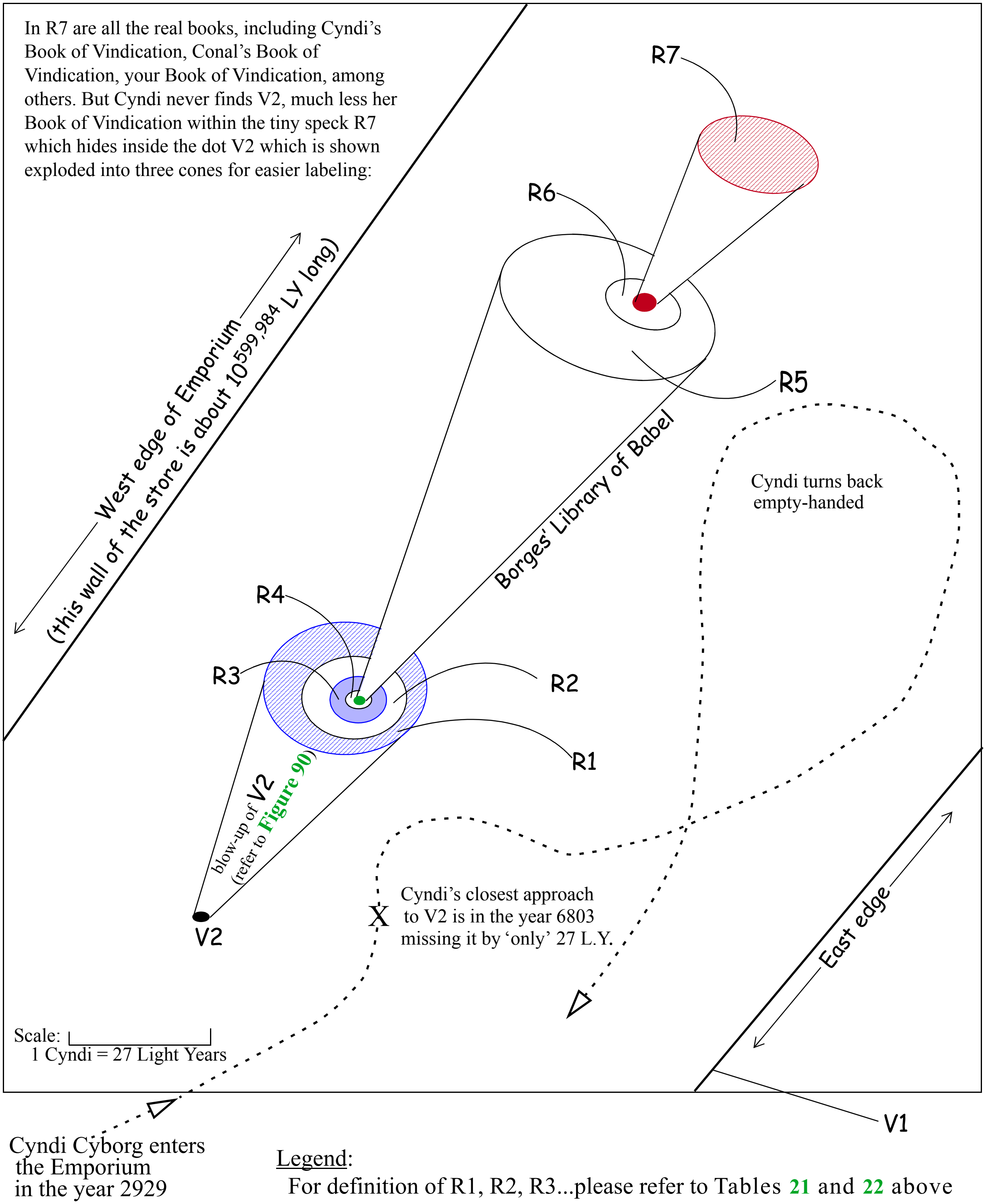


FIGURE 93: Partial Floor Plan of the Pre-sorted *BVE* with 3-stage blow-up of V2 'dot'

In **Figure 93** we see Cyndi's itinerary, drawn as a dotted line across the floor plan of a Pre-sorted *BVE*.

Sadly, for all her thousands of years of wandering and analysis, she never determines the location of V2, the subset within which the good stuff, R3, hides like a needle in a haystack, eluding even her hi-tech probes.

The path (dotted line) tells the tale: In her several millennia of browsing the Emporium, Cyndi finds only reels of grade 'V1' to peruse: mostly pure video snow from beginning to end. With a little imagination we can flesh the story out: Following up on a notion of Poundstone, let's say one of the more 'interesting' ones that she samples is pure white except for one green pixel in frame # 070310 of 100,000. Or, another treasure for her journal: one that is pure black save for twenty-two periwinkle pixels in frame # 005207 of 100,000. This will give you an inkling of how much chance she has of finding her own Personal Video of Vindication in the R7 ring: next to nil.

You'll recall that I described this particular Emporium as a relatively 'friendly' one, because it is pre-sorted: that's why we've indicated a clean boundary marking off V2 (a small black circle) from V1 (= all the rest of the lozenge-shaped plane).

Even with this pre-sorting, the *BVE* is so immense that one may never even find his way into the V2 region, much less to R2 or R3 where all the movies reside. In other words, in practical terms the pre-sorting doesn't help that much. Maybe it even hinders. Absent the pre-sorting, though, it would be a truly *truly* hellacious place, suggesting an Evil Deity. (For you software developers, what do you suppose the Sort algorithm looks like and how much RAM did they reserve on their computer to execute it, eh? And how long did it take to run? Meantime, mightn't the stars have blinked out?)

Does the vista of **Figure 93** strike you as remotely or impossibly futuristic? Or, instead, does its overall trashiness have a curiously familiar ring to you?

If you're tuned in to the cultural trends of the past 30-odd years, or if you've ever read Leonard B. Meyer (1967, 1994), it should strike you that we've already been shoved by cultural forces (of the 1960s, 1970s, 1980s) then catapulted by the Word Wide Web (in the 1990s) into something closely akin to the 'Utopia' I've depicted. Our own kind of hell-under-construction. Not that we're deep into the landscape (it's too vast for us to have penetrated it very deeply in this relatively short period);

but for certain we're over the threshold, standing on the inside. Our circumstance can be conveyed succinctly in terms of one of those good news / bad news jokes:

- The good news is, everyone's an artist, a poet, a publisher, a voice, a reality-show star with his very own 15 Minutes of Fame.[132]
- The bad news is everyone's an artist, an e-poet, an e-publisher, a reality show star with a Voice, and therefore it might be that nothing really matters anymore. It's one big nondescript hash of maybe-excellence-maybe-mediocrity; who cares? Everything is so darned 'equa' and 'creative' and 'wonderful' that it's indistinguishable from trash. (For a slightly different angle on this, see the discussion of a diamond on heaped glass, page **408**.)

Welcome to *Utopia*.

Whether consciously or not, you and I have already 'advanced' to *BVE*-dom (*BVE* doom?) and, paraphrasing the lyrics of "Hotel California" of pop song fame, "You can enter but you'll never find the checkout counter" in the Emporium of All.

132. But not really. If you've ever done the math, you'll know what a terrific lie that is. Let's forget the rest of the world and say only the selfish Americans each need to have their 15 minutes of fame. Even if they spread their fame-fest across two TV channels, it would require 2,853 years of around-the-clock broadcasts to get the job done for all 200,000,000 Americans — with the vast majority of participants making their appearance only as cadavers, long after their years on Earth had expired. This creepy spectacle of the Cadaver Cavalcade Show, where each is on display for its 'fair share' of 15 minutes, thus hogging two channels 24 hours a day for two millennia (or five channels for a thousand years), is yet another lesson in how numbers actually behave as distinct from how we vaguely *think* they might behave.

La certidumbre
de que todo está escrito
nos anula o nos afantasma.
— Jorge Luis Borges*, Ficciones*

(The certitude that all has been written
annuls us, or makes us phantoms.)

...like a painted ship on a painted sea
— Joseph Conrad, *Victory*

Above we used the device of the Borges Video Emporium as our vehicle for exploring **Information** to one of its far limits. Through that thought-experiment we found that even if there were enough atoms to build such an emporium, it would be a thankless task resulting in Nightmare, Dystopia.

Undaunted by that exercise, we now attempt an even broader view, that of the astrophysicist, though simplified drastically for this context. Specifically, we'll take a few crumbs from the table of the Holographic Principle, as they fell to the masses in Bekenstein's 2003 *Scientific American* article, pp. 3-4:(133)

> A Universe Painted on Its Boundary...In 1999 Raphael Bousso...proposed a modified holographic bound... Light emitted from the inner surface of a spherical shell...

The topic itself (black hole physics) I find overwhelming, though Bekenstein's notion of 'information' leaves me decidedly underwhelmed. Still, what I do like is his image of a universe projected from the 'painted' 2D interior of a spherical shell. Let's run with that.

As one might imagine, the literature on the Holographic Principle works without reference to a Creator or other outside force acting upon a given model. By contrast, I will insist on an entity, **e**, perched on the exterior of the model and running the show from there. I need this divinity not for reasons of philosophy or religious faith but because we will be using the Bousso model (in a simplified form) as our framework for further exploration of the **L1-L4** idea introduced earlier. And if we can imagine such an entity trying to decide how much of **L1, L2, L3**... to include in

133. My page references will be to the on-line printer-friendly version of the article, "Information in the Holographic Universe," dated July 14, 2003, 5 pages in length. (A version with illustrations appeared in the *August* 2003 issue of the magazine itself. I mention the latter here only because of the July/August discrepancy which could otherwise be confusing.)

her projection 'down' into the spherical space, the thought-experiment will help us delve into the nature of levels **L1-L4** and decide whether they are real and important or just gratuitous figments of my imagination. Against the black ruminations to come, one can think of this section as the 'Scherzo'.

For our purposes, **Figure 94** may be described in the following straightforward fashion: A static (timeless) 3D universe is projected from a painted 2D film that forms the interior of the spherical shell.

(Context note: In serious papers on the Holographic Principle, the situation regarding dimensions is necessarily more specific and detailed. In one kind of model, the interior of the spherical shell is understood to be a 4D space — namely our familiar world of 3 spacial dimensions plus time as the fourth — projected from a 3D 'paint' or film which is represented only *abstractly* by the 2D interior of a sphere, to save the illustrator from having to depict projections from a 3D film! In another model, one manages with *literally* a 2D painted surface from which the familiar 4D universe is projected somehow. **Figure 94** draws on elements of both the 3D model and 2D model but is itself only a bastardized toy for a thought experiment, not congruent with any *one* model prevalent in the world of Holographic Principle theorizing.)

So, everything we need to 'describe a whole universe' resides already, in some form or other, right there on **page 347**:

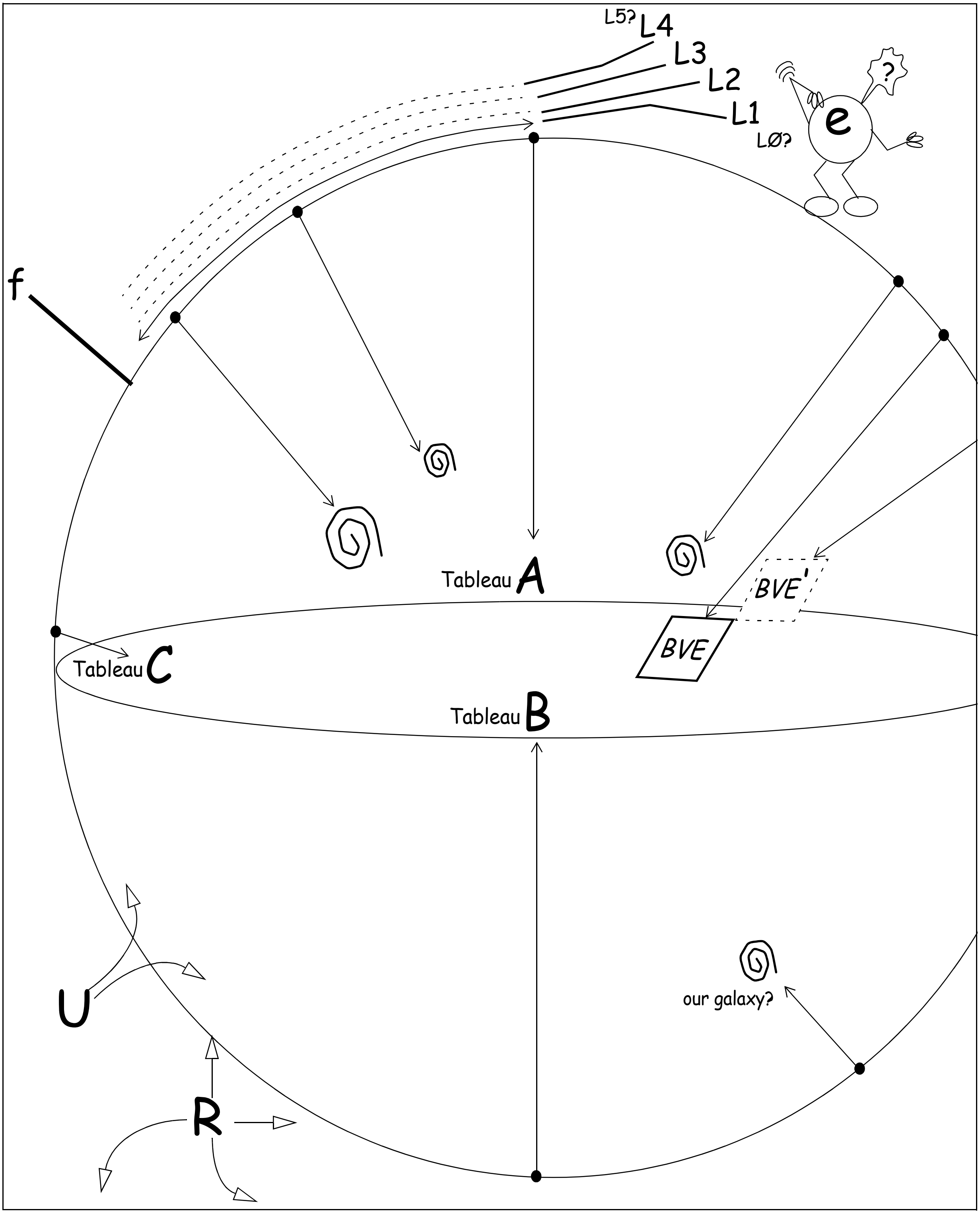


FIGURE 94: Static Universe projected from ‘painted’ interior of a sphere

That was easy. But what about L1, L2, L3, and L4? These are four distinct 'flavors' of Information to be incorporated in the single surface of the film, f, for projection into the interior. These are added elements of my own that depart from those suggested by the Bekenstein article. Likewise the elements labeled A, B, C, BVE, and BVE′ to be explained in due course, in the Key to **Figure 94** on **page 350**.

But first, we have a few preliminaries to dispose of: Some general remarks on the genesis, starting point, and fidelity of the holographic 'message' traveling from the film, f, to the interior:

- *Genesis.* The title of Chapter 1 in Smolin (2001) is: "There is nothing outside the universe." And he is adamant on the point. For purposes of exploring Information, I find it equally important to establish the opposite rule here: "There is an entity, e, outside the Universe, U. She is a sentient being, busily designing and tweaking the quadruple layer of holographic film." This is not a philosophical or religious assertion but a device that helps one study the topic at hand, that's all. It provides a foil for doing thought experiments about postulated levels (L1-L4) of Information.
- *Starting point.* From what point in cosmic history does the action of the hologram-movie commence? And, once that has been decided, where on the 'reel' does the movie begin playing? Let's say arbitrarily that the sentient being is designing a hologram that starts about 'now', give or take a million years, not a hologram that starts at the Big Bang and plays through 'now' and beyond. (The latter would seem too cruel a joke, as one scrutinized celestial evidence to discover the history of The Universe, when really it was just the reset button on a fancy piece of technology, perhaps a Hallmark Hologram for Little Sister's Birthday.)
- *Fidelity.* Having made a conscious decision to paint the holographic films, the entity might be concerned with accuracy of transmission: as an instance of her desired Universe is projected, frame by frame as it were, into the spherical space of the chosen realm, U, what is its level of integrity relative to its true form as defined by the painted film?
  When faced with roughly analogous challenges in the world of **TOES**, one speaks of a *fidelity criterion*. When Jane Doe pronounces "sssssometimes..." over the telephone, the synthesizer in the ear-cup at the other end needn't reproduce the precise (and onerously complex) wave form of this particular brand of a hesitating 's'; all it needs to do is consult its electronic palette and find a reasonable s-like sound (a generic 's') and pump it out, and the listener is happy, having detected zero infidelity for that particular sound. By contrast, Jane's vowel 'i' would require more than a canned i-sound to pass muster. Those are examples of fidelity criteria (after Pierce, p. 139). Also, in **TOES** one never assumes perfect

transmission. There will be deliberate omissions and random errors. One must decide up front what degree of fidelity and what degree of error-handling will be acceptable.

This brings us to the Cookie-Crumb Criterion: Will it suffice to have 231 cookie-crumbs on the floor of my car in a representation of 'this world today' per my count just now, when really there 'ought to have been' 232 as per the specifications on the film? If we answer Yes to the proposed compromise, might it be a slippery slope? Elsewhere, what if the entity becomes careless and dumps a million snowflakes on someone's windshield when really there should be a thousand per her own spec. Could there be adverse consequences? And by the way, how do we even *define* 'one crumb'? And having cleared that hurdle, what about all the leftover *infra*-crumbs which must also count for *something* in any grand scheme that claims to deal with Information on a comprehensive Bekensteinian scale? And for all that, we're still looking at the crumbs as mere **δata** thus far, not yet as [retroactively forensic] Information: At which convenience store were the cookies purchased, and how close to the time of the clerk's demise in an armed robbery was the time of that purchase? Could it be that the clerk was shot only for this package of cookies? Wouldn't that be a mitigating factor, suggesting mental impairment on the part of the perpetrator? And so on. Do you begin to have the first inkling of what we're really dealing with here?

Not that it's a burning issue in this context, but for form's sake let's assume a tolerance of

+/- 2% for the holographic projection, from the film to an instantiation of the Universe. (That is to say, the entity, in a pinch, will settle for as few as 226.3 oatmeal raisin cookie crumbs on the floor of my car as a good enough approximation of 232 as specified in her holographic film, but not a fraction less! And since I actually find 231 crumbs on the specified day, 'today', everything's fine. Even from a forensic point of view, I hope. Should it come to that. The one telltale crumb that might be found in the criminal's cuff. I can't tell you how glad I am to know that Someone is looking out for me, monitoring all these Way Pesky Details that the astrophysicist seems willing to brush aside.)

Now for the *Key* to **Figure 94**:

- Levels LØ-L5 are not meant as fixed and absolute. Rather, these labels represent a notional ladder of δ**ata**/Information complexity levels, as a guide to speculations such as:
  L5 = ?
  L4 = *meta*-Information?
  L3 = Information?
  L2 = δ**ata**
  L1 = potential forensic δ**ata**
  LØ = The concept of Self-Oblivionating δ**ata** come back to haunt us?
  (For more about this, see **Table 12**, **page 304**.)
  These layers are an intimation, a reminder, that more than one *kind* of ‘information stuff’ is probably required in order for the world, in all its complexity (or, in all its macroscopic squalor and messiness, if you like), to be projected from **f** into the spherical interior.
  For example, ‘the rainbow I see’ cannot be pinned down as mere δ**ata**; nor, for that matter, does it seem to fit quite at the Information level (which is generally built on top of a δ**ata** infrastructure). Rather, ‘the rainbow I see’ must be assigned to an intermediate level of abstraction. It should not be *too* high since it can, after all, be photographed if you stand where I stand. What shall we call it? Level L2½? (This rainbow idea I’ve stolen from N. Herbert, *Quantum Reality*, p. 162, where the author notes that a thing may be “object*ive* but not an object”; italics added. It’s a clever idea with many possible applications.)
- **e** = the entity; i.e., the putative Being or God who is running the show — wondering (in her thought balloon) how much of L1, L2, L3, L4 might be needed to populate the interior with a plausible instance(134) of **U**.
- **U** = the known Universe, depicted as the contents of the sphere enclosed by boundary, **s**. The contents of the sphere (exclusive of its skin at **f**) are to be understood as one immense hologram. The idea is that we mistakenly perceive the sphere’s contents as *the* Cosmos, whereas **R** is the real thing and ours is rather fake, a mere toy subset of **R**. Thus, we can think of ‘**U**’ standing for Universe, but more importantly it stands for Unreal.
- **R** = the *Real* place inside of which the whole show is merely a projection. (We find it natural to say ‘merely’ in such a context, but that word may be an unfair pejorative.)
  Meanwhile, to the entity, **e**, the unlimited area labeled **R** would be ‘the Cosmos’. For you, **R** might be experienced first as a Meta-Universe, assuming you could

134. I.e., with at least 226.3 crumbs on the floor of my car, as explained earlier; and with Bach really understood to *be* Bach; and so on.

ever break through the skin of **U**, the known Universe, to find it on the other side of **f**.[135] Later, you would adopt the entity's view and recognize **R** as the Cosmos.

- *BVE* = an instance of an *un*sorted Borges Video Emporium, this being a variation on the Pre-sorted *BVE* that was described earlier.
  Certainly this comprehensive library of every possible video wouldn't be a necessary, expected part of the Universe, the way galaxies and gamma rays and kittens and tea cups are. But neither should there be anything preventing an omnipotent entity from throwing a *BVE* into the mix — provided there were enough atoms[136] in the Cosmos, of course (details, details).
  So, for the sake of argument (and mischievous fun), we're assuming that an unsorted *BVE does exist* somewhere in the picture. And having had the gall to represent one such conglomeration in **Figure 94**, we might as well turn greedy and represent a second instance labeled *BVE′*, whose sisterly relationship to *BVE* will be explained shortly, by none other than Jorge Luis Borges.
- *A*, B, *C* = labels for various teacup-intensive tableaux, to be explained below, notably the Teacup at the End of the Universe.

galaxies (not to scale)

Whether you take seriously the main premise of **Figure 94** (that Plato was righter than he could have imagined, and we're all just shadow creatures being played back in some deity's Holographic Home Theater with SurroundSound, perhaps to the accompaniment of Olympian nachos noshing) is unimportant here. What *is* important is the mental exercise of contemplating such a scenario, for the thought-experiment helps us inch our way toward an inkling of what Information is. In whatever whimsical or normal context, Information is still Information; it's quite 'democratic' in that regard.

Relating L1, L2... back to V1, V2...

Are the levels called L1, L2, L3, L4 in **Figure 94** similar to levels V1, V2 (R1, R2,

135. Think of yourself as Jim Carey in the movie *The Truman Show*, trying to find a door that leads from the stage set to the outside world; except the suspected 'stage set' in this case is the entire known Universe.
136. Poundstone concludes that there certainly are *not* enough atoms, not even at the rate of one atom per video! In **Figure 94**, to help dramatize other aspects of the *BVE*, I assume (incorrectly, I fear) that there *are* enough atoms available for the construction of such a project, twice: first as *BVE* and again as *BVE′*.

R3) in **Figure 93**? Yes, but there is also an important difference: In **Figure 94**, L1 should be understood to *undergird* L2, L3, L4, whereas, V1 in **Figure 93** is the unstructured *residue* after sorting everything 'better than V1' into the V2-or-higher circle. Saying it another way, by the time we enter the V2 circle (which in turn contains R1, R2, R3...), all of the V1 stuff is behind us, mercifully excluded from consideration.

If you're the entity, **e**, planning out your Universe, you might be worried about where to 'locate' the sorting criteria that Poundstone proposes: *video snow*, *abstract*, *figurative*, *Good/Bad*. Are these sorting criteria to be located within the *BVE* itself? In other words, should they be 'sent down' as an integral part of the *BVE* holdings — perhaps as a kind of glued-on *meta*δ**ata**? From one viewpoint, such *meta*δ**ata** would seem unnecessary. One can make the case that the *BVE* is self-sufficient (complete in every detail) even as '*dumb δata*', the tagging or sorting of which would be *nice* but not *required*. (*That's* why the concept is so haunting.) Well then, should these sorting concepts of *video snow*, *abstract*, *figurative*, *Good/Bad* be built into the potential Earthling and Martian visitors instead? That seems almost as pointless as having those concepts reside somehow within the walls of the *BVE* itself. After all, the chances are almost nil that an Earthling or Martian will ever stumble on the *BVE* (or on a piece of it: one's own personal Video at the End of the Universe, so to say). So the potential visitors (as designed by an omnipotent entity, **e**) have no need for such concepts, do they? And indeed, returning to the real world for a moment, very few of your writers think that way: Borges and Poundstone — theirs is a rare and peculiar kind of meditation. Still, the ideas *exist*, by Jove, and once articulated by Borges or Poundstone, they make perfect sense. Where is the locus of those outrageous ideas?

Still, just in case, an entity, **e**, might use one of the 'extra' layers in her L2, L3, L4... scheme to handle this kind of Information: It's not required for the basic architecture of either a *BVE* or an earthling in isolation, and yet it will come into play if an earthling ever discovers a real *BVE* or simply meditates on an imaginary *BVE*. So hadn't it better be somewhere 'in the air'? Hadn't it better be on tap, somehow, for that contingency? As when an earthling looks up and 'sees a rainbow'?

Yes, on reflection, it should be part of **e**'s design for the Universe.

Context is everything: The Teacups in Tableaux A, B, C

Is there anyone who can deny that a teacup discovered by a human traveler at the End of the Universe, so to say, would convey *some* degree of Information? True, the space traveler might be mulling any number of competing *explanations* for the teacup he encounters out there:

- Someone else got here ahead of me?
- A space alien planted it here as a pleasant surprise, to make you earthlings feel 'at home'?
- Our supposed Universe is just one big holographic projection, so why not have a few stray teacups just randomly 'painted' hither and yon, in unexpected places? And so on.
- Is it a case of two convergent cultures (earthling culture and alien culture)?
- Have I time-travelled to elsewhere and elsewhen?

But for all these uncertainties about how or why the teacup turned up in such an odd location, I contend that any such traveler would find, in the mere presence of such an artifact, *some* considerable measure of Information (potential or immediate). The proof would be the traveler's reaction. He/she would not trudge past it. Rather, the traveler would halt to touch it, test it, turn it over, perhaps even dash it to the ground to see if it shattered, and thus rule out a simple hallucination (granted this would not rule out more complex hallucinations that might include the illusion of seeing it shatter or bounce like rubber, but it would be a start toward extracting Information latent in the teacup-as-δ**ata**).

But is 'one teacup's worth of Information' always the same, in any context? To suggest a variety of contexts, let's compare three simple tableaux, represented schematically in **Figure 94** by the labels A, B, C:

Tableau A. Teacup at the north end of the Universe. Let's say this is the one already described. The teacup is intact, well-preserved, even 'pretty' if you like (or comical or whimsical or absurd if you prefer: possessing whatever quality you think a proper Teacup at the End of the Universe should possess). It raises questions such as those already bulleted above.

Tableau B. Now we're near the south edge of the Universe, where a space traveler (it could be Cyndi Cyborg again) passes a motley collection of white sand and grey pebbles, among which are the smithereens of one pulverized off-white teacup. Will she even notice the obscure shards? Even if she notices the shards and harbors the suspicion of 'a broken artifact', will she have the time/tools/patience/interest to try putting humpty-dumpty back together? Very likely she will not. For the space traveler, this teacup possesses far less Information value than the one in Tableau A. (At this point, one might recall various metaphors that are used to explain **Entropy**[137] but our purpose here is different.)

Tableau C. On a deserted planet near the west edge of the Universe, a traveler comes across, of all things, an entire teacup factory. It appears that the production line halted centuries ago. The traveler estimates something on the order of a thousand teacups, standing single file on the long-silent conveyor belt, all of them intact save one that has been broken by someone or something. Its remains lie in shards, in-between two intact teacups, say two-thirds of the way down the line. Even without a special 'address' among the one thousand, most will agree that it carries some degree of forensic potential already (i.e., Information), just because it's the broken one among 999 unbroken cups.

If, on closer inspection, we observe that the broken item was teacup number 618 out of 1000, then the Information-potential takes on a new complexion: It is hard not to wonder about a possible 'message' alluding to the Golden Mean (*phi*), which is encoded geometrically in the Parthenon, and which is derived numerically as:

$$\phi = (\sqrt{5} - 1) / 2 = 0.61803$$

Or, if position 618 out of 1000 seems not to be a strong enough potential 'message', let's say teacup number 61,803 out of 100,000 teacups is the only one that is broken:

137. No doubt the image of Tableau B was put into my head by the broken teacup in Bekenstein's discussion of entropy (Bekenstein, 2003, p. 2). Several years after receiving that subliminal influence, I noticed that a broken teacup figures prominently in the video entitled *A Brief History of Time* (1991), which celebrates Stephen Hawking's life. *There's Something About Mary* is the title of a film; likewise, there's something about teacups...

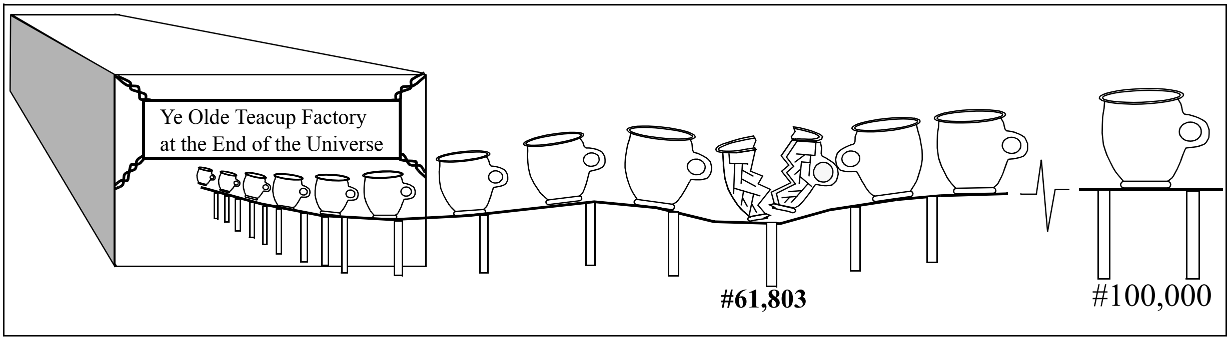


FIGURE 95: There's Something About Teacups

Now, in the implied juxtaposition of the numbers 61,803 and 100,000, I feel that even the greatest skeptic would have to admit a likely allusion to the Golden Cut or Divine Proportion (to use the term that Kepler borrowed from Luca Pacioli).

Please note, if you haven't already, the crucial role of context:

In Tableau A, an intact teacup was the star of the show. In fact, that one teacup was the whole show. In Tableau C, on the other hand, any individual teacup, no matter how perfectly white and shiny and intact it may be, is ultimately 'just another one' among the 99,999 boring ones. It's the only one that might provide some forensics as to *how* the production line stopped, *why* it stopped, and *when*. That sort of thing.

In Tableau B, the (broken) teacup is of minimal interest. Worse yet, its degradation is such that it may not even be noted by the traveler from afar. *¡Qué lástima!* Whereas, in Tableau C, it's precisely the broken teacup that *must* be noted and *must* be the star of the show.

Just to round out the possible patterns and reinforce the importance of context, we could also propose a Tableau C′ (not represented in **Figure 94**) as the mirror image of C: now all the broken teacups are the boring ones; only the intact one, Teacup #61,803, 'says something', by holding out the hope of forensic Information, or by conveying a symbolic message: the number ϕ.

Finally, we could have Tableau B′ as a variation on B: As before, it's a shattered cup with no companion cups, let's say. But this time it happens to be part of an encryption scheme: It's a special kind of teacup that shatters always into exactly 42 pieces, with exactly 17 different possible configurations of the pieces that have been defined as meaningful, and the configuration is selectable by he or she who shatters it. All the traveler needs is her machine for reassembling the 42 pieces and her code book for looking up which of the 17 meaningful configurations was selected in this instance. Voilà, she can 'read the encrypted message'. So, 'disorder' and **Entropy** have subtleties to watch for: Tableau B′

demonstrates that even a shattered teacup that is *probably* of no interest (like the one presented in Tableau B), *might*, for all we know, harbor a gold mine of Information 'internally' — *independent* of the context. Without knowing its history, we can't say. Also, this can be taken as a playful 'proof' that when certain theorists annoy us by saying 'more disorder = more Information', they are right (kind of, some of the time).

In everyday conversation, we talk as if we believe that Information resides in the medium itself: inside a computer memory chip, inside a teacup. But what if Information resides at a higher level than the medium in question, in an abstract layer where 'context is everything'? Then we can't be so glib about its representation and manipulation.

Note that the difference between a setup featuring 'teacup #618 out of 1000' vs. a setup featuring 'teacup # 61,803 out of 100,000' is not one of 'less' or 'more' Information. Rather, it's a matter of 'less likely to *be* Information' vs. 'more likely to *be* Information'. That's the real difference. This *assumes* belief in probability and randomness.(138)

This has been my attempt at using a small object, the teacup, to show the importance of context. The lesson is: Mathematical theory tells only a fraction of the story; only from a higher perspective can you clarify the mosaic of δ**ata**, *DERN (aka Shannon information)*, and Information.

To further explore the interplay of context and Information, here are a few scat syllables that might be applied to a jazz riff:(139)

shoo-buh-doo, shoo-buh-doo, shoo-buh-doo, BEEBOP!

One can use 'dumb δ**ata**' to depict it, and it will just be whatever it is. But if the entity, **e**, wishes to ensure that her daughter, elètte, will hear this phrase as an earthling would, then she needs *meta*δ**ata**, explaining that the 'reading frame' must treat these four musical 'words' as a musical sentence, wherein we've played with

138. When I drafted this section in 2003, the two concepts still struck me as faintly suspect. I've since done an about-face, as indicated by the inclusion in this volume of **Appendix F: God IS the Dice**, written in 2008. (For a slight taste of how probability might be regarded as 'suspect', see page **398**, where I revisit Richard von Mises' early misgivings on the subject.)

139. In the parlance of classical musicians, that would be "a short melodic ostinato." A motif that repeats itself obsessively.

expectations (probability): Having reiterated the first 'word' three times, is the musical thought complete and clear, or would it work even better with four instances of *shoo-buh-doo*, thus making the concluding *BEEBOP* even slightly more unexpected and surprising?

> shoo-buh-doo, shoo-buh-doo, shoo-buh-doo, shoo-buh-doo, BEEBOP!

How about ten instances of *shoo-buh-doo*? Would that be too many? Yes, unless we brought the phrase down to a whisper and inserted a dead silence (dramatic pause) just before the *BEEBOP*, then it seems to work again:

> shoo-buh-doo [10 times...], *pause*, BEEBOP!

How much of this kind of contextual setup does the little one need in order to 'get it' just the way an earthling listener would? Or might she never ever get it? On the one hand, she's the Daughter of God, so she's a quick study and shouldn't need *much* of a clue, should she? On the other hand, she's a nonhuman entity, so we shouldn't expect her to necessarily hear it the earthling way without *some* amount of *meta*δ**ata** to guide her. How much *meta*δ**ata** and context will suffice?

BVE and *BVE′*

To supplement my rather lightweight Teacup and Bebop examples above, here is an example of 'context' that some readers might find more thought-provoking:

> If only we possessed a cyborg battalion large enough to physically sample it and a computer large enough to analyze it, we might discover that there existed side by side with 'Borges Video Emporium — Unsorted', a perfect copy of it, pixel for pixel. With the perfectly *dis*ordered Emporium thus repeating itself verbatim as a second Emporium, identical to the first in every detail (call it Emporium prime), wouldn't we have the intimation of perfect *order*? At this point, a presumed Utter Chaos would suddenly be perceived as Perfect Order, thus making a mockery of all human 'thought' and 'analysis', so inadequate to the task.

That's a loose paraphrase of the final paragraph in Borges' *La Biblioteca de Babel* (1941), reworded in terms of our video emporium. In **Figure 94**, the idea was represented graphically already by the presence of *BVE′* (Borge Video Emporium prime) adjacent to *BVE*, such that the secondary emporium might — by an infinitesimal chance — be entered just as one was exiting the primary emporium, and so on forever through and endless chain of such emporia.

With this image of a library that is limitless and chaotic yet periodic, Borges has hit upon something more powerful than its inverse, those pockets of order-within-disorder over which the Entropy Theoretician is wont to ruminate, sometimes inventing silly terms like 'negative entropy'. Once again, Borges manages to cast a shadow over everything — in this instance, over the very notion of **Entropy** itself. He beats the entropists at their own game. (In a subsequent reference we'll see him anticipate Poundstone again, this time by fifty years.) One is inclined to acknowledge Borges not only as the Founding Father of Emporiumology, so to say, but also as the current and continuing master of the domain. Using only words, and alluding to no fancy computational device, there is no detail of the Horror that his keenly lurid imagination did not intuit, as he worked in isolation in the dim distant past of the 1930s and 1940s.

A context for all three Tableaux — *A*, B, and *C*

Let's return to **Figure 94** and consider the three teacup tableaux in the larger context of U, along with the *BVE* and the *BVE′*. Here's the rationale for showing all these objects together in 'one space' — all within the region labeled U:

Each vignette involving one or more teacups at some fabulously remote edge of the Universe is in itself absorbing (I hope), but this doesn't relieve one of the responsibility of stepping back to view all of them together, then posing a bigger question that goes something like this:

> From an L2, L3, L4 standpoint, is there an entity (such as '**e**' or God) who actually 'cares' (gives a rip) about the Gestalt of A-and-B-and-*C* and all other such configurations within U at once (meaning within the same millennium, let's say, give or take a couple centuries)? Or, is it good enough from God's standpoint that the raw δ**ata** exist at the L1 level — the bare minimum recipe for simply making *A*, B, *C* happen, without regard to Information at L3 (useful knowledge) or judgments at L4 (aesthetic value)?

A picture encompassing *A*, B, and *C* helps one gain, literally and figuratively, that perspective.

We said that a good U need not include a Borges Video Emporium. We've depicted an instance of U whose maker did happen to include a *BVE* for the following reason: It's a useful tool for developing one's understanding of Big Numbers in general and of quantity-of-Information in particular. When we are so bold as to speak of 'all the Information in the Universe', do we mean it in the sense of δ**ata** or Information? I've tried to persuade you (and myself) that the latter is what we must mean. However, one of the eeriest results of visiting the *BVE* is this: Upon exiting from a tour of V4 specifically, one is not nearly so sure that δ**ata** alone *cannot* do the job of defining U.

Here's how I resolve the paradox, or at least come to terms with it:

Step 1: Whatever this great thing is, the one known as 'Brandenberg Concerto No. 5', I am confident that it must exist already, somewhere in the Borges Music Archive (let's call it that).

Step 2: Therefore, the person J.S. Bach is no longer 'important'. We have de-mystified his contribution, and here we stop worrying about *meta***δata** and commentary and 'proofs of greatness' vs. dead white men and all that. Only the **δata** matters; everything else is a side show, a red herring.

Step 3: But wait — how shall we *find* the Brandenberg Concerto No. 5 among all the dross in the Borges Music Archive? (And, if one is a space alien, how shall one understand it?) Good questions. So it turns out the *meta***δata** (or whatever) *is* important after all. Just not in the way we originally imagined: It's important so that the Borges Music Archive can be sifted and indexed, allowing one to browse in the 'good' sections, and not have to meander forever in the White Noise section (= the musical equivalent of Cyndi Cyborg's plight as depicted on **page 342**). But the indexing in turn means still more **δata** storage is required. And this leads to a familiar question: Is there enough room in space — are there enough atoms or quarks in the Universe to hold the **δata**?

Thus, we begin to inkle that even on a '**δata** only' basis, *sans* Information, we're looking at some horrifically big numbers.

And so much the worse if *meta***δata** and indexing (in short, Information) tuns out to be the name of the game: If music were food, then most fine citizens of the world would be sitting down to a dinner of three-day-old garbage, as I would characterize much of our 'popular' music, relative to Bach. *Why* is the average human ear so garbage-tolerant?

Could it be that the DERN-inherent-in-the-cold-**δata**-of-the-score-written-by-Bach is not *by itself sufficient* to get the message across? Well, obviously, yes. It is not sufficient. So, if you're interested in sending the Bach *Brandenburg Concerto No. 5* from 'here' to 'there' (e.g., from the holographic film 'down' into a projected instantiation of the Universe), you had better have a *plan* for addressing that other element that seems to elude 95% of the earthling population.

- Here's one plan:

You create a ton of *meta***δata** to accompany the plain **δata** of the musical score. You annotate. You explain. You pack whole Music Appreciation courses into that little *meta*δ**ata** field. ("Good Morning, class. You've probably noticed that ice water tastes better than a Fido Feces Milkshake with Cheese Bubblers? Well, Bach is kind of like that — like the sip of ice water, I mean. Take this phrase, for example...")

- Here's another plan:

You hypothesize that the full picture about the phenomenon known as '*Bach*' (or the phenomenon known as '*AC/DC*') is distributed across a whole ensemble of various earthlings who 'get' *this* part or *that* part of Bach (or of Angus Young) individually, and *all* of 'it' collectively. And therefore, you create on the film a proper and complete ensemble of such creatures-to-be-projected along with the score itself, such that the score will be properly understood and appreciated. Otherwise, you fail.

- Here's another plan:

I admit that this great pointyhead ivory tower value we assign to Bach is really just hokum in the Large Scheme of Things, where far greater wonders are created and destroyed daily in the crucible of the Crab Nebula, for instance, so get over it and forget this dead white Teutonic male scribbler of inconsequential earthling ditties.

- Here's another plan:

In the Borges Music Archive (by analogy with the Borges Video Emporium to be described later), the *Brandenburg Concerto No. 5* appears on a certain shelf *automatically*, without the help of Bach. So forget him already. There's nothing so special about any of his scores.

So nagging is the *Brandenburg Concerto No. 5* question that at times it sends me off in the following direction (which is wrongheaded, I hope!):

In general, **U** consists of objects, and these are described by **L1** (such that the whole Universe could be copied somewhere, or such that the whole Universe is actually a holographic projection from the films **L1-L4**). However, some important parts of **U** are already 'just information' to begin with:

- The idea-of-Bach's-*Brandenburg Concerto No. 5*
- The idea-of-Mozart's-*Symphony No. 40*

Recall that Mozart could perceive each of his compositions as a timeless three-dimensional solid. Bach very likely had the same ability. That's what I mean by "The idea of..." I mean it literally, in its most amazing sense: x in its totality, as one huge structure in the mind.

In **U**, it must be the *Brandenburg Concerto No. 5* as information (the *idea* of the concerto) and Mozart's 40th as information (the *idea* of the g minor symphony) that counts, even more than an instance or two of the score. So how do we capture this δ**ata**/Information stuff in **U** and represent it in terms of L1-L4, whose purpose generally is to operate the other way around, turning objects in **U** into δ**ata** and thence into Information?

In short, the astrophysicist can have it whatever way he wants, but he must have a strategy for handling all this before he talks blithely of all the Information in the Universe, as though it were just a matter of sending a few Morse Code pulses down the telegraph line from Albuquerque to Santa Fe.

Very Big Numbers

Nowadays I sense a cavalier attitude toward big numbers, no doubt inspired by our success at ultra-miniaturization of computer components of late. Thus, sounding more like a preteen neophyte than Grand Old Man of Astrophysics, we have Bekenstein playing with ideas such as: "How much information does it take to describe a whole universe?" (Who knows what he means by 'information' and who knows what he means by 'a whole universe', but the one sure thing is his impudent disregard for big numbers.) Once upon a time, thoughtful people took time to worry a bit about such things. In Gamow, we are treated to a vision of the stars blinking out before the priests have been able to transfer the 64 disks of the Tower of Brahma simply from 'this needle to that needle' according to the rules.(140) Or the Automatic Printing Presses (one for each atom in the Universe, already an impossibility) having printed, at the rate of atomic vibrations, only one thirtieth of 1 per cent of the total lines required after 3 billion years.(141) Taking another tack, Borges invites us to imagine the line...

O Time your pyramids

...lurking sardonically on the penultimate page of a 410-page volume comprised otherwise of nothing but gibberish. (*Oh tiempo tus pirámides*, Borges, p. 89.)

In Poundstone, we have allied meditations that touch the twin problems of building a Universal Video Library and the equally daunting one of finding one of its

140. Gamow, p. 11: "...it would take slightly more than *fifty-eight thousand billion years* to accomplish."
141. Gamow, p. 14.

holdings:

All videotapes are made of atoms, and there are not $10^{10^{11}}$ atoms* in the observable universe.

— Poundstone, p. 95

Unfortunately, there are $10^{10^{11}}$ call numbers and $10^{10^{11}}$ videotapes.**
By Shannon's definition, the call numbers contain just as much [$I_{nformation}$] as the videotapes... The demon's sorting scheme is like a library where patrons must ask for books by reciting their complete texts.

— Poundstone, p. 99

* The double exponent (10 to the [10 to the 11th]) puts us somewhere between a google and a googleplex of atoms: i.e., the number required in manufacturing the tapes that would stock the Universal Video Library (or its variant that I call the Borges Video Emporium.)

** The machine that creates the Universal Video Library "manufacturers a tape to match each call number" (Poundstone, p. 92), so the *δata* for a given tape and its call number are one and the same. The first call number in Poundstone's Universal Video Library (or in our *BVE*) would be all 0's — some few billions of them. The last call number would be all 1's. Somewhere in-between would be found — as a video text item — your Book of Vindication, as described in Borges, p. 93).

In Poundstone's Universal Library, each video's binary data stream (010001101110011...) must *itself* serve as the call number. Thus, video madness is mapped one-to-one to call numbers beyond human reckoning. Once again, Borges offers a literary version of the same idea (anticipating Poundstone by 50 years this time). The Borges version(142) is called a Map of the Empire. But this is not just any map. This one is the apotheosis of maps, matched point for point to the physical Empire (raising the question of which one is primary, which is secondary: could the physical Empire simply be a blueprint for making the sacred Map that lies stretched out upon it?) Here is a realm where the saying, 'the map is not the territory', could only inspire a nervous titter among its denizens. Better say, "Dwell not beneath the Map, m'am, where sun and air are in deficit, but hie thee to the topside, using tooth and nail if need be." In both cases, some keeper of the **Information** (a Video Librarian, a Royal Cartographer) carries out his job so conscientiously as to create the Perfect Hell.

Here's another passage in Jorge Luis Borges that has an indirect bearing on the notion of a manufactured, holographic Universe:

> *Cuando se proclamó que la Biblioteca abarcaba todos los libros, la primera impresión fue de extravagante felicidad...El universo estaba justificado, el universo bruscamente usurpó las dimensiones ilimitadas de la esperanza.* Borges, p. 92

142. The piece I'll be referring to here is called "Of Exactitude in Science", which comes from Borges' *A Universal History of Infamy* (1935, 1972), p. 141. All the other Borges references have been to *"La Biblioteca..."* in *Ficciones* (1941, 1997).

> When it was proclaimed that the Library comprised all books, the first reaction was extravagant joy... The [immensity of the] Universe was justified; for, suddenly it *matched* (143) the illimitable dimensions of [our collective] Hope!

The notion of the Cosmos-as-just-someone's-hologram (a birthday hologram from the entity, **e**, to her daughter, **e**lètte?) has a similar flavor, in this sense: It resolves all questions about the extent or meaning of the Universe. In Borges' sardonic vision, the Cosmos is just a place big enough to accommodate that doggone Library from hell. And you needn't write your novel: it already exists out there. On some dusty shelf or other. So, have a beer and be happy.

In the holographic vision of the Universe, our supposed Cosmos is just a projected image from somewhere and elsewhen. We should all get over it and stop worrying about stuff. None of this was ever real anyway. We're just the movie playing out.

Now, with more comprehension, we'll revisit the line of Borges that was cited on **page 345**:

> *La certidumbre de que todo está escrito nos anula o nos afantasma.*

The certitude that all has been written has the power to annul us or turn us into phantoms, says Borges (p. 98). Or, revisiting the Conrad epigraph, could it be that your whole world — every object, every gesture — has the quality (*mutatis mutandis* to accommodate the different number of dimensions) of a painted ship on a painted sea?(144)

And if we buy the holographic principle, isn't that exactly what we are: not real, but phantom shadows all? Creatures of pure **Information**.

Or, did the **δata** alone suffice to get you here?

That's the haunting question.

* * * * * * * * * * * * * * * * * *

A funny thing happens sometimes. Maybe you stop everything and put many months of effort into trying to redefine and clarify a single concept: the concept of

143. Here we are thrown a curve by Borges' quirkiness: No one seems comfortable to simply translate "*usurpó las dimensiones ilimitadas*" directly as "*usurped* the illimitable dimensions"; rather, they do an interpretive tap dance, morphing it into "*expanded to* the limitless dimensions" (Kerrigan, p. 62) or "*became congruent with* the unlimited width and breadth" (Hurley, p. 26). As baffled as any by the quirk in Borges' phrasing, I've opted for '*matched*' in my own informal, on-the-fly rendition above.

144. Joseph Conrad, *Victory*, Part III, Chapter 1, p. 168.

Information, for example. Then one day it hits you:

> Actually, there is *no such thing* — not out there where it counts. The totality of all our Information is merely a *human artifact*, analogous to and only slightly more interesting than, say, the twigs in a robin's nest (Enchanting!), the branches in a beaver dam (Clever!). Meantime, the Cosmos does *its* thing on utterly alien axes. And Information falls (in this view) to the level of phantasmagoric illusion of confused earthlings.

True, there is a field called Physics of Information where information is regarded as physical, not a mystical non-physical entity. But their assertion falls flat, coming from a Hammer to whom the whole world is a Nail (= the physics of δ**ata** storage). The Hammer sounds out of place and unconvincing when making pronouncements about Information (= something other than its accustomed Nail). Thus, undeterred by the Hammer's pronouncement, as we explored various angles earlier, sometimes we *did* try viewing Information as a 'mystical non-physical entity', if you like. And here I've done far worse by proposing that Information is simply an earthling fetish and *illusion*. It doesn't get more non-physical than that, and still I'm unrepentant.

There are three paths I know of, and probably several others, that lead independently to the same unsettling picture of what the Cosmos might really be, as distinct from what earthlings wish it to be, based on their naïve extrapolations from a presumption of the primacy of δ**ata**/Information:

- Path 1: Follow some discussions of the subtlety and importance of the δ**ata**/Information distinction for navigating the human realm, and eventually you have to start wondering: But where is all the δ**ata** of the Cosmos hiding, and what would be *its* Information counterpart? What if the Universe simply 'doesn't care' about this and that's why 99.9% of all our potential δ**ata** seems to hemorrhage into Oblivion second by second? Perhaps the Universe long ago deemed unaffordable any extravagance of the kind we have built up into a foolish ant hill of late, calling it The Age of Information? (Or, conversely, if the whole supposed 'Universe' as we know it *is* pure Information already, and we are just its 3D shadowstuff, where/what is the δ**ata**-reel from which this fake 'Universe' is being played back, and can there possibly be enough atoms in the Cosmos beyond the film to have supplied its requisite 'paint'? This is not the way an astrophysicist thinks, but these would be reasonable questions to entertain in the context of this appendix at least.)
- Path 2: Having explored L1, L2, L3, L4, which we first saw in **Figure 94** on **page 347**, it would be natural to speculate as follows: "What if there were also an LØ or an L5?" As I picture it, LØ would be a kind of self-sufficient bedrock of the Cosmos comprised of Dumb Data or anti-δ**ata**: something mindless and anarchic that might share a few attributes of δ**ata** as we know it, while having *no*

potential for ever being transformed into useful Information. Something even lower than Potentially Forensic cookie-crumb-δ**ata** of L1.

- Path 3: Through his half-century of dreams and intuition and literary flights of fancy, H.P. Lovecraft finds himself coming back time and again to stand at the edge of a black void that bears a striking resemblance to the abyss toward which Path 1 and Path 2 seem to be tilting and lurching: "I have seen the dark universe yawning, where the black planets roll without aim," could well be his epitaph. (For the source, and for a sampling of other such passages, see **page 374** below.)

In short, once you start thinking along the lines of Path 1/2/3 (any or all of them), it is all too easy to envision a Universe where Information is an irrelevance, an earthling artifact that doesn't even count.

Far from being an Information-intensive place, as seems natural to the human psyche, it's a place where something like anti-δ**ata** (and by extension anti-Information) must be the order of the day. A place where the First Cause would hardly know what to do with 'all the Information in the Universe' even if such were handed to her/him/it on a silver platter.

Now we examine the three paths each in turn:

Path 1, Self-Oblivionating δata

If Information were really so important in some grand scheme of the Universe, its underlying δ**ata** would not be allowed (by laws of Nature) to evaporate at the rate of 99.999% every second the way it does. That, however, is the reality. From our mass media pundits, we hear about 'information overload' (primarily their doing of course!), and we accept the 'overload' idea uncritically only because our brains are so small relative to what they would need to be for life in a (genuinely) Information-intensive Universe. It *seems* like overload, but really if you step back and think about it, our true situation is the polar opposite of what 'information overload' suggests: in my life and in your life, scarcely anything that *might* become Information is in fact captured *as* Information.

The vast majority of it is lost — a circumstance that means *all* of us are living (already, without space travel) in a Black Hole of sorts, by virtue of all the uncaptured and basically *uncapturable* **δata** that leaks out of our lives in a torrent, moment by moment.[145]

Once you're attuned to it, the message seems to come in from all sides: **Information** *is only a notion, a preoccupation of certain macroscopic creatures, such as earthlings.* Just because you've formulated the concept of **Information**, you expect it to correspond to something real or meaningful, up in Andromeda, down in an atom. But *why* should your notion of **Information** be relevant on Andromeda or an atom any more than burrow number 5,431,755 in the long proud Oral History of Badgers should be relevant to your human domain? That's the embarrassing question.

As a mental exercise, let's turn it around, though, and suppose **Information** *was* 'valued by the Cosmos' as part of the grand plan, and was therefore *not* being hemorrhaged away into Oblivion, second by second. What then? That would create an even worse structural problem. In that scenario, the Cosmos would find itself so glutted with **Information** it would come to a screeching halt after the first few seconds of Creation. Why? Consider the situation for electron orbitals, for instance. Each of the electrons in the countless atoms in and around you can be in a variety of energy states, occupying a high- or low-energy shell. Science can tell you all about these shells and orbitals in a *general* way that will explain, for instance, why hydrogen and oxygen combine to form a compound but neon and chromium do not. Yet no one could hope to capture all the *particulars* of one atom as its electrons actually shifted orbitals and absorbed or released energy — say one atom of mercury, with 80 electrons to account for, in a fluorescent lamp during one month's use. A modest enough proposal? Here I'm not even talking about Heisenberg uncertainty, mind you. I'm talking about the sheer *bulk* of hypothesized **Information** that would be

145. For many of its readers, this has been a prominent subtext of the novel Ulysses: so many happenings in a single day of an ostensibly humdrum life that even such a prolix Dubliner as James Joyce cannot capture one ten thousandth of the whole in his fat rollicking volume. In retort, one might say, "Well, what do you expect? It's such a jumbled mess down here at the macroscale level where we're all caught like flies milling about in molasses, midway between the cosmic and the nanoscale, where life would be neat and clean and coherent." Really? There might yet be a music of the spheres, but down on the nanoscale the models do not become 'clean' as once believed; quite the opposite, as we enter the domain of wave-particle duality and Heisenberg's uncertainty and even perhaps an 'entanglement demon' as a quantum-mechanical variation on Maxwell's demon. (For the latter, see Seth Lloyd's article in Leff & Rex, pp. 212-220; or Leff & Rex, p. 32 for a synopsis.)

available *before* you hit that wall. Enough to crash all the computers on the planet I dare say, long before the requisite one month's **δata** had been captured for that *one* atom of mercury among its sisterly millions in the fluorescent tube.

If the electron orbitals for mercury sound a bit too tricky or theoretical as our point of attack on the primacy of Information, then never mind chemistry, never mind physics, and turn the beam on yourself for a moment: consider your own myriad daily activities.

- How exactly do you enter your car?
- What exactly do the fingers of your left and right hand do in the vicinity of the dashboard and steering wheel in those first three seconds of the 9-to-5 day?
- And what might be the statistics on one's heart and lungs at that juncture? And so on.

We're only a few seconds into your day, and again we threaten already to fill up whole banks of computers if we've agreed to do this **δata** collection for, say, everyone in the neighborhood, never mind everyone on the planet: The capture of everything about the first three seconds of everyone's day. Surely not an unreasonable goal. Among the **δata** points I have in mind, there are a scant few that might be regarded as Found-and-Lost-**δata**, as when one happens to glance down at the odometer and correlate its digits with 'in the garage' on such-and-such date. (But who really cares? Hence, 'Lost' after 'Found'.) But by and large the **δata** points vanish even before one knows they exist, and are therefore best characterized as Self-Oblivionating-**δata**, a kind of **δata** that dies even before it is born. It's all there *in principle*, but as a practical matter you're *not* going to analyze it, you're *not* going to name it, you're *not* going to organize it, and you're *not* going to capture it, not in this century or the next. And as for the past, the corresponding **δata** are gone forever. Think about it: Even the **δata** on what you were doing a few minutes ago is already gone. Irretrievable for Eternity. And now some more is gone. And now some more. And more. All falling in a torrent into Oblivion. Partly because so much of it is 'don't care' **δata**, I'll grant you, but *chiefly* because we lack the mechanisms for capturing and storing it, even if we did care.

Forensics and the challenge of describing Potential Retroactive Information

Earlier we saw the stark contrast between *δata* and Information. To illustrate the point, we used the example of *δata*, whose key for turning it back into Information was (a) present, (b) lost, or (c) unknown, and so on. In that context, we had the advantage of being sure at all times that it once *had been* Information: That was a given, per my artificial construction of the examples. There was just the question of finding the *δata*'s proper interpretation to *illuminate* that aspect and turn it *back* into Information, as when 'cm' is [re-]appended to '47' to indicate unambiguously 'forty-seven centimeters'.

Also, implicit in that discussion was the circumstance where data communication is a de facto form of encryption (because '110' doesn't look anything like the word 'violet'), even where encryption per se is not the intent; this effect is intensified, of course, whenever a data compression algorithm is applied on top of the encoding step, as when we create a 'ZIP' file for convenience. Then the **δata** is two steps removed from being Information (or three steps removed, if you like, for the case where [a] 'cm' is missing, [b] the numeral '47' is encoded, and [c] the file is compressed).

Definition of '*crumb*' as a technical term

Now consider the case of *crumbs* — potentially thousands out of the existing billions of cookie crumbs extant on the planet as we speak — that might one day *become* Information, after the fact. That's a separate flavor, one that pertains to the world of forensics (among others), as noted in passing in **Figure 85** on **page 300**. These items are something like *δata* waiting to become Information; however, they are different enough from conventional *δata* (in the sense that pertains through most of **Appendix D: The Fifty Years' Gibberish: So-Called Information Theory**) that I feel compelled to assign them a separate name: *crumbs* as a technical term, referring not only to cookie crumbs but to anything similar such as the random eyelash on the carpet or particle of zinc dust in one's trouser cuff, and so on. In short, it is anything at all that might conceivably have forensic significance later, given a new context that suddenly puts it in the lime light because it is now observed by a detective to be in intimate contact with either a victim or an alleged perpetrator of a crime. In **Table 23**, I've tried to integrate this new type of Information, the *crumb*, into an earlier picture of how *δata*/Information are related. It is clearly not a very happy coexistence:

TABLE 23: Cookie Crumb Forensics compared with Information/*δata*/Information cycle

Time-line	t1	t2	t3
Type of Information	Original State: Clear Information	Transformed into *δata* by removal of units	Transformed back into Information by reinstatement of *units*
Regular (non-Forensic)(1)	'47 cm'	'47'	'47 cm'
	Original state: Murky Information	n/a	Partially transformed by *Detective* into clear Information
Potentially Forensic(2)	∃ crumbs (none is specified)	n/a	∃ c crumbs (a specific one)
	∃ eyelashes (subliminal only)		∃ e eyelashes (specific)
	∃ zinc-dust-particles (quasi-invisible)		∃ x zinc-dust-particles (a specific particle)

1. Reading left to right, when we come to t2, the units are now implied rather than explicit (cm). This makes storage more efficient, but there is now vulnerability since the 'translation key' is easily lost, in which case it may not be possible to convert the data back into Information — the more so if it has also been encoded and compressed for convenience of transmission and/or explicitly encrypted on top of all that de facto encryption!
2. With Potentially Forensic Information, there may be no units involved, nor any δ**ata** for that matter, only the question of "Does it exist of not?" for which we've borrowed the logician's symbol ∃. (Read "∃ crumbs" as "There exist some crumbs"; read "∃ c crumbs" as "There exists a 'c' belonging to the group 'crumbs' "; and so on). In the table, we show the case where one is initially aware of, say, the existence of '100 crumbs' as a vaguely defined group (at t1), and only after a crime is committed one particular crumb takes on forensic significance (the specific crumb 'c' at t3), because it has been observed on the person of the criminal or on the person of the victim. At t1, all the crumbs can be thought of as Potentially Forensic Information, and at t3 the one crumb 'c' has been transformed into Retroactively Forensic Information. (This table is a variation on **Figure 85**, with the pile of cookie crumbs shifted arbitrarily to t1 instead of t2, to gain a different perspective on the pattern.)

If the lowly *crumb* can be this important for all of us, crawling on a planet-speck called Earth, who is to say the same principle wouldn't apply — in the perspective of some higher entity — to all the *crumbs* in the Cosmos? All of them must be precious, given their great forensic potential, in case of some Cosmic calamity: your moon *crumbs*, your Pluto *crumbs*, and so on. That would be the putative design philosophy. But given the magnitude of our imagined Solar system *crumb* count (and never mind the Cosmic *crumb* count), that scenario should strike one immediately as insane, if one has any feel at all for Very Big Numbers. Rather than being entertained as a serious design philosophy, then, the *crumb* as Potential Retroactive Information would best be accepted as yet another indication that humans are simply not equipped to understand their Home (the Universe). Even if you sweep that one under the rug, other such messages will continue arriving from all sides, reminding you that the great *puta madre* **Information** that *you* consider so important mixes not at all with the *Cosmos*, rather like oil with water.

From the macroscopic mess of many vexing cookie crumbs (and their quasi-crumb cousins, crumblettes, and infracrumblish specks all patiently awaiting their possible information-ization should a crime occur), let us turn to a meditation on the interior of a single pristine raindrop, since the pretty raindrop too is a proud participant in Life. In the following item, the author avers that the information required (I would say *δata* required) to describe a single raindrop would exceed *all the speech yet uttered on this planet*: http://math.ucr.edu/home/baez/information.html.
(See also www.sims.berkeley.edu/research/projects/how-much-info-2003.)

And mind you, that would be the state of the raindrop for just one instant, not the instant before or after the proposed descriptive exercise.

Going all the way to the other extreme, let's consider a case where we *do* have All the **Information** in the Universe, alledgedly at our fingertips, yet haven't a prayer of accessing it:

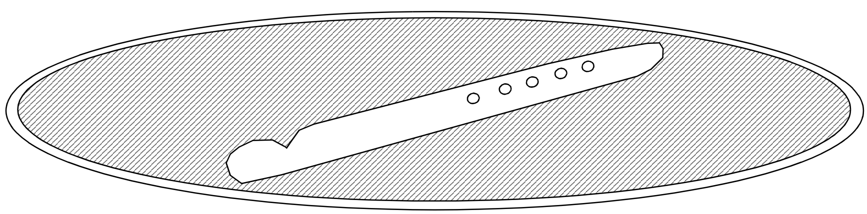


FIGURE 96: Still Life: 'Flute on a Silver Platter'

We've been told that the object on the platter in **Figure 96** has a length of 'one flute' exactly, by imperial decree. And, for convenience, let's say 'one flute' turns out to be about the same as 'one foot' in the English measurement system. We can see that the notch (the mouthpiece) has been carved about one sixth or one seventh of the way down its length. Now, to access this flute-as-database contraption, all we need to do is determine *exactly* where that notch is, and presto: one is holding in his hairy palms All the **Information** in the Universe.

It's a special flute, manufactured such that the notch marks *the* decimal fraction[146] that contains all the *δata* needed to describe the state of the Universe — as of the date 01/01/3008, let's say, just to pick a point in time. In other words, the flute is exquisitely machined to a googleplex of significant figures, but of course one can never know for sure if it is the database it claims to be, since our measuring instruments are so coarse compared to those of the Grand Vizier who fashioned the flute on his *very* special lathe for the Mistress or Master of the Universe.

For example, measured to 7 decimals, do we find that the notch is at position 0.1428571 feet or at 0.1428579 feet? If it's the latter, it has begun to diverge slightly from the 142857 repeating group required of a pristine 1/7. But already my instruments fail me here, let's say. Or if not here, then at the 100th digit or 3000th digit. Sooner rather than later the game will be up, and we'll be nowhere near the desired googleplex of accuracy, hence none the wiser than when we began. (By design, it's an all or nothing game. Either you *read* the notch all the way out to the intended degree of accuracy and dump the resultant number into binary form inside a Really Big Computer to become Omniscient Queen of the Universe, or you *don't*. There's not much point trying to read only the first one thousand *δata* points or so out of a googleplex-ish total. Thus, the mild-mannered flute on a silver tray remains one of the most cruel and sardonic jokes that God has ever put up his sleeve.)

Earlier among these Path 1 arguments, we introduced the specter of Too Much **Information** (the galactic counterpart of our current vernacular expression, 'TMI', employed with a smirk after someone has volunteered details of their personal life that we'd rather not know about). We pictured a glut that would overwhelm the Universe (*if* it had been imprudently designed as an **Information**-intensive place, which I believe it surely was not). Related to that idea (and to the difficulty we've just observed in our flute-as-database exercise), there is the question of certain

146. The idea is not original with me. In a *Scientific American* article in the 1980s, I saw the idea given in terms of a nick on a glass rod. Here, as homage to H.P. Lovecraft, I've traded the nicked rod for a notched flute, to go along with his recurrent image of the "mindless daemon-sultan Azathoth [who] blasphemes at infinity's centre [with his] disgustingly carven flute of ivory" (from "The Dream Quest of Unknown Kadath" in *The Dream Cycle of H.P. Lovecraft*, pp. 163 and 190).
Incidentally, Wiener bumps obscurely against a far edge of this same idea, which he writes as ' $.a_1\ a_2\ a_3 ... a_n$ ' followed by the remark that "the number of choices made [0 or 1] and the consequent amount of information is infinite" (Wiener, 1948, p. 61). And yes, that's an all-important decimal point that he tosses in to the left of 'a_1'!

measurements that earthlings flatter themselves as making while in fact they are impossible to perform. Take the case of circles and the venerable number *pi* (discussed on page **165**f). Like the notched flute, the circle appears to be another sly joke that God threw down to confuse his creatures.

Rather than meditate on something pretty like Euler's formula, why not meditate on the quadratic equation for a moment: $x = [-b \pm \sqrt{(b^2 - 4ac)}]/2a$. (Remember that gem?) And ask yourselves why *that* exists only in such a hideous and intractable form. Doesn't the innate ugliness of the quadratic equation tell you just as much about Truth and Nature as the lyricism of Euler's discovery?

Path 2: Absolute Zero for Information: LØ

Earlier we looked at unitless **δata** (**Table 13**) under a comfortable tacit assumption that went something like this:

> Of course it's really Information [L3]. It's just that we've lost the units [such as *cm*] and must accept the numbers as mere **δata** [L2] temporarily, until such time as they can be restored to their true nature, which is that of Information.

But what if that was just an anthropocentric fairy-tale? What if the Cosmos not only can tolerate unitless numbers (the ones we've called **δata** by way of distinguishing them from Information), but can even tolerate a kind of dumb **δata** or anti-**δata** foundation for the spacetime continuum? (Here we abandon the Real/Unreal dichotomy of **Figure 94**. The implicit view is now of a place that is starkly real — not holographic — yet of distressingly low intelligence, so to say. A kind of Dumb Cosmos, the pieces of which rip along mindlessly, Godlessly, in a blind blizzard of process.) In terms of L1, L2, L3...,[147] the natural way to represent such a hostile pre-**δata** soup would be with the label LØ — intimating something even lower than our Potentially Forensic cookie-crumb-**δata**, if that were possible. The name we'll assign it is Innately Dumb Data.

I've proposed the name Innately Dumb Data to differentiate this realm (or this

147. To offset these ruminations about a Godless LØ populated by **antiδata** as the pervasive texture of a thoroughly Dumb Cosmos, let's also explore the other direction for a moment. Somewhere in the Universe, could there exist something like L5, L6, L7...? (Now we've returned to the framework of **Figure 94**, building on the picture given there of L1-L4.) Rather in the same way that Mathematics tossed around the idea of 4D, 5D, 6D... well before physics or engineering saw anything in the real world that might connect with those queer-sounding dimensions, so one may propose L5, L6, L7... to play with, even though we don't know what they mean (yet).

philosophical premise) from that of the Designated Dumb Thing Down There (introduced on page **121** as an element of **Bottom Turtle Relativism**). Admittedly, the idea of LØ is abstract; I find that it tends to slip away from me as soon as I think I 'have it'. Perhaps as a psychological defense mechanism because the truth of LØ is so unsettling? In this regard, **Figure 97** can be helpful: we are now on the left arm of the x-axis, in the vicinity of U1000. I.e., I am treating the terms 'Innately Dumb Data' and 'anti-δ**ata**' as synonymous. (By the way, the picture I'm trying to paint here might be a distant relative of Smolin's Chapter 4: "The universe is made of processes not things.")

Path 3: H.P. Lovecraft

In Path 1 and Path 2, logic led us to doubt the centrality of Information, and even to doubt its existence (outside the provincialism of Earth, that is). In the poetry and fiction of H.P. Lovecraft (1890-1937), we hear the voice of someone who knows a similar place well, but who found it via dreams and intuition, not by logic. HPL is a writer with many faces, only one of which seems widely known. A full list would include wistful lyricist, earnest wide-eyed horrorist, fay humorist, Cosmic Medium and — rather absurdly — flaming-Anglophile-cum-eugenicist. The one I have in mind just now — that of a Cosmic Medium — is worth knowing if you haven't made its acquaintance yet. He is no Emily Dickinson, but he succeeds now and then at conjuring a fair imitation of the sibyl's arresting voice. Below I've tried to distill this aspect of HPL into four quoted passages, two from his versification efforts and two from his fiction. In the third passage (1929), notice how he manages to toss off space-time as a "fixt mass" with an ease and authority reminiscent of Dickinson. In the fourth passage (1935), notice that the suns of his world have gone black. While the former was no doubt influenced by mass media reports of the time regarding Einstein's work, I would attribute the latter image not to any knowledge of Chandrasekhar's limiting mass and its grim implications for Sirius, or to knowledge of the neutron star conjured up by court jester Zwicky (Thorne, p. 140-178), but rather to his own rather unsettling powers of introspection and direct intuition:

I have whirl'd with the earth at the dawning,
  When the sky was a vaporous flame,
I have seen the dark universe yawning,
  Where the black planets roll without aim —
Where they roll in their horror unheeded,
  Without knowledge or lustre or name.
    — second stanza of "Nemesis" [1917]

Wise men told him his simple fancies were inane and childish, and even more absurd because their actors persist in fancying them full of meaning and purpose as *the blind cosmos grinds aimlessly on* from nothing to something and from something back to nothing again, *neither heeding nor knowing* the wishes or existence of the minds that flicker for a second now and then in the darkness.
    — from "The Silver Key" [1926], p. 27

It moves me most when slanting sunbeams glow
On old farm buildings set against a hill,
And paint with life the shapes which linger still
From centuries less a dream than this we know.
In that strange light I feel I am not far
From the fixt mass whose sides the ages are.
    — final stanza of the final poem in "Fungi from Yuggoth" [1929]

Before his eyes a kaleidoscopic range of phantasmal images played, all of them dissolving at intervals into the picture of a vast, unplumbed abyss of night wherein whirled *suns and worlds of an even profounder blackness.*
    — from "The Haunter of the Dark" [1935], p. 304(148)

148. Sources for the HPL passages that I've quoted on this page are as follows: "Nemesis" can be found in S.T. Joshi, ed. *The Ancient Track: The Complete Poetical Works of H.P. Lovecraft* (Night Shade Books, 2001), pp. 27-28. (Of the 6 lines I have quoted, HPL used the latter 4 as epigraph to his story, "The Haunter of the Dark" (1935). Here I've adopted the punctuation he used in 1935 in preference to the punctuation and line breaks of his 1917 original.) "The Silver Key" is in *The Dream Cycle of H.P. Lovecraft* (Ballantine Books, 1995), pp. 193-203"Fungi from Yuggoth" is in *The Ancient Track,* pp. 64-79. "The Haunter of the Dark" is in Joshi and Cannon eds., *More Annotated H.P. Lovecraft* (Dell Publishing, 1999), pp. 277-312. Emphasis was added in all four passages to show pertinence. In particular, given its particular context, his phrase "Without knowledge...or name" could be translated into our terminology as "Lacking Information... or its corresponding δ**ata**." Thus, it lies in the realm of anti-δ**ata**; see **Figure 97**.

In **Figure 97** we try to develop a framework in which all of the main topics introduced earlier can now be seen together as part of a whole.

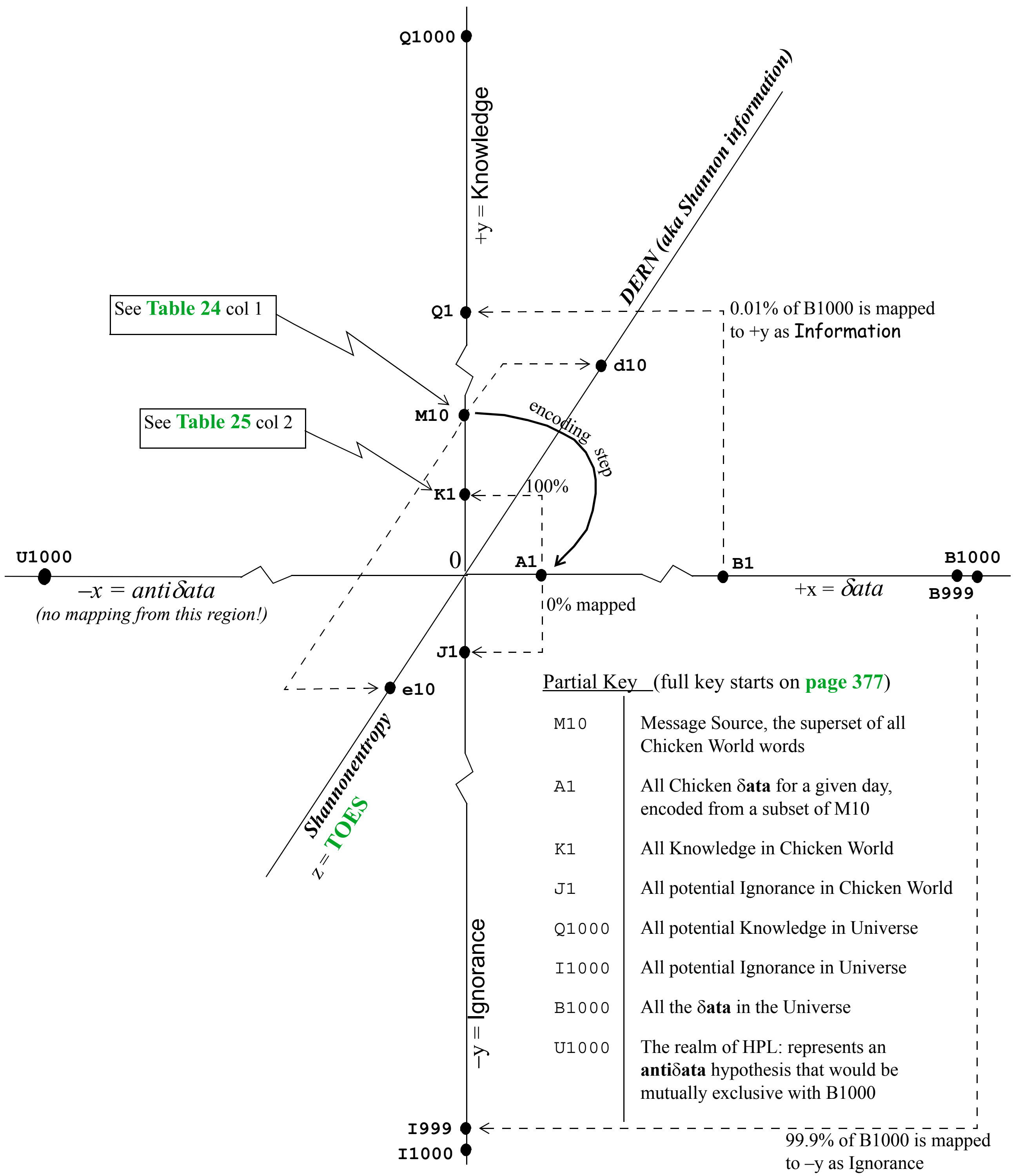


FIGURE 97: One Map for Everything

Full Key to **Figure 97**:

M10	Point M10 on the y-axis represents a toy Message Source. To see the particular Message Source I have in mind, please refer to column 1 (Word List) in **Table 24 (Chicken Language Deluxe)** on **page 380**. This Message Source is an augmentation of the Chicken Language developed in **Appendix D: The Fifty Years' Gibberish: So-Called Information Theory**. It is used this time (in **Table 24**) to illustrate ***DERN (aka Shannon information)*** instead of the ***Shannonentropy***.
A1	A subset of A10, representing All the Knowledge in Chicken World, stored as δ**ata**. This point corresponds to column 1 in **Table 25** on **page 380**.
curved arrow	The curved arrow from M10 to A1 represents the encoding step. Note that while encoding was explored in detail earlier, encoding plays *no* particular role in this diagram, and is therefore reduced to an arrow. This is a way of minimally acknowledging the step that gets us from the abstract lexicon of the Message Source (M10) to the repository of 'real chicken δ**ata**' at A1, which maps to 'real chicken Information' at K1. Note in passing the implications regarding the y-axis: We have reserved it as the home not only for Information in the sense of δ**ata**/Information, but also for things that might be 'bigger than Information' (for a given context), such as the Message Source for Chicken Language Deluxe at M10 in this picture.
K1	This point represents all the potential Knowledge in Chicken World. Compare J1. *All* δ**ata** from A1 is mapped via the dotted line to Information at K1. All is well in Chicken World. Relationships of the A1/K1 variety are what we explored in depth in **Chapter** . Point K1 corresponds to column 2 in **Table 25**.
J1	This point represents all the potential Ignorance of Chicken World. Since Chicken World is built upon a toy Message Source (Chicken Language Deluxe), by fiat we define the mapping as going 100% up to K1 and 0% down to J1. Thus, the dot labeled 'J1' is in the diagram only to show a *potential* mapping that didn't happen. (Our chickens enjoy total knowledge of their world. They are blissfully naïve of the potential humiliation lurking at J1.)
d10	An instance of ***DERN (aka Shannon information)***, located at an arbitrary position on the z-axis. By serendipity, the line bending backward from M10 to d10 serves admirably as a symbol of all the twisted interpretations and resultant confusion about **TOES**. For details, see **Stake through the heart** on page **286**.
e10	This point represents $H = -\Sigma p_i \log p_i$, the ***Shannonentropy*** of the toy Message Source at M10. Relationships of the M10/e10 variety are what we explored in some depth earlier.
	= discontinuous scale, as we move from a toy world up to the real Universe. (Nor has anything been drawn to scale on either side of the jag.)

Q1000 I1000 B1000	Some outer limits of the real Universe are suggested by the 3 dots labeled Q1000, I 1000, B1000, representing All the potential Knowledge; All the potential Ignorance; and All the raw δ**ata** in the Universe.
B1	This point represents a small percentage, say 0.1%, of B1000. Only this amount is transformed into useful Information, represented by point Q1 on the y-axis. We label it B1 by analogy with A1. There is no magic in the number 0.1%, nor has the graphic been drawn to scale on the basis of that number, which is merely meant to suggest “a very small portion of the whole, whatever the whole may be”. (For consistency, one can imagine mappings from B1000 to d1000 and to e1000 on the z-axis, but I omit these from the graphic to reduce clutter and to limit its overall size on the page.)
Q1	Shows the amount of data that is successfully mapped to the y-axis via some kind of δ**ata**/Information translation process as described in **Chapter** . Since B1 is defined above as 0.1% of B1000, Q1 would be 0.1% of Q1000.
B999	This point represents most of the δ**ata** in the Universe, say 99.9%. All of B999 is lost, whether as Found-and-Lost-δ**ata** or as Potential-δ**ata**-Lost or as Self-Oblivionating-δ**ata** (chiefly the latter)**.** To minimize the visual clutter, these 3 categories are lumped together as a single category called ‘B999’ in the diagram. For details, see **Path 1, Self-Oblivionating δata** (**page 365**f) and **Path 2: Absolute Zero for Information: LØ** (**page 372**f).
I999	Shows where B999 is mapped on the Ignorance arm of the y-axis. Since I999 is 99.9% of I1000, one could say we all live in an effective ‘black hole’ (Information-wise). No travel to far galaxies is required for that experience, only awareness of the Self-Oblivionating-δ**ata** all around you.

U1000	This point represents all that might reside as fanciful '**antiδata**' on the negative arm of the x-axis. Suitable names for the U1000 point might be Cthulhu...the crawling chaos...Nyarlathotep — if you're familiar with H.P. Lovecraft. This *isolated point*, U1000, which is inherently *not* mappable to the y-axis, is the most likely model of reality, I think, although it is difficult to articulate: The denizens of U1000 would be something like δ**ata**, but 'mindless' and directionless, comprising a self-sufficient machine for driving a Dumb Cosmos 'blindly' as it were; hence my provisional tag 'antiδ**ata**' and its placement at the extreme far left on the x-axis, like a mirror of B1000, as I attempt to summarize its diverse negative attributes, which make it reminiscent of LØ introduced earlier. U1000 and B1000 are mutually exclusive: These two points represent competing theories, only one of which can be the correct window on the Cosmos. U1000 is reminiscent of a realm intuited by H.P. Lovecraft (**page 373**f), but it is also a realm that one can arrive in by the following logic: I999 at 99.9% would seem to be an indicator of a system that is severely broken: That much leakage into Oblivion seems an unlikely model for a 'coherent Universe'. True, U1000 paints an even darker picture, but it possesses the virtue of simplicity and self-consistency, and is therefore more persuasive than I999. See also text **page 365**f.

TABLE 24: Chicken Language Deluxe

Word List = Message Source[1]	encoding scheme	Number of possible messages: W	DERN[2] $= \log_2 W$
listen-up!	000		
russet-today	001		
russet-tomorrow	010		
white-today	011		
white-tomorrow	100		
Andalusian-today	101		
Andalusian-tomorrow	110		
clucking-done!	111	$2^3 = 8$	3

1. This is the exhaustive list, consisting entirely of ‘double’-words, in the glued-together manner of German or Lakota. 000/111 are reserved for indicating ‘start utterance/end utterance’ respectively.
2. Many write $\mathbf{I = \log_2 W}$ here and call this column the ‘measure of information’. I disagree vehemently with that practice.
   See **Stake through the heart** on page **286**.

TABLE 25: Chicken World News

All the δ**ata** in Chicken World on a given day	All the Information in Chicken World on a given day[1]
001	russet-today
100	white-tomorrow
101	Andalusian-today
110	Andalusian-tomorrow

1. Rules:
   In Chicken World, it’s always ‘today’.
   In Chicken World, one may say something about ‘tomorrow’ (i.e., predict an egg’s contents), but there is no ‘yesterday’. (Chickens are optimistic but not sentimental.)
   Thus, the contents of this table represent a plausible *exhaustive* list for a given day’s δ**ata** and Information in the world defined.

Correspondences to **Figure 97**:

Column 1 in **Table 24** (the Word List or 'Message Source') corresponds to M10 in **Figure 97**.
Column 2 in **Table 24** corresponds to the curved arrow joining M10 to A1.
Column 4 in **Table 24** corresponds to point d10.

Column 1 in **Table 25** corresponds to point A1.
Column 2 in **Table 25** corresponds to point K1.

In **Figure 97**, the **TOES** axis (z) is distinct from the Ignorance/Knowledge axis (y), and both of these are distinct from the computer storage axis (provided to accommodate **δata** *or* anti**δata** but not both, as explained above). Hence three dimensions, so that each has its own imaginary 'space' to occupy. Meanwhile, the dotted lines leading from the horizontal axis to the vertical axis represent processes by which **δata** may either be preserved and transformed, or lost. (Such **δata** might also be lost in a black hole's 'horizon entropy', *à la* Bousso, p. 7, but that would be off our map.) Following dotted lines from the y-axis to z-axis, we see a Message Source mapped up to *DERN (aka Shannon information)* and down to Shannon *Shannonentropy*.

In passing I would like to mention *The Refrigerator and the Universe*, a book by Goldstein & Goldstein that deals mainly with **Entropy** but also takes a crack at the **Entropy** / *Shannonentropy* relationship. Indirectly, the layout of **Figure 97** was suggested to me by a passage in their chapter entitled 'Entropy and/or Information':

> *Entropy measures ignorance, information measures knowledge.* Goldstein, p. 218

To the uninitiated, the passage above may look unremarkable, but for those of you who have been wandering the desert it will be recognized as an epiphany, an oasis of sanity in the wasteland of **TOES**-related literature! That passage gave me the y-axis in **Figure 97**, as a foundation, and from there I built the z-axis and x-axis, which leads in turn to the idea of a**ntiδata**. Like *i*, the latter seems only whimsical at first, but eventually makes a renewed bid for our attention when multiple paths are seen leading toward it. Thus, in an indirect but very important way, I am indebted to the Goldsteins. Having said that, I'll mention that I was disappointed to see them follow the herd by allowing this chestnut...

$$\text{' } I = \log_2 W \text{ '}$$

...into their book (Goldstein, pp. 217, 404, 411) as their formal definition of 'Information' (tailored as always to borrow reflected glory from Boltzmann's

Entropy formula for Statistical Thermodynamics: $S = k\log_e W$. I remain adamant that the absurd little quantity called '$\log_2 W$' in **TOES** *must* be demystified and *must* be renamed *yesterday* as follows...

DERN (aka Shannon information)

...where DERN = Degree of Encoding Richness Needed. If my diatribe sounds vaguely familiar, yes, it was given already in **Stake through the heart** (!) on page **286**f. But I think it's worth repeating, every hour of every day until the insanity stops.

Finally, I have a smaller bone to pick with the Goldsteins: They attribute the 'I' formula to Shannon, whereas I find neither the formula nor the concept anywhere in Shannon's landmark paper. Not to say Shannon was entirely blameless in the *general* confusion surrounding what has come to be known as 'Shannon information': He stretched the one term 'information' over a wide range of meanings, letting it be his catchall. "[*H* is a] reasonable measure of choice or information," says Shannon on p. 11, thus revealing that 'information' in his lexicon is not a solid, well-defined term (whereas everything else in his paper appears rigorous). After all, more 'choice' on the sender's side means more 'uncertainty' on the receiver's side (as Shannon himself remarks, elsewhere in the paper; that part of **TOES** everyone always agrees on). Thus, indirectly, the phrase "choice or information" on p. 11 comes close to an admission that, much of the time, 'information' actually means 'uncertainty' in **TOES**. Frequently, the word 'information' also seems to work as shorthand for "correctly received *δata*" (or "intelligence," as in Pierce, p. 39). True, the word '**δata**' too can be found in Shannon's paper, but only in a special context; he uses the word exclusively in connection with his error correction theorem on pp. 20-21, where he speaks of "correction data". Within the confines of Shannon's paper, the use of 'information' as a convenient shorthand for something else seems natural, but this practice of his is what permits the word to wreak havoc outside his paper: "Despite Shannon's explicit disclaimer, the seductive appeal of a physics of information proved irresistible, even to Shannon." (Corning & Kline, p. 467)

If there's a single point I've been trying to make all this time, it is precisely that there can *never be* a **TOES** formula that begins with *I = anything*! That's the **Information** Grail that everyone pines for (and that Wiener willingly pimped for, inaugurating half a century of confusion), but it simply can't be. Everyone loves the great *puta madre* **Information**, but there is no magic word *kazam* that will ensnare Her in a formula. Not for another few centuries at least.

Revisiting the Atom

Once having entertained certain blood-chilling suspicions about the true nature of the Cosmos (via Path 1/2/3 above), can we find no road back to a philosophy of optimism? HPL at least flirts with the idea of the-atom-as-God ("...bidding him find wonder in the atom's vortex," in "The Silver Key" [1926], p. 194), but soon returns to the familiarity and comfort of a dark hysterical view. So we leave him there, brooding over places where the black planets roll without aim. Or, better yet, and to drive his Unwholesome Influence still further from our minds, lets leave him perched tragicomically in two unwitting self-portraits, a pair of fine charcoal sketches, as it were: "an unused [onyx] quarry [with its] chiselled vacancies...was left all alone in the twilight, with only the raven and the rumoured Shantak-bird [HPL] to brood on its immensities...Dawn found the ship in sight of Sarkomand's ruined quays of basalt, where [our guy] still waited, squatting like a black horned gargoyle on a broken column by crumbling sphinxes of that fearful city which lived and died before the years of man." — from "The Dream Quest of Unknown Kadath," pages 151 and 176, in *The Dream Cycle of H.P. Lovecraft.*

In terms of our Path 1/2/3, what Nature is telling you is that δ**ata** doesn't even exist at the macroscopic level, never mind **Information**; rather, it's an **LØ** world (left side of **Figure 97**). Meanwhile, in the particle physics milieu (as represented by T.D. Lee, 1988), I think Nature is trying to tell *them* that 'It's **L2** all the way down'. And my objection to their methods is their unkillable assumption that if only they dig deep enough, a bedrock of DDTDT will be discovered at the bottom (locked in eternally at **L2**, let's say), thus allowing Symmetry to be reinstated upon her Throne 'from above' (at **L3**).

In case the dot labeled 'U1000' happens to be *the* salient portion of **Figure 97** (as I believe it is), that leaves you alone with the Atom in a cold forbidding Universe, so to say. Therefore, it behooves you to stop making assumptions about how dumb and passive the Atom's constituents might be. To the contrary, you should give them always the benefit of the doubt. To get a warm-fuzzy about the place you're fated to occupy (the Cosmos), you need all parts of the Atom to be as alive and intelligent as possible, not arbitrarily 'dead' or dumbed down. After all, the Atom may turn out to be your 'only friend'. The Atom may turn out to be God.

Appendix F: God *IS* the Dice

This appendix is devoted to the field of probability and statistics, which was represented in **Figure 29** on page **95** as one of the three 'pure' subjects. (Granted that statistics is a tool notoriously popular for abuse by *others* — e.g., by any economist, politician, attorney, marketeer or sociologist with an ax to grind — one observes that the skies over the land of probability-and-statistics itself remain clear. Thus, this appendix might have been called The Probability Redemption, to point up the parallels with The Chemistry Redemption as introduced in **Chapter I**.)

I choose to launch our discussion from an area that may seem needlessly obscure or arcane: one that involves both Utopia and quantum mechanics. If you bear with me, you will see after a page or two how this provides an excellent perspective on the *whole* field of probability, granted there are many other points of departure one might have chosen instead.

Three perspectives on a tossed coin

The coin toss is the minimal experiment for demonstrating probabilities. We begin by considering a coin toss, but only from the standpoint of speed, *not* yet anything to do with probability *per se*. Suppose we have a set of four tosses (trials), occurring at time 1, time 2, time 3, and time 4, resulting in Head, Tail, Tail, Head (HTHT). In **Figure 98**, I present three ways of viewing such a sequence. I characterize the tosses as Instantaneous, Fast and Slow-Motion, dependant on which realm they occur in:

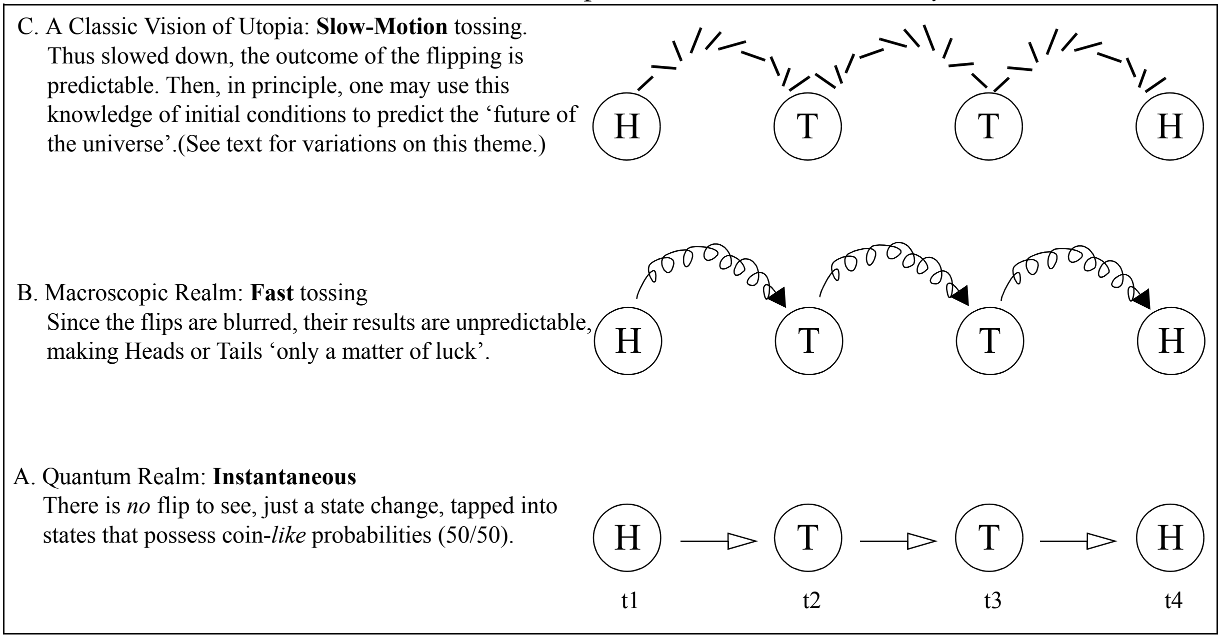


FIGURE 98: Coin Toss as Instantaneous, Fast, or Slow-Motion

Explanation of **Figure 98**:

A. Quantum Realm (submicroscopic scale). A notional coin(149) enters a new state, Heads or Tails, but with no trajectory, no path for traveling from one state to the other. These transformations just happen. Without flips, as it were. (Compare **Figure 35** on page **133**.)

B. Macroscopic Realm (our world). There is a visible trajectory as the coin flips through space and time, but the motion is so quick that no one (except perhaps a trained magician) can follow its progress to call Heads or Tails accurately.

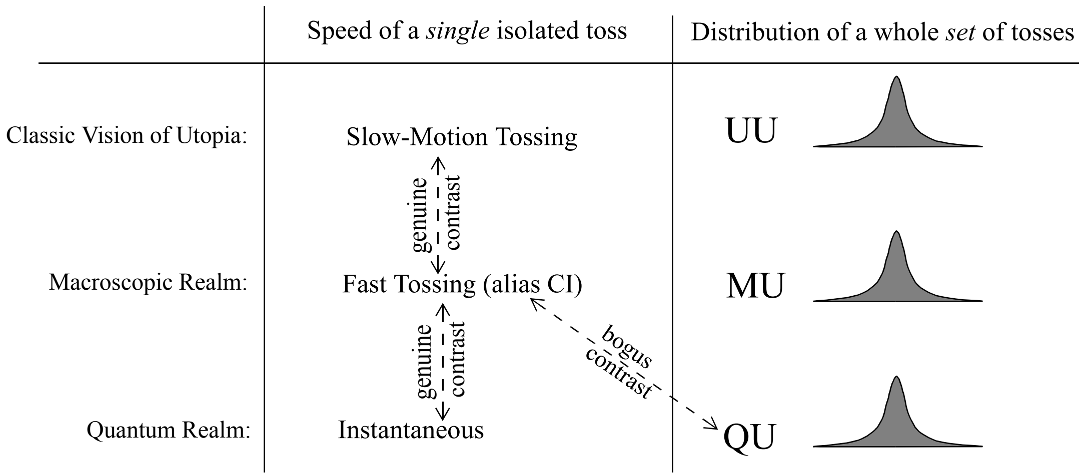
C. In an imaginary place called Classical Utopia (often dreamed of by prominent nineteenth century scientists who flirted with the notion of a Clockwork Universe), the universe is observed in slow motion. The exact coordinates and velocity of any object can be measured, and any future position or state (H or T) computed from initial conditions. Thus, in principle, the universe is revealed as a perfect and thoroughly knowable 'machine'. Let's call this 'Vigorous Utopia', the playground of the hard-core Determinist (whose big computational task would require Gargantuan vigor and then some). Alternatively, one might just lean back and watch the show passively, taking advantage of the slow-motion

149. Since there are no literal coins at this submicroscopic level (unless invented via nanotechnology!), imagine a subatomic particle that possesses two states labeled H and T. Discussions often focus on the 'electron cloud' contrasted with the presumed electron trajectory of pre-quantum mechanics, but the electron is needlessly complex for our purposes here; hence the imaginary 'coin' as proxy (except in the Legend to **Figure 99** where I touch briefly on one of the real quantum curves).

tossing only to the extent that he can now call Heads or Tails and win all his bets. Meanwhile, the universe continues as before, unfolding in probabilistic fashion. Call this 'Lazy Utopia'.

Why all this bother with **Figure 98**, which I warned you is *not* about probability? Because it helps us isolate a subtopic that is shmushed together with quantum probability in most 'popular' presentations. That insidious subtopic needs to be filtered out so that we can think straight about the real topic yet to come: Yes, there is an intriguing difference in the way a coin gets 'tossed' (literally or figuratively) in the three dominions depicted graphically above. But this question of tossing *speed* (instantaneous, fast, or slow-motion) has only a slight and indirect pertinence to the topic at hand, viz. the probabilistic *distribution* of Heads and Tails in a set of, say, 100 trials.

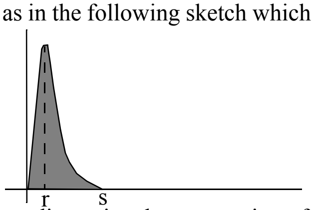
The two subtopics should be forever segregated like this:



Legend:

UU = Utopian Uncertainty (see text)	CI = Classical Ignorance (see text)
MU = Macroscopic Uncertainty (the everyday world)	QU = Quantum Uncertainty

A note about the curves: Our choice of a symmetrical curve to occupy the QU cell is fanciful, driven by the notion of a coin toss at the submicroscopic level introduced in **Figure 98**. The real curves associated with QU are skewed, as in the following sketch which represents densities for the simplest case, the s-orbital in a hydrogen atom:



This curve is a two-dimensional cross-section of the hydrogen atom's 'electron cloud', with the x-axis representing the electron's distance from the proton and the y-axis representing the electron cloud's probability density. The picture says, in effect, "The electron is most likely found at radius r, close to the proton, but might appear in any other part of the imaginary sphere of radius s." (Being contained by a notional sphere, the electron cloud *could* be represented symmetrically around zero, but by convention its graph begins *at* zero, giving it the skewed look seen here.)
After Metz, pp. 314-315, Figure 15-8, plot of $a_0R(r)^*R(r)r^2$ for the 1s subshell.

FIGURE 99: Anatomy of a False Dichotomy: CI 'versus' QU

In the literature, Classical Ignorance (CI) is contrasted with QU.[150] In **Figure 99**, we represent this practice of the status quo by an arrow that joins the Fast Tossing cell to the QU cell at a slant. Yes, the Fast Tossing cell has *something* to do with Classical Ignorance (CI), but that discussion makes sense only if we stay in the same column and contrast it with Slow-Motion Tossing. I.e., to be coherent, one must remain on the (vertical) Axis of Ignorance, so to say, and not go sliding off slantwise to QU, magnetically alluring though the QU cell may be. That's a bad habit for two reasons: [1] as suggested by the graphic above, it is illogical (resulting in a bogus contrast, something akin to a false dichotomy); and [2] it makes readers forget about the MU cell, just when they need it most, so to speak, thus riling the unconscious which feels that *all* of Big Bad Uncertainty has thus been imputed to row 3, the Quantum Realm!

Before we leave **Figure 99**, I should explain the idea behind 'Utopian Uncertainty', even though the UU cell is only pro forma, not part of a real world: If you slow down the coin toss trials and blissfully record their vectors and coordinates with an eye to calling Heads or Tails, you're only in the place I called Lazy Utopia. Meanwhile, we expect that the coin tosses' distribution will play out exactly as in a nonUtopia: Along with his sister Uncertainty who occupies the adjacent thrown, Probability still rules the world, even one decorated by kittens and rainbows. Hence the little humped curve, even in the UU cell. But what about Vigorous Utopia, where the die-hard Determinist vows to dump all initial conditions into his Groß Wie Nie (Big Like Never) computer and thus foresee the Future of Everything? I say the pattern of probabilistic distribution is *still* present here. Being a dominant

150. The following is a representative statement of the (presumed) CI/QU dichotomy: "Classical ignorance can be expressed as follows: the world has a well-defined state, but we do not happen to know what it is. But this is not what we mean by quantum uncertainty. In quantum uncertainty, it is no longer the case that the world possesses a definite classical state. Even particles with a well-defined quantum state do not possess trajectories...We emphasize that *this dichotomy* between quantum uncertainty and classical ignorance is no abstract distinction. It has a perfect clear experimental signature: the appearance and disappearance of an interference pattern [in the double-slit experiment]." — Greenstein and Zajonc, pp. 52-53 (italics added). While most focus on Classical Ignorance, a few try to set the stage in seemingly opposite terms. For instance, Munowitz (p. 162) speaks of the difference between the *certain* knowledge of classical mechanics and the *probabilistic* knowledge of quantum mechanics. But this makes for an even worse dichotomy, as it overtly associates probability with quantum mechanics uniquely. I've made these two citations not to pick on the authors (who stand in 'good company' with a boatload of others, alas!), but simply to provide a point of reference for discussion.

thread in the very fabric of the universe — as some of us believe — it cannot be 'wrung out' of the computations. Logically, the universe could quite well be *probabilistic* AND *determinist* at the same time. (God says, "Let there be Probabilistic Distributions, in just *this* Way," and the deed is done.) Whereas, setting up that pair as a *necessary* dichotomy is a word trap to avoid, a tying together of shoelaces of the kind Wittgenstein warns us to avoid.

Back to the main argument. Why hamper yourselves by acting as if the cell at row 2, column 2, were a vast gaping hole in the fabric of the universe? Given the prominent role of probability in quantum mechanics, you need that cell to be properly populated by 'MU' so that 'QU' beneath it won't seem so ridiculously alien and unapproachable; what you don't need is the fiction that uncertainty is unique to quantum mechanics, typecast as 'yet another weird feature' of that (admittedly weird) realm.

There is yet another objection I have to the customary CI/QU talk: Thus focusing on the negative concepts of 'ignorance' and 'uncertainty', one forgets that when the glass is half empty it may also be described as half full. Look again at the curves in **Figure 99** and realize that their dark familiar profiles represent a kind of certainty too, not *just* a picture of uncertainty.

Gamow's *One, Two, Three...Infinity* contains a related idea: Chapter VIII is entitled 'The Law of Disorder'; but really this is a trick for ushering in the Law of Statistical Behavior: What seems to be a kind of discombobulated mess at the beginning of the chapter turns out to be Gamow's prelude to certainty, a few pages later.

Continuing the argument in that spirit one might even propose that 'God *is* the dice' thus doing an end run around Einstein's objection that "God does not play dice with the universe."(151)

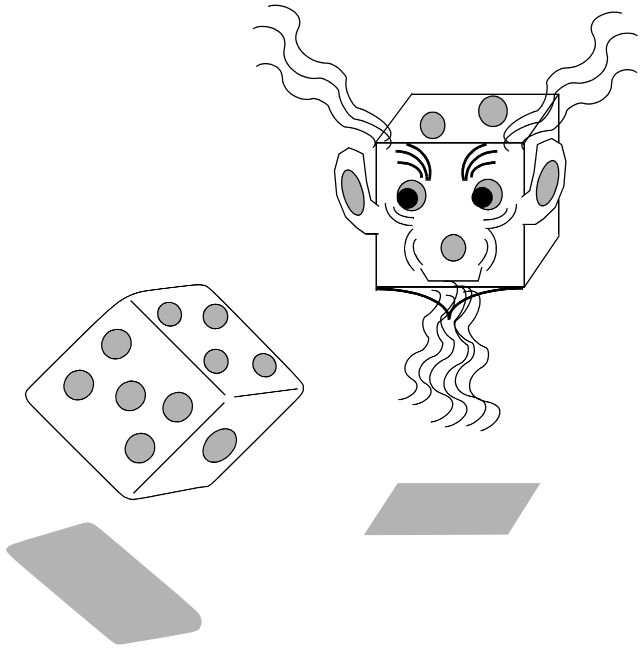


FIGURE 100: God *is* the Dice

Or, as proposed by Kaplan and Kaplan (p. 11), "The probabilistic reply is that perhaps the universe is playing dice with God."

151. In a 12/12/26 letter to Max Born, Einstein wrote, "Quantum mechanics is certainly imposing. But an inner voice tells me that it is not yet the real thing. The theory says a lot, but does not really bring us any closer to the secret of the 'old one'. I, at any rate, am convinced that *He* is not playing at dice." [This is a 'mixed' translation, based on the following three sources: Pais, p. 261; Nick Herbert, p. 119; and wikiquote.org.] In a practice that is understandable but unfortunate, the four sentences above are routinely boiled down by everyone (myself included) to the following fake 'quotation': "God does not play dice with the universe."

The M&M™ Epiphany

Anyway, it is time for us to play with M&M's. We will now get our hands dirty, as promised, by investigating the M&M Epiphany alias Matchstick Satori.[152]

Preparation

Acquire the following:
2 Red M&M's (hereafter referred to as '2R')
3 Green M&M's (hereafter '3G')
4 Yellow M&M's (hereafter '4Y')
1 paper dish or glass bowl for 'mixing' (randomizing)

You'll want to use peanut M&M's of course, since they're more fun to eat afterwards. But in that case you must be careful to select candies of the same approximate size, choosing only the large ones or only the small ones. (The size of a peanut M&M varies over a surprisingly wide range within a given package.)

Alternate materials:
Nine kitchen matches dabbed by colored markers so that they too have subgroups of 2R, 3G, 4Y. Or, 9 'party toothpicks' with cellophane decorations in three or more colors for identification.

152. Since probability is the topic, why not formulate the exercise in terms of a pack of cards or pair of dice? Why do I insist on M&M's or matchsticks? In a word, because Familiarity Breeds Contempt (or jadedness at least). You've rolled dice, you've shuffled cards, you've tossed coins so many times that you 'already know about that stuff'. Or so you assume, like so many nonpainters claiming that they 'know how to look at a chair' when really they don't, unless they've had a drawing class. Everyone needs the M&M's to awaken from the trance and see probability as if for the first time ever. Also, unlike dice or cards or coins, they happen to be edible.

Procedure

1. Toss all 9 M&M's (or matches) into the paper dish or glass bowl.
2. Use your fingers to swirl the 9 objects about and thoroughly mix them up.
3. With eyes closed, pick out a random trio of the M&M's (or matches).
4. Open your hand and look at the trio of objects.

5a. If the trio of M&M's contains one or more Y, record this trial as 'F' for Failure.[153]

5b. Conversely, if the trio contains no Y, record this trial as 'S' for Success.

6. Toss your trio of objects back into the dish. Repeat from Step 2.

A note about 'technique': In repeating the cycle, try to perform Step 2 and Step 3 'always the same way' to the extent humanly possible. The goal is to avoid bias and ensure randomness.

How many times should one repeat Steps 2 through 6? Depending on your patience level, I would suggest choosing 36 trials or 84 trials total. (The reason for these particular numbers will be explained shortly.) The important thing is to decide on a specific number of trials ahead of time and stick with it. Otherwise, you will likely find yourself tempted to 'cheat' to make the experiment work (or to make it fail, depending on your bias!) By the same token, it would be best if you did one whole set of trials NOW before reading further. (But this is a minor point whereas picking

153. In probability and statistics, the labels 'Failure' and 'Success' are often quite arbitrary, carrying no more significance than 'X' and 'Y' in algebra. This will be as good a time as any to explain the genesis of the M&M experiment, in the course of which you will see why 'no yellow' spells Success in this instance. In Jay L. Devore, *Probability and Statistics for Engineering and the Sciences* (2004, Sixth Edition), p. 74, there is a problem (#38d) that reads as follows: "A box in a certain supply room contains four 40-W lightbulbs, five 60-W bulbs, and six 75-W bulbs... Suppose now that bulbs are to be selected one by one until a 75-W bulb is found. What is the probability that it is necessary to examine at least six bulbs?" Translated from statisticians' lingo into English, the question becomes slightly less confusing: "What is the chance that with *five* selections in hand there is still no 75-W bulb among them, thus requiring a sixth draw, *at least*, before I can obtain a 75-W bulb?" For convenience I've scaled the problem down to where it involves only 2 + 3 + 4 objects instead, colored R, G, Y respectively. Now the question becomes: "What is the probability that it will be necessary to examine at least *four* M&M's to obtain *one* yellow?" or in plain English: "What is the chance that *no* yellow M&M's will be found among the *three* I select?" Thus, the flow of the logic is such that the label 'Success' gets attached (counter intuitively) to any combination involving R or G with *no* Y present. Eventually, in the discussion of **Figure 101**, we'll see how this all plays out in terms of numbers, leading to a Success probability of 11.9% (which lies between 1/8 and 1/9).

a number and sticking with it is crucial.)

* * * * * * * * * * *

How did you fare with your set of 36 trials or 84 trials? If you were 'lucky', in the special sense defined below, you will have recorded a Success rate in the neighborhood of 1/9, meaning something on the order of 4 Successes out of a total of 36 trials or 10 Successes out of a total of 84 trials. If you were 'unlucky', your particular set of trials might have yielded a Success/Failure ratio so far away from 1/9 that you doubt the validity of my prediction or the basic setup of the problem. (The theoretical underpinnings for the value 1/9 will be given shortly, in the discussion of **Figure 101**.)

Sidebar on 'Chances about Chance' or 'Being Lucky with Luck'

Not to say this subtopic hasn't been studied rigorously, even exhaustively, by your biped mathematicians using elegant terminology,(154) but I introduce it with my naïve term, 'chances about chance' by way of noting that it intersects with your everyday life, and is not something purely abstract or academic. Here's the classic scenario: One day, having noted his/her child's curiosity about the chance for Heads or Tails in a coin toss, a parent tosses a coin 20 times, say, in hopes that this will help teach the child the concept of '50/50 odds'. *If* the parent is lucky that day, the coin will 'behave', by straying not too far from the center of the bell curve, yielding results such as 12 heads and 8 tails, for instance. In this case, the child will probably(155) believe the parent isn't totally blowing smoke. *If* the parent is unlucky that day, there might be 15 heads and 5 tails, say, or even 20 heads and zero tails. Disaster! Where is the parent's credibility now? Evidently there is something in the world like 'luck about luck'.

In fact, the innocent-sounding parent/child vignette above leads almost immediately into the area of probability known as the Binomial Theorem, and thence to calculus

154. For example, the same idea is conveyed by Freund, pp. 203-204, when he deliberately uses the term 'expect' two times in the same sentence: "...what differences we can reasonably *expect* between what we *expect* and what we get" (my italics). That's his segue into a discussion of *deviation from the mean* (Freund, p. 204), *the standard deviation* (p. 206), Chebyshev's Theorem (p. 211), and the Law of Large Numbers (p. 214).
155. Note how the child introduces a third layer of probability here. So, is *this* the 'bottom turtle' or is there an infinite regress of chances about chances about chances...? I leave this as an 'exercise for the reader' to determine.

and the Central Limit Theory.(156) Fortunately, much of that can be bypassed by the casually curious student, however, thanks to the Internet where one will find various Binomial Theorem Calculators. With such an on-line calculator, one can easily obtain precise answers to the kind of questions raised in the previous paragraph. The interface to such calculators is simple and friendly. Behind the scenes, the heavy lifting is done by the following equation, from which cumulative probabilities are obtained:

$$P(X) = \frac{N!}{x!(N-x)!}\pi^x(1-\pi)^{N-x}$$

(Note in passing: In the equation above, π has nothing to do with 3.14...; rather, it stands for 'probability'. This is a good indication that "we're not in Kansas anymore, Toto," i.e., no longer in the realm of Queen Mathematics, where the Greek letter π qua *pi* is a Totem to be polished and oiled, not casually recycled for a brand-new use.)

From such a calculator, our hapless parent may learn that s/he has a scant 17.6% chance that 20 flips will show 10 heads exactly. However, there is hope: If the parent can tolerate (and the child be convinced by) something in the range of 9 to 11 heads within 20 flips, one might take courage from the fact that there is a cumulative 49% chance of this happening. Or, at 100 flips, the calculator tells us the odds rise to this: '72% for obtaining between 45 heads and 55 heads'. Still not wonderful, but such are the realities for the parent to ponder. At least s/he now knows the exact cost (in time and effort) of moving beyond 17.6% to a more favorable regime.

Returning to the M&M's, per the equation shown in **Figure 101** below, the 'expected' outcome happens to be 11.9%. (And, by way of fitting this into a familiar context, these 11.9% odds for Red and/or Green M&M's correspond to the 50% odds we expect for Heads on a tossed coin.) Now let's bring in the Binomial Theorem Calculator: It tells us that in a set of 36 trials with the M&M's, there would be only a 20.4% chance that exactly 4 Successes would occur (that being the number

156. Also to fundamental questions such as "*Why* is there normal distribution?" At first glance, this seems to be addressed in Gonick and Smith, *The Cartoon Guide to Statistics*, p. 83: "...Demoivre's discovery about the binomial is a special case of ... [the] 'Fuzzy Central Limit Theorem'...data that are influenced by many small and unrelated random effects are approximately normally distributed." Or is that just a tautology that circumvents my question, "Why *that* particular humped shape?"

of Successes needed to confirm 11.9% when rounded to whole numbers: 4/36 = 1/9 ≈ 0.1190). Similarly, in a set of 84 trials, the chance of getting exactly 10 Successes would be only 13.3%. But if we relax our requirements a bit, then the chance for getting 3 *or* 4 *or* 5 Successes out of 36 trials would be 56.5%. And for a range between 7 and 13 Successes out of 84 trials, the chance would be 76.4%. The calculator has guided us into an area where, subjectively, the glass now feels more than 'half full' perhaps, although there is still plenty of uncertainly in the situation, too.

The M&M theory section, as promised: detail behind the figure 0.1190 (= 11.9%)

You probably didn't realize it, but written in Mother Nature there is a Theory of Tri-Colored M&M's. Her theory looks like this:

2R + 3G = 5 at the start of the calculation.
Y is not represented explicitly, only R&G.

There are 10 ways for the 3 M&Ms to be comprised of R & G only.

$$\frac{\binom{5}{3}}{\binom{9}{3}} = \frac{\frac{5!}{3!(5-3)!}}{\frac{9!}{3!(9-3)!}} = \frac{\frac{60}{6}}{\frac{506}{6}} = \frac{10}{84} = 0.1190$$

There are 84 ways for 3 M&Ms to be drawn from the total pool of 9 M&Ms.

FIGURE 101: Figuring the odds on 'no yellow M&M™ among the first three'

After you expand them and divide them out, the factorials in **Figure 101** reduce to the ratio 10/84 = 5/42 ≈ 0.1190 or 11.9%. Or, moving toward rounder numbers for convenience, we can rethink 0.1190 as a number that resides somewhere between 1/8 (= 0.125) and 1/9 (= 0.111). This explains certain percentages and fractions cited earlier in this discussion.[157]

Earlier I asked if you had been 'lucky' with your 36 or 84 trials, meaning I hope your proportion of Successes (so-called) fell somewhere in the ballpark of our 'expected value', which is approximately 1/9. But I hope that you have been lucky in another way too: that you begin to see probability as a medium for 'communing' as it were:

Here is a formula that turns out to be a four-tiered factorial layer cake (**Figure 101**); it

157. As for the equation in **Figure 101**, it is 'the answer' to the scaled-down version of the Devore problem that I described in detail in footnote **153** above.

is jotted down on a sheet of paper by a C student in statistics. The student may now apply that formula to anything at all: To M&M's or matchsticks or lightbulbs. And does the universe (or God) respond with the 'correct behavior'? Yes, so long as one chooses a reasonable number of trials and enjoys a fair amount of 'luck about luck', as explained earlier. Isn't that rather amazing? How does the whole universe 'know' just what to do with all such objects, including the *particular* nine M&M's that you chose for your set of trials? Why shouldn't those lowly, laughable peanuts dipped in chocolate just rattle around aimlessly in the bowl, in a completely *un*patterned way, with *no* rhyme or reason? Who or what is 'watching' them to make sure they conform to the equation that says, in effect: "Thou shalt exhibit a 10/84 Success ratio for the reds and greens, when and if an earthling or a *tanuki* (the Japanese raccoon dog) or a robot ever places you into a series of trials, whether here and now, or tomorrow, or 20 million years from tomorrow." *That's* probability. In my view, the fields of inorganic chemistry and probability-and-statistics provide the ONLY two languages for an earthling to 'commune with God' (or commune with nature, commune with the cosmos, commune with something Out There, etc.)

Getting Physical

Even when approached as a lesson only about probability, the M&M exercise suggests already that equations of the kind shown in **Figure 101** represent something very real, I hope, not just the ivory tower. But if we take a closer look at the exercise, we'll see that it is not about probability exclusively. Two of its five repeating steps have only to do with randomness: Recall the note about technique: "...perform Step 2 and Step 3 'always the same way' to the extent humanly possible. The goal is to avoid bias and ensure randomness". And this in turn is something *physical* — not only because of the obvious 'shuffling' that goes on in the bowl, but because in randomness itself a physical component is recognized by the experts.

When and how did randomness become formalized as part of probability theory? At one point in his work, Richard von Mises was concerned that all of Probability might just be a tautology: Humans invent coins. Coins have two sides. Of course they land Heads half the time. So what? It's all a silly self-fulfilling prophecy, only a human artifact, not a messenger of the gods.[158]

How can the tautology be avoided? By bringing in randomness. Academics excel at slicing and dicing and naming things. Often this serves them well. But it can also trip them up. They set up a field called 'Probability'. But where in the meantime is Randomology, so to say? Randomness is an integral part of the whole picture, so important that the whole field might have been *named* 'Randomology' except for the fact that such a name would sound awkward and undignified. And the interesting thing about randomness is it can't be faked — it requires a physical source.

Qualification: Actually there are at least two kinds of random number generators, known as TRNGs (True Random Number Generators) and PRNGs (Pseudo Random Number Generators). Each comes with pros and cons, plus the various techniques for combining results to achieve 'flat distribution' for encrypting purposes. However, to make a point I'm emphasizing the purist, philosophical facet of the subject here: high quality randomness requires a physical link to Nature, and this sets probability uniquely apart from all other parts of mathematics. For expedience, I've used the term 'mathematics' in the larger sense just now, and likewise in the quotation that follows, we find 'mathematical' used in the sense that subsumes probability. Elsewhere, I try to avoid this usage, precisely because of the tendency described here for probability to set itself apart as a world unto itself.

> [Most mathematical operations can be performed] without ever leaving the precincts of mathland. The one exception is randomness. When a calculation asks for a random number, no mathematical apparatus can supply it [i.e., not at the high level of randomness *quality* that is typically required by the prospective consumer of randomness]. There is no alternative but to reach outside the mathematical empyrean into the grubby world of noisy circuits and decaying atomic nuclei. What a strange maneuver! Hayes, p. 35

Conversely, when a sequence *is* truly random, the biped will often object that it

158. I've paraphrased loosely from Kaplan & Kaplan, p. 48. On that same page, we may note in passing the phrase "...the dice had become the gods." It conveys roughly the *opposite* of what I mean by "God *is* the dice"! Given the historical context, von Mises was understandably concerned that focusing too narrowly on dice, and such might cause one to miss the bigger picture and pursue a phantom topic.

'doesn't seem random [enough]'. This came up most amusingly in connection with an iPod model called The Shuffle. Customers said the shuffling of their tunes didn't seem *sufficiently* random, so the company dutifully dumbed down the algorithm to make it less truly random (but more apparently random to the human sensibility).

Familiarity Breeds Contempt — Except When It Breeds Bewilderment

Earlier I mentioned my concern that 'familiarity breeds contempt'. In the field of probability, there is at least one notable exception to that notion, however: The Monty Hall problem. This problem alludes to the archetypal TV game show, Let's Make a Deal, where the host for many years was one Monty Hall. That makes the circumstance of the puzzle very *familiar* to many many people. But the answer to the puzzle tends to inspire incredulity, *not* contempt. Here's the setup: There are three doors for the contestant to choose from, behind which there are a Mercedes, a goat, and a goat. The contestant chooses a door, hoping it's the one behind which the gift of a Mercedes awaits her. Next, the host opens one of the two doors not chosen, revealing a goat. The question is:

At this juncture (after Monty Hall has opened one door to reveal a goat), should our contestant switch from the initially chosen closed door to the other closed door, and why? Or why not?

Presented with this question, many have a reaction such as the following "Why switch? How can the odds have changed just because the host opened one of the three doors? That's absurd."

But the probablist will tell you, "The answer is, Yes. Switch to the other door."

Pondering this, you may at first feel that here, finally, is an example at the macroscopic level to match the mystery of the two-slits experiment at the microscopic level (the famous quantum mechanics experiment demonstrating wave-particle duality). But really our two goats are not invested with *that* much mystery. It's just that they make their appearance in a context whose logic is very unfamiliar, the very opposite of intuitive. To see why the answer is 'Yes', one must engage in two small but crucial mind-bends: [1] You must look at the proceedings not from (your) contestant's viewpoint but from Monty Hall's viewpoint; [2] you must think in terms of multiple contests over time, not just 'this contest' which you *may indeed lose* by switching doors — we're not saying you won't; you must realize that the puzzle is an Olympian contemplation of the odds, not the particulars on the ground. (Why? Because implicitly that's how the puzzle is conceived.)

For argument's sake, we'll assume that both aspects of Let's Make a Deal vary randomly: the assignment of doors number one, two, three, and the choice by a contestant of one of the three numbered doors. (In reality, one suspects that the contestants' choices do not split evenly across the three doors, but that possible nuance can be disregarded here.) Accordingly, the whole game boils down to three possible scenarios that can be represented this way...

	Door #1	Door #2	Door #3
Case A:	M	G	G
Case B	G	M	G
Case C	G	G	M

...where M = Mercedes (the prize), G = goat (a booby prize).

Let's say the contestant starts out by choosing Door #1. (I.e., she points to Door #1 and announces it as her [tentative] choice, but the door remains closed for now.) Looking at column #1 in the figure above, we see that the odds of success for this choice are 1/3, because we assume that Case A, Case B and Case C are all equally likely. Now let's consider Monty Hall's perspective, which of necessity must focus on the area enclosed by the dotted line because this is the region not chosen by the contestant. Monty Hall must open one door. Now one third of the time, he will find himself in Case A, where he is free to open EITHER Door #2 OR Door #3 to reveal a goat to the contestant. Two thirds of the time, Monty Hall will find himself in Case B or Case C where he does *not* have such freedom: To reveal a goat, there is only one door that he may open — namely, Door #3 if he finds himself in Case B or Door #2 if he finds himself in Case C. Now that we've seen the world from Monty Hall's perspective, it is clear that if the contestant switches doors, she is guaranteed to land on M *if* he happens to be in Case B or Case C — which is to say 2/3 of the time. Granted, if he happens to be in Case A, then switching doors is a disaster. But — over the long haul — this 'disaster' can occur only 1/3 of the time. The other 2/3 of the time, one is guaranteed the prize. In other words, the switch-doors strategy allows one to trade up from his initial odds of 1/3 to improved odds of 2/3 — thus doubling his chance of winning the prize. Saying it another way, if you switch doors, you've hitched your odds to the (flip side of) the host's superior odds. That's the rationale for saying 'Yes' to the invitation and selecting the only door not yet referenced either by yourself or by the host. (We started this pass through the logic as follows: "Let's say the contestant starts out by choosing Door #1." If we start again, taking the premise of Door #2 instead, we find that the probabilities remain the same, and likewise for Door #3. So our statements above are good for the whole game, not restricted to the Door #1 scenario.)

Appendix G: Time's End (1967) and Garbage World (1992)

Poets and novelists have long been admired for their ability to anticipate the future through 'intuition' (which in practical terms must mean sensitivity to the calculus of the moment). Still, it seems remarkable that Baudelaire and Kafka should have caught Garbage World in their radar so far ahead of the age of mass media and the Internet. With his phrase 'carefully selected garbage', Charles Baudelaire might have been commenting on a certain brand of 'critically acclaimed television' that came on the scene circa 2000, except the year is 1869:

> Ah miserable dog, if I had offered you a package of excrement you would have sniffed at it with delight [rather than back away in terror as you did just now from this bottle of perfume]... In this you resemble the public, which should never be offered delicate perfumes that infuriate them, but only carefully selected garbage
> (from Charles Baudelaire's *Paris Spleen*, tr. Louise Varèse, 1947, p. 11)

In the following, the writer might seem to be looking back on the final decades of the twentieth century, but this can't be since the date is only 1917:

> All that he does seems to him, it is true, extraordinarily new, but also, because of the incredible spate of new things, extraordinarily amateurish, indeed scarcely tolerable, incapable of becoming history, breaking short the chain of the generations, cutting off for the first time at its most profound source the music of the world, which before him could at least be divined. Sometimes in his arrogance he has more anxiety for the world than for himself.
> (This 1917 Aphorism is used by John Updike as the epigraph to his *Forward* to Franz Kafka, *The Complete Stories* [1971] 486 pages. It is found on page ix of that volume.)

Some six or seven years ahead of the cyberspace tsunami itself (usually dated to 1992, when the World Wide Web took off), Stanislaw Lem nailed already one of the major problems associated with it. Here he is circa 1986 engaged in a Borgesian game of 'reviewing' a nonexistent book. But, as when the fool holds forth in *Lear*, truer words were never spoken:

> As we leaf through this thick volume...we encounter, from time to time, data that tell us that we live in an era where the flowering of art is barely distinguishable from its demise. The rules and boundaries that distinguish art from what cannot be art have eroded completely and disappeared. Thus, on the one hand, more works of art are being created in the world than cars, planes, tractors, locomotives, and ships combined. On the other hand, that great volume is lost, as it were, in the still greater volume of objects that have no use whatever. For me these number gave rise to black thoughts. First, the world of art has been shattered once and for all, and no art lover can piece things together again, even if he is only interested in one area, like painting or sculpture... What good is it if everything that is beautiful lies at our disposal, and can even be called up on the screen of a home computer, if we are — again — like a child facing the ocean with a spoon? And, as I glanced at the tables of how many different kinds of "works of art" are made per minute (and of what materials), I was saddened by the banality of those works. If archaeologists in the distant future make excavations to learn what kind of graphic art was produced in our era, they will find nothing. They will not be able to distinguish our everyday garbage and litter from our "works of art," because often there is no objective difference between them.
>
> — Lem (1986), p. 27

With its phrase "called up on the screen of a home computer," the Lem passage can be read as a brilliant premonition of what happened with full force only in 1992, when the WWW took off. But the passage looks back in time as well. Back toward Leonard B. Meyer, perhaps, whose *Music, The Arts, and Ideas*: *Patterns and Predictions in Twentieth-Century Culture* was published in 1967 and reissued with a 33-page Postlude in 1994. Both Meyer and Lem are trying to make sense of a world where the whole coordinate system has vanished, replaced by nothing. While Lem's vision is dark, Meyer's is guardedly optimistic: At one point Meyer writes bravely, "I find nothing shocking or deplorable in this [altered world of the arts]" (Meyer, p. 178). Elsewhere he speaks of the 'cresting' of trends in contrast to the 'victory' that might have been enjoyed by a particular school or faction, before a certain watershed date. Many would be surprised to learn that the date he alluded to was nowhere in his own era, rather four years prior to his own date of birth, which is to say 1914 (see Meyer, pp. 172-175). But if some had thus proclaimed a sort of 'heat death' for the arts way back at the beginning of World War I, then what had been the point of all that chest-thumping by the different factions in 'modern music', well into the 1950s? And what was this thing called 'twentieth-century music' anyway?

Consider the following riddle: "What ties the following works together: *Symphonies of Winds* by Stravinsky, the *Concord Sonata* by Ives, *Amériques* by Varèse, *Kammermusik*

No. 1 and *Kleine Kammermusik für fünf Bläser* by Hindemith, *La création du monde* by Milhaud, *Symphony No. 6* by Sibelius, *Enfantines* by Bloch, *Symphony No. 7* by Sibelius, *Serenade* by Schoenberg, *Turandot* by Puccini, *Rhapsody in Blue* by Gershwin, *Suite for Piano* (Opus 25) by Schoenberg, *Wozzeck* by Berg, *Four Pieces* for mixed choir by Schoenberg, *Show Boat* by Kern, *String Quartet No. 4* by Bartók, *Threepenny Opera* by Weill, *Quintette en forme de choros* by Villa-Lobos, and the *Symphony* of Anton Webern?"

Yes, they are all twentieth-century works. But that is not the salient point. The point is they are all *1920s* works. After begging special treatment for a very few isolated works such as Stravinsky's *Rite* (1913) and Ligeti's *Atmosphères* (1961), one can make the case that the vibrant and jam-packed Twenties were essentially 'it' for all of the twentieth century, no matter if your taste runs to the ultramodern or to the antimodern modernism of Sibelius and Puccini: it *all* comes to a climax (and unacknowledged *end*) in the Roaring Twenties. For anyone who knows the literature, this should be a simple *aha* moment: Yes, a disproportionate number of the extraordinary works fall in the 1920s and, conversely, the cupboard is surprisingly bare in every subsequent decade. Thus one is inclined to place 'that certain date' later than the one alluded to by Meyer. Perhaps the true watershed was 1922. That's the year of Hindemith's wind quintet (Kleine Kammermusik, Opus 24, No. 2), which is sometimes identified as the start of Twentieth Century neoclassicism, but in which one can also hear the encapsulated history *of all white occidental music* down through the ages, especially in the ultra-magical harmonies of measures 60 through 69 of the finale.

No, 1924 is better still: the year of Schoenberg's *Serenade*, which in retrospect was *the* voice of occidental Twentieth Century music, now stentorian, now soughing, generally pranking like an otter, although sometimes somber as a butterfly wing, and as delicate in its beauty as an Anton Webern 'novel in a sigh'.

1924! likewise the year of Jean Sibelius's last symphony *and* the demise of Puccini, who gave us 'Nessun dorma' in the opera *Turandot* (which was not quite completed by Puccini himself).

And yet, a number of white composers '*of* the Twentieth Century' (as they would have conceived it their whole lives long, with never a second thought) were born after the 1920s *and* have died already, having never quite comprehended the lay of the land, their place in a branch of the stream that peters out in the sands of Oblivion. Meanwhile, into what new channel did the mainstream of music history actually flow after the 1920s? It lives on in the domain of an Ebony Aristocracy, let's call it: From 1930 on, white time is dead, and black time takes over, so to say. But eventually even the Ebony Aristocracy, all the long way from Duke Ellington to Eric Dolphy, must be consumed by the gaping, omnivorous jaws of Garbage World, which is my name for the sea change of 1992 when the World Wide Web took off, and time stopped for *everyone*.

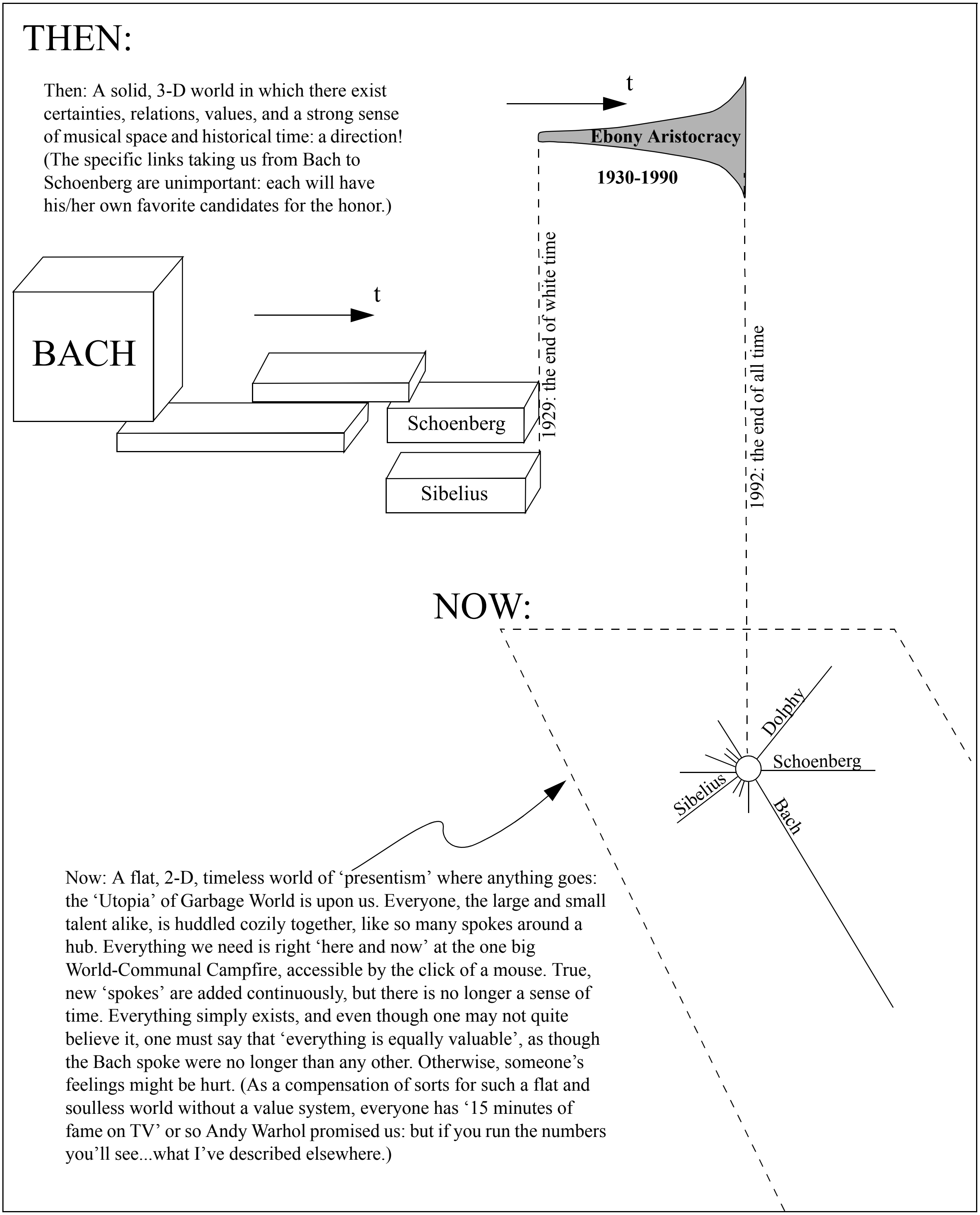


FIGURE 102: White Time, Black Time, and Garbage World Utopia

If we remove the Ebony Aristocracy from the equation, the picture is essentially the same one that emerges from a close reading of Meyer (1967), except that our interpretation of the terrain is dark, rather in tune with Lem, who sees an unequivocal dystopia prompting one's conscience to search for the Exit sign.

Here is a random example showing how profoundly the world of art differs for the 'THEN' and 'NOW' portions of **Figure 102**: Consider the following praise for saxophonist/composer Paul Desmond's "Take Five" (1959):

> "[Its 5/4 meter is] one of the most defiant time signatures in all music."

Evidently, in 1959, one could write that as partial explanation of why the piece stood out, and have it published in a set of liner notes. (As a side issue, note that it was an absurd statement even in 1959. If Desmond's meter represented 'defiance' then I guess the likes of Stravinsky and Villa-Lobos were defiance squared, for their meters had been running circles around 5/4 for half a century already, and never mind Desmond's exact contemporary, Pierre Boulez, who, if invited to the party, could have weighed in with defiance raised to the nth power, conducting 5 with his right hand against 3 with his left and 2 with raised eyebrows, or so the story goes. Desmond's piece endures as a classic thanks to its fine *Gestalt*, not because it uses a 'defiant' meter! But that's not the point; the point is:) Today, one would be laughed at or better yet demoted on the spot for drafting such unusable copy. Even *if* the babble about meter were vaguely plausible.

Why does such rhetoric look so antiquated today? Partly because 'anything goes'; partly because the landscape is sliced too thin (into quiet Internet niches and grottoes, no longer featuring 'schools' or factions itching for a brawl); partly because the public is jaded by (the illusion of) information overload and quite numb or immune to shock of *whatever* kind, not just aesthetic shock.

The best image for understanding the odd position of the painter/musician/poet/novelist in the post-cyberspace era is one used by Stanislaw Lem: Picture a diamond. The diamond is buried in a heap of broken glass — or better yet, resting on the surface of the heap.

It's a metaphor that would go perfectly with the passage we quoted earlier from "One Human Minute" (Lem, p. 27), although in fact Lem introduces the image from a roughly opposite motivation, in a different piece, "The Upside-Down Evolution" (in the same volume, p. 38). The image is helpful in reminding us that the diamond really *is* something different — objectively different — it's just that finding or noticing or even *believing* in the 'diamond' is difficult in the context of Garbage World with its mountain ranges of sparkling 'broken glass' to trudge.

The good news is you can create your own niche at will by self-publishing on the Web. You set up your home page or you upload your YouTube clip, and when a few or a gaggle of kindred spirits find you via the web, a niche-of-your-own will form out in cyberspace — naturally, organically, with a bare minimum of merchandising required. "Life is good. I have my 15 minutes of fame." Well, kind-of.

The bad news is, your poem (or whatever) may be perceived not as a diamond but as 'just another piece of glass' on the mile-high heap of everybody else's good, bad and indifferent efforts at poetry. (Or then again, perhaps your poem *is* only 'glass' — hard to say in this Brave New World in which art-historical time is frozen and the value structure bottom has fallen out. A famous cartoon in *The New Yorker* from the 1950s comes to mind: Psychiatrist to patient, about his inferiority complex: "Has it occurred to you, Mr. Jones, that perhaps you *are* inferior?") Nor can this state of the arts be undone. The toothpaste is out of the tube or, rather, the sand is out of the hour glass, never to be reinstated. Thus the need for a brand-new philosophy, a brand-new way of looking at the world. As provided in these pages.

> We are living in a society and culture that is in dissolution. Pack this paragraph with your own headlines about eroded values, crime, educational decline, what have you. There are many causes, many explanations. But behind them all, vague and menacing, is this recognition: that the understandings and assumptions that were formerly operative in society no longer feel valid. Things have shifted; they keep shifting. We all feel a desire for connection, for meaning, but we don't seem to know what to connect with what, and we are utterly at sea about our place as individuals in the world at large. The maps no longer describe the territory we inhabit. There is no clear path to the future. We trust that the species will blunder on, but we don't know where *to.* We feel imprisoned in a momentum that is not of our own making.
>
> — from Sven Birkerts, *The Gutenberg Elegies: The Fate of Reading in an Electronic Age* (1994), quoted in Elliott, pp. 56-57

Now why would chemistry of all subjects provide the way out, a kind of salvation? Briefly: Basic chemistry provides the perfect bridge from the macroscopic realm down to the atomic realm. And as you begin, via chemistry, to 'commune with' the atomic realm, you will gradually come to believe that such a realm *exists* (the first big hurdle); you'll come to accept it viscerally, not just intellectually because the science teacher says, "Learn Avogadro's number, it will be on the exam." And once you do that, it will be safe for you to gradually start relinquishing your grip on the macroscopic realm and to recognize it for what it is: Flimsy Foam Cubed. Not worthy of your study (via organic chemistry, e.g.) or further concern. And in the process, the travesty of Garbage World should begin to lose its sting. Beyond the use of niche-ism as a coping mechanism, you'll have a real weapon for fighting back.

Appendix H: The Crystal Set Mystique

…and why the crystal set opens a child-size door upon the Kingdom of Physics for **nobody** *save the moneyed Wunderkind who has his own ways of storming the castle already!*

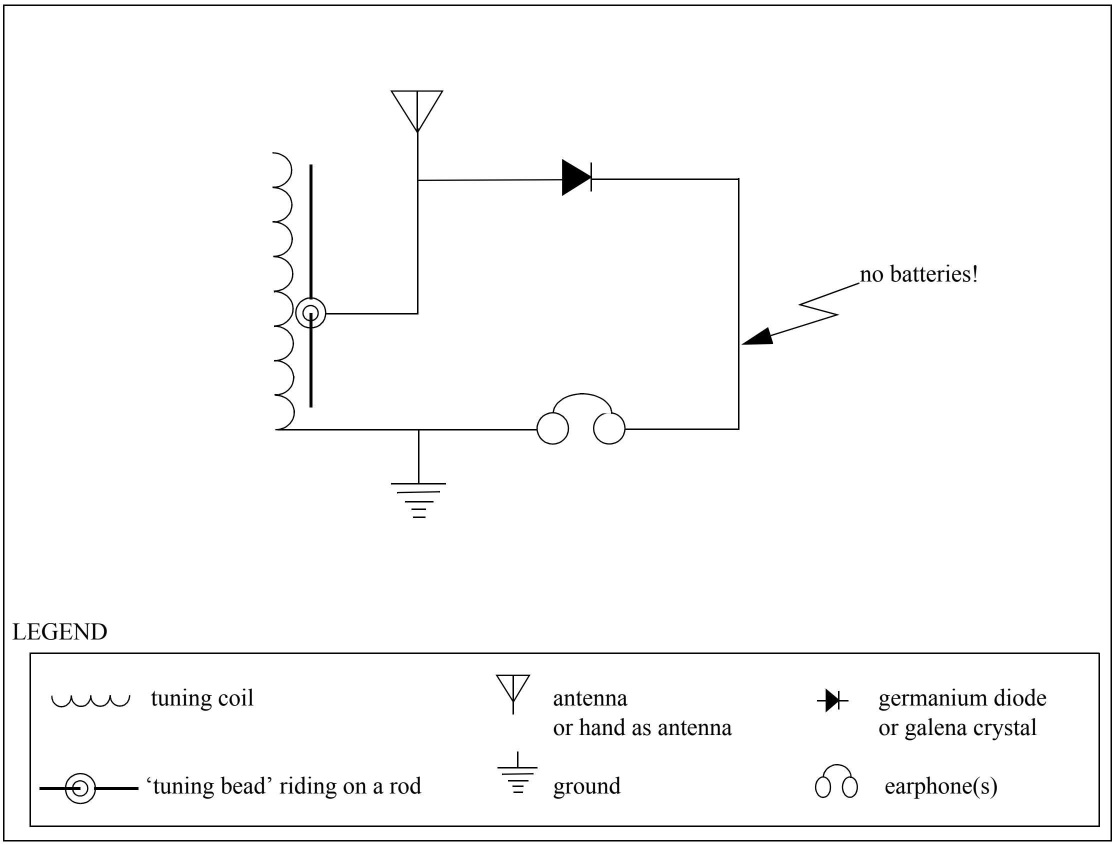


FIGURE 103: The Minimal Crystal Set

Viewed from a distance, the crystal set has the charm of simple elegance; the allure of something-for-nothing ('no batteries included' NOR needed!); plus the ultimate Implied Warranty: "This device *may be (re-)constructed* ANYWHERE in the known universe, even from rusty scraps," so to say. Admittedly, all of that *does* represent a kind of magic. I've fallen for it myself. Repeatedly.

In **Figure 103** we've met one member of the Crystal Set family.[159] Let's meet some other members of this great burgeoning tribe:

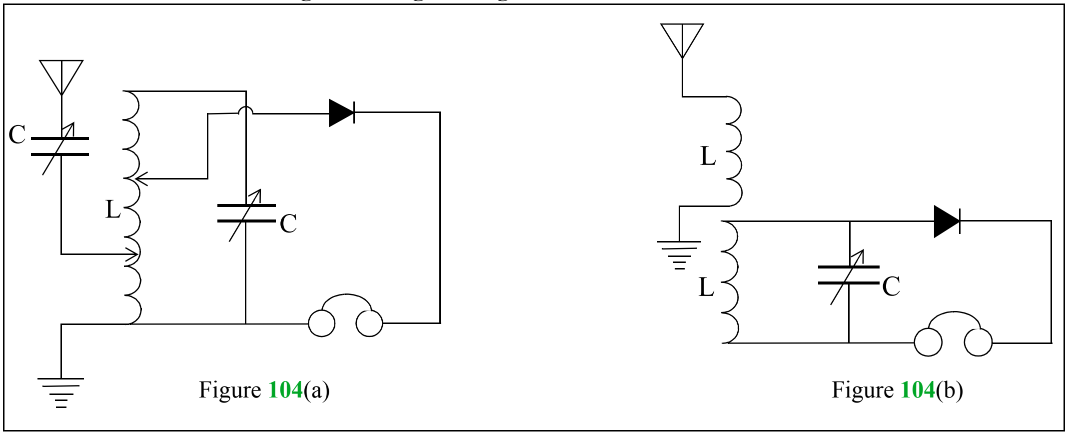


FIGURE 104: Two More Crystal Sets, Suddenly Not So Simple

In **Figure 104**a, two variable capacitors (C) have been added to the circuit, and now the tuning coil (L) has two 'taps' (represented by arrows), one for the antenna and another for the diode. In **Figure 104**b, the primary circuit has a capacitor added, and both the antenna and ground are now attached elsewhere, to a secondary coil that somehow 'knows about' the primary coil. (Such coils are often labeled 'L' probably to honor the contributions of Heinrich Lenz. Naively, I think of 'L' as standing for 'loop'.) In the schematic, the secondary coil is shown 'above' the primary, although physically that might not be their arrangement. One might be nested inside the other, for example. Meanwhile, in the literature here and there, one might begin to notice the following equation for determining frequency on a crystal set.

159. In **Figure 103** my intention is to portray the absolute bare bones crystal set as I understand it, the kind that works even without capacitors, and/or resistors, and/or a raft of transformers and vernier dials and spider coils. Creative members of the World-wide Crystal Set Cult may devise versions that are yet more truly minimal. For instance, some have reported good results using "a wire and anything oxidized" in lieu of the classic cat whisker and galena crystal, e.g., an old razor blade or, my favorite: "a piece of burnt copper", says a chap in the Netherlands.

$$f = \frac{1}{2\pi\sqrt{L\,(C_v + C_a)}}$$

where L = tuning inductance
C_v = variable tuning capacitance
C_a = aerial capacitance

In a blink, we've been transported from a world of presumed kid stuff to an adult cottage industry, which can (and evidently does) fill whole lifetimes, not just childhoods. Do a web search, and you'll see that the theory and practice of crystal set technology is rich enough to occupy tens of thousands of 'xtal set' geeks all around the globe, well into their retirement and dotage.

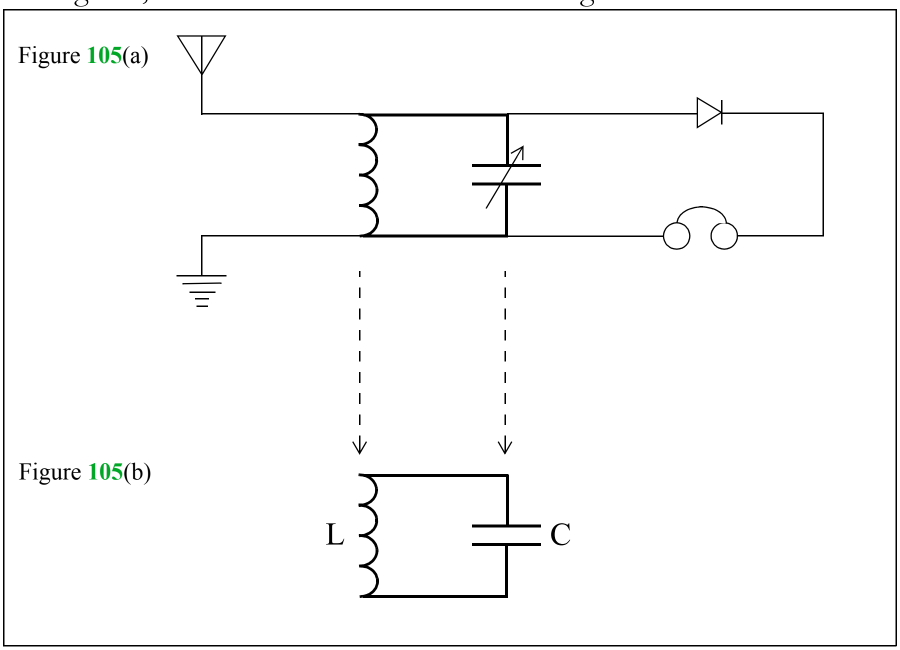


FIGURE 105: LC Circuit as recaptured 'essence' of one's childhood crystal set

At some point one might notice the LC circuit or 'tank circuit' that appears in every physics textbook. Since it seems to be the extracted *essence* of a crystal set, recaptured and isolated for study on the laboratory bench, as it were, let's look at that circuit instead. In focusing on an LC circuit in isolation (**Figure 105**b), I am hoping for something pure and basic, a stepping stone that might be used later in an attempt to (fully) understand the crystal set circuits in **Figure 104**. But as we'll soon see, by focusing on a 'plain' LC circuit, new problems replace the old.

For example: Can the pure LC circuit as depicted in **Figure 105**b actually *do* anything without power? The answer is: No (unless the capacitor had been charged already by some 'offstage' actor). Then how can this very same circuit do actual work as a radio-station tuner in **Figure 105**a, which likewise lacks a power source? The answer is almost literally 'blowing in the wind': the circuit as drawn in **Figure 105**a *is* powered, but in a subtle, invisible way (seldom appreciated by the child who receives this gift for Christmas). It takes its power in minute millivolt quantities, via the antenna, 'from the sky', i.e., ultimately from the transmitters of the various local radio stations. (As an example, in one of my crystal sets, the reading is 115 mV AC in the LC circuit on the left, coming out of nowhere as it were.) Thus, if we wish to try out an LC circuit in isolation, in a more controlled environment, *sans* paired variable capacitors and *sans* coupled inductance coils (as shown in Figures **104**a and **104**b, both of which still rank as 'very simple crystal sets'), we must supply power by a mundane alternative method. Why not a battery? Then **Figure 106** would be our modified LC circuit:

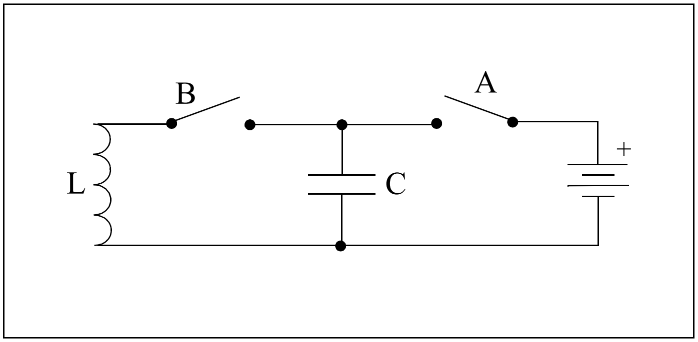


FIGURE 106: LC Circuit with Power Source Added

The general idea is this: With switch B still open, you close switch A to connect the battery and charge up the capacitor, C (which becomes in effect a miniature battery itself); see **Figure 107**a.

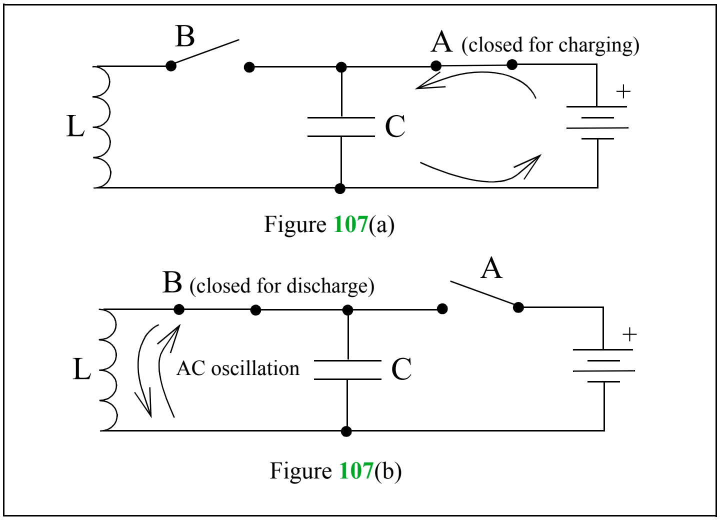


Figure 107(a)

Figure 107(b)

FIGURE 107: Charging and Discharging the Capacitor

Later, you will open switch A to disconnect the battery, then close switch B to let the capacitor discharge its stored up energy through the inductance coil, L; see **Figure 107**b.

But how much is 'later'? And how do you know the circuit is *doing* anything? And *what* is it supposed to do, out of context?

In the context of a crystal set, the LC circuit is said to be the 'tuning circuit'. But here, in Figures 106 and 107, as the LC circuit might appear in a physics text? Here, one usually applies a more generic concept: an oscillator circuit (of which a tuning circuit is a special case). This name suggests that the LC circuit might be a little bit like, or possibly a lot like, a pendulum or a back yard swing, as its current travels rapidly clockwise then counterclockwise, as though bouncing off the plates of the capacitor. Hence the nickname 'tank circuit' because of a resemblance between the movement of the electric current and that of water sloshing to and fro in a tank, suggested by the arrows in **Figure 107**b.

In the context of a crystal set, our naive 'proof' that the circuit is oscillating is the operation of the radio: The LC circuit is said to be in *resonance* with the radio station we hear, thus 'tuned in' to it. But in isolation, the LC circuit offers us nothing obvious to see or hear. What if we could measure its frequency, then? That would make it seem 'real'. Better yet, since the physics books have equations for calculating the expected frequency, given the amount of inductance and capacitance for a specific L and C, let's do that too: calculate the frequency; then measure it; and finally, compare the two numbers. We've all seen multimeters in the hardware store that measure amperage or voltage, but what about frequency, expressed in hertz (Hz)? For that, you need a fairly high-priced multimeter. And what about the coil, L. What would be its unit of measure? You'll want to measure its inductance, expressed in millihenrys (mH). Does that same deluxe multimeter that measures Hz also measure mH? Oddly enough, no, in many cases. It is quite difficult to locate a multimeter that is *so* deluxe as to offer Hz *and* mH *and* uF.

We want that third scale for testing our capacitor, whose capacitance is expressed in microfarads (abbreviated μF or uF). The capacitor will identify itself on the side as, say, '1000 uF', but what if it's a dud? Hence the need for a uF scale too.

On the ninth or tenth web site visited, one finally locates a deluxe-*enough* (and expensive enough) multimeter, one that offers everything needed, for this most rudimentary problem at the beginning of the Inductance chapter in a physics text. (In adding 'moneyed' before 'Wunderkind' above, it was this hassle and related ones that I had in mind.)

Now we have the means to measure the coil's inductance in millihenrys, but what *is* an inductance coil exactly? Should we make one or buy one? (In Minnesota, we have a surplus store called Ax-Man. Perfect for this sort of thing. Plenty of old solenoids available for a song. Also there are hobby shops, and some of the electronics kits for children happen to contain inductance coils, though they might be called something else, such as 'antenna coil' or 'speaker transformer coil'.) Let's say we have located one such coil and measured its impedance as 0.367 mH. Now we can calculate the expected frequency of the LC circuit as:

$$f = \frac{1}{(2\pi\sqrt{LC})} = \frac{1}{2\pi\,[(0.367 \text{ X } 10^{-3}\text{ H} * 1000 \text{ X } 10^{-6}\text{ F}]^{1/2}} = 262 \text{ Hz}$$

Having calculated this theoretical frequency, we can apply the multimeter probes as shown next to measure the frequency directly, while switch B is closed and the LC circuit is oscillating.

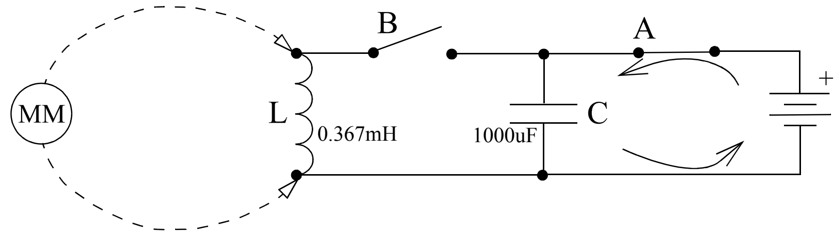


Figure 108(a) Multimeter (MM) dormant while capacitor C is charging

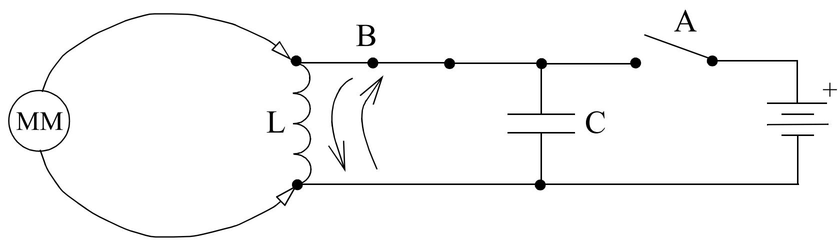


Figure 108(b) Multimeter reading frequency in hertz (Hz) while capacitor is discharging

FIGURE 108: The LC Circuit with Multimeter Probes Attached

But for how long does the LC oscillation last? In this kind of setup (**Figure 108**b), the display of Hz values on the multimeter is erratic, often showing 'nothing' or 'out of range' for a moment, then flashing a value that might be plausible or not. And then the show is over. Time to open switch B and close switch A for a few seconds so that the capacitor can be recharged (**Figure 108**a).

For the record, using the setup depicted in **Figure 108**, I have read 224 Hz and 225 Hz on several occasions, values that are clearly in the ballpark of the calculated figure, 226 Hz, but there have also been readings that had only a distant relation or no relation to 226 Hz, such as 700 Hz and 87.5 Hz. On balance, it's an awkward situation that doesn't inspire confidence. Contrary to expectation, it is actually worse than when the LC circuit had the crystal set radio for context. In the latter case, at least you have steady oscillation, so long as the remote radio station(s) in question continue broadcasting. Here, everything seems ephemeral and transient.

Let's take some time out to access the situation. Without even thinking about it, we've chosen DC to power the LC circuit (i.e., via a battery as portrayed in Figures 106 through 108). Why? Because it is so 'simple and natural' to throw a battery into the circuit, and because most of the textbooks introduce the LC circuit just this way, to boot. But now it occurs to you: the oscillator itself is an *AC* creature, so to say, and thinking back on its role in the crystal set: there it is powered by (minute pulses of) what? An induced *AC* current that is 'pulled down from the sky'. So why are we even dealing with DC power? Shouldn't we be using AC? An extended analogy will help clarify the situation and show the way forward.

To explain resonance, a textbook author will often draw an analogy between the current in an oscillator and the motion of a back yard swing. One recalls the paradox that even with (or especially with) repeated *gentle* pushes, the swing finds its naturally *strongest* motion across the *widest* possible arc, whereas random arrhythmic shoving gets you nowhere. Thus, resonance is emphatically *not* something passive that you simply 'fall into' but something *driven*. On the other hand, you can't drive it boorishly. It requires finesse. (As Einstein observes, the Lord is subtle though not malicious.) Extending this swing analogy as it pertains to our case, all we have done so far (up through **Figure 108**) is mimic the *passive* situation where Dad holds the swing high and simply *let's go* (because just then the family dog leaps the fence and someone must chase it, let's say). That situation corresponds to us opening switch B and closing switch A and trying to measure the oscillation's frequency on the multimeter. Yes, our electronic 'swing' is in motion, *somewhere* in the vicinity of its resonant frequency, but it has yet to be driven, so we cannot say it is in a true state of resonance. Stated in technical terms, here is the contrast:

> Time dependent electromagnetic effects (for example, time-dependent charging and discharging of capacitors) which are transient in DC circuits are persistent in AC circuits.
>
> source: webpages.ursinus.edu/riley/courses/p112/labs/node10.html (Physics 112)

That's crucial information, but rarely is it ever spelled out this way (in plain English!) by textbook authors, probably because to them it is second nature or 'obvious'.

Anyway, we need to chuck the battery (DC), and use AC instead. That much is clear. But we dare not plug this fragile looking circuit into a wall socket. That would probably burn it out and/or trip the domestic circuit breaker.

How does one obtain a steady but reasonably *low*-intensity supply of AC current? Wouldn't that be what an electronics hobbyist calls a 'power supply'? Try a web search. What you see at first is industrial power supplies, priced in the thousands of dollars. How do we move in the opposite direction, back toward the hobbyist's market? It turns out that what we're looking for is called a 'bench power supply'. Google that, and we're back on track. But even here, in the world of bench power supplies, one with low-voltage AC output is still not easy to find. Look hard and one might find a model that offers fixed voltage output (say 6 volts AC), but what one really needs (for reasons explained below) is a *variable*, low-voltage AC power supply. Eventually we locate a rather exotic gadget known as a 'variable transformer' with AC output. This one features output from 1 to 130 volts AC, so it looks like a candidate for being, in effect, our 'AC power supply' (although it will surely need modification to tone down the intensity of its output).

Finally, we can begin!

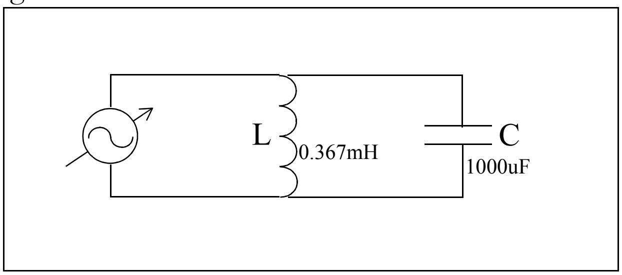


FIGURE 109: LC Circuit Driven by a Bench AC Power Supply

With the setup shown in **Figure 109**, we have a continuous 'nudge' from the AC power supply at far left.[(160)] In **Figure 110**, we add the multimeter in two different configurations — first for measuring current in mA, then for measuring frequency in Hz.

160. In **Figure 109**, the AC power source is symbolized by a sine wave in a circle, pierced by an arrow that signifies 'variable'. In effect, this AC power source replaces the antenna-and-ground component depicted in **Figure 103**. Since the LC circuit in a crystal set is driven by induced AC voltage 'from the sky', that part of the crystal set is *implicitly* a 'parallel LC circuit' not a 'series LC circuit'; in **Figure 109** we attach the AC power source accordingly, to form an *explicit* parallel LC circuit.

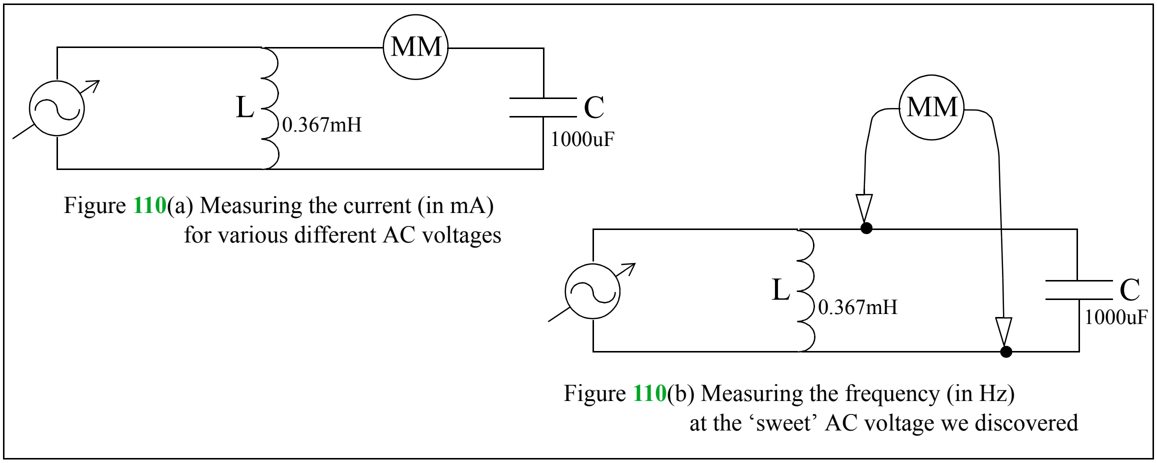


FIGURE 110: How to find the Resonant Frequency

We could immediately measure frequency as depicted in **Figure 110**b, but that would not be very meaningful. (Even if we found f = 224 Hz it would only mean this is *one* possible frequency of the LC circuit; it would not confirm our calculation that 224 Hz is *the* resonant frequency.) Instead, we need to first put the multimeter in series with the LC circuit and use it in its role as ammeter (**Figure 110**a). Why as an ammeter? Because in a parallel LC circuit, the relation between current and frequency looks like this...

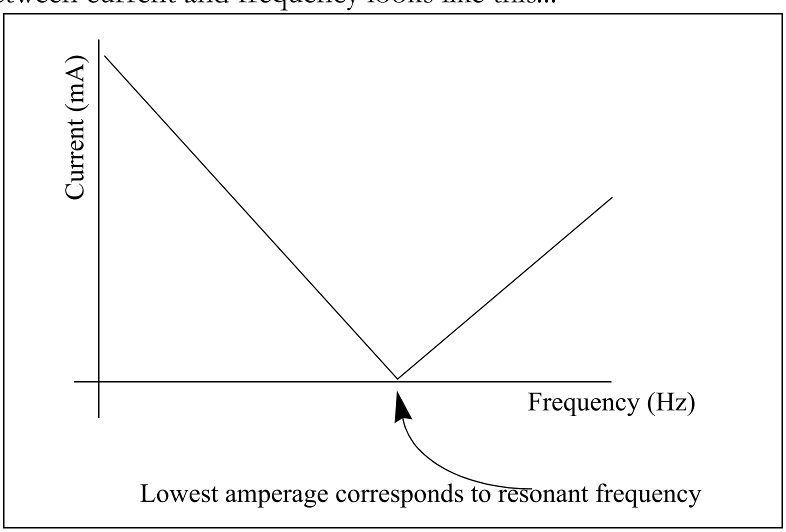


FIGURE 111: Bode Plot for Parallel LC Circuit

...and it's the low point in the curve that tells us where the resonant frequency is![(161)]

So, vary the voltage while the multimeter is attached as in **Figure 110**a, and note where the

161. Just for the sake of completeness, here's the opposite case: For a *series* LC circuit, the Bode plot first rises then falls, and the resonant frequency can be read off the x-axis as soon as you've determined where the curve peaks (instead of dips). Not relevant to the *parallel* LC circuit under discussion.

current in mA is lowest. (This is the sweet spot.) Leave the voltage dial at that setting, and switch to the setup depicted in **Figure 110**b. Now use the multimeter to measure frequency instead. Compare this measured frequency with the calculated frequency (which, as mentioned earlier, would be 224 Hz for this particular coil and capacitor). The two values should be close.

Returning to the crystal set (**Figure 103**), now we have some understanding of its LC circuit or 'tuning circuit' at last: Typically a crystal set has a variable capacitor, and with this its capacitance can be adjusted so that the resonant frequency of the LC circuit matches the broadcast frequency of a given radio station.

But we still haven't talked about *how* an LC circuit resonates exactly. The analogies of sloshing water, or that of the backyard swing, were a good way to start the discussion, but eventually one becomes curious to know what actually goes on inside an oscillator.

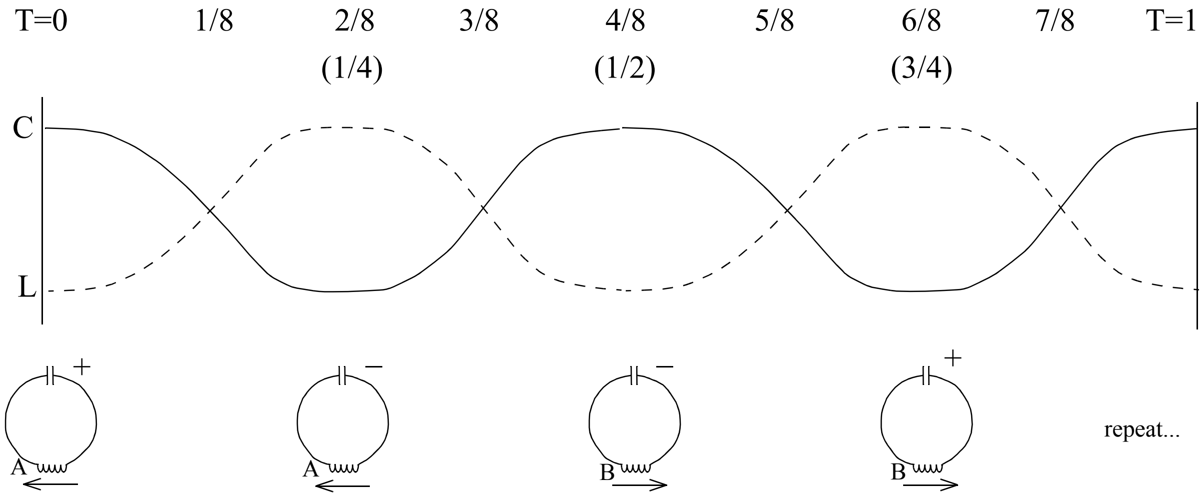


Figure 108(a) Superimposed energy cycles for capacitance (C) and inductance (L), requiring one double period to repeat

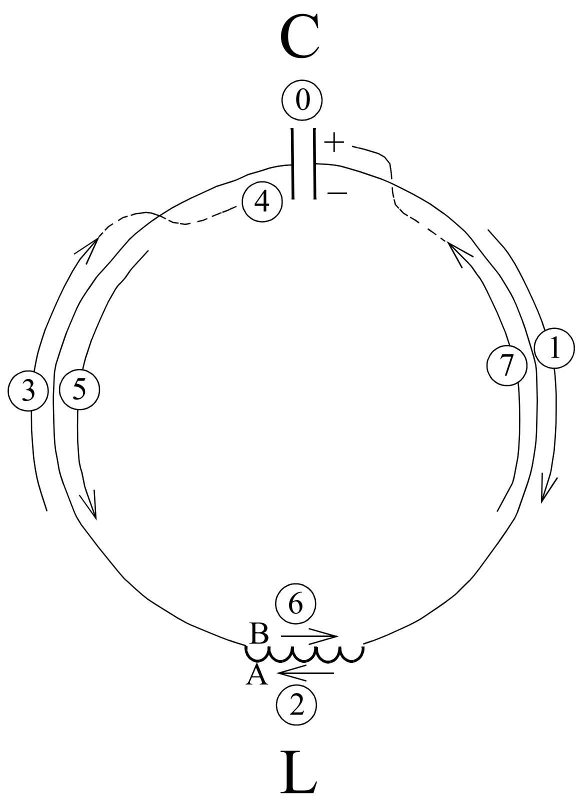


Figure 108(b): LC circuit rounded and rotated to show correspondence with figure (a) above.

Legend: see text

FIGURE 112: Where the Energy is Stored: Anatomy of One Full Oscillation Cycle

Annotations for **Figure 112**:

SUBDIVISION OF OSCILLATION CYCLE INTO 8 EIGHTHS	#	DESCRIPTION OF THE MILESTONES
t = 0	0	all energy is in capacitor, C
t = 1/8	1	electrical energy starts to flow to the coil, L
t = 1/4	2	all energy is in L (and C's polarity is reversed)
t = 3/8	3	magnetic energy starts to flow to C
t = 1/2	4	all energy is in C (and L's magnetic field is reversed)
t = 5/8	5	electrical energy starts to flow the *opposite* way to L
t = 3/4	6	all energy is in L (and C's polarity is reversed)
t = 7/8	7	magnetic energy starts to flow to C

In developing the graphics in **Figure 112**, I've taken as my framework a physics.arizona.edu scheme where you divide the oscillation cycle into eight segments, summing to T = 1. I believe this is the best way to represent an oscillation, but it can be confusing at first since a period labeled 'T' usually contains *one* wave measured from peak to peak (or trough to trough); whereas, in this unusual scheme, you must remind yourself constantly that our one period 'T' is defined (for good reason) to comprise *two* such waves. (Saying it another way: Near the top of **Figure 112** we choose to label the horizontal halfway point as '4/8'; but that's where normally one would see 'T = 1', indicating the completion of one whole period already.)

Labels on the coil, L: On the depictions of the coil, I use 'A' and 'B' as arbitrary markers to represent reversals of the magnetic field direction. 'N' and 'S' would have looked odd because the coils are 'lying down' and pointing east to west as it were. Otherwise, one might have used the labels 'N' and 'S' instead of 'A' and 'B'. In any event, they are arbitrary.

Labels on the capacitor, C: At time 0 the right-hand plate is positive; at time 4 the right-hand plate is negative. By referring to **Figure 112**a, one can understand what the seemingly juxtaposed +/– signs in **Figure 112**b mean: these are not like the coexisting +/– labels on a battery symbol; rather, they represent different times in the cycle, stacked up 'in one place' (almost) to make the picture concise. Likewise the seemingly 'juxtaposed' labels 'A' and 'B' for L in **Figure 112**b.

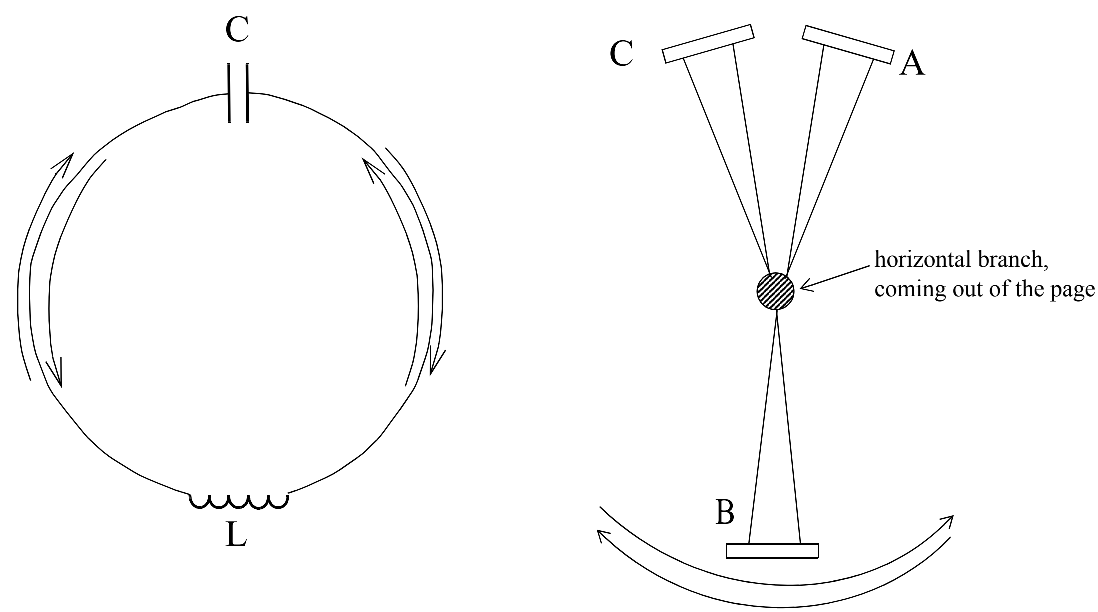


Figure 113(a) LC Oscillator (in my rounded and rotated version) Figure 113(b) 'Extreme' Swinging to mimic oscillator

FIGURE 113: Extending the Swing Analogy

In Figure 112 (abbreviated as Figure 113a), we saw that a single cycle of oscillation is equal to two full cycles in the more familiar sense of 'a wave measured from peak to peak (or trough to trough)'. Only after we have traversed the LC circuit both clockwise and counterclockwise once, have we returned to the initial state as regards the capacitor's polarity (i.e., right-hand plate positive, as arbitrarily designated in Figure 112 and Figure 113a). To that extent, the LC circuit is more complex than a swing. However, we can see that the basic swing analogy is still valid if we imagine every ride starting at position A in Figure 113b — i.e., high in the tree's branches, and nearly upside-down. Now there is virtually no difference between the swing's motion and that of the LC oscillator: To complete a cycle of oscillation, each travels the circle twice, except for a thin wedge at the top of the circle.

Now that we've finally understood how to build a simple LC circuit in such a way that it can be 'driven' and easily measured, let's turn to the question of understanding *why* it does what it does. In other words, where does the frequency equation...

$$f = \frac{1}{(2\pi \sqrt{LC})}$$

...actually come from? In nature, such things do not simply occur ad hoc. They are always part of a 'family' of related processes.

The short answer: That equation happens to be the solution[162] to this second-order differential equation...

$$L\frac{d^2Q}{dt^2} + \frac{1}{C}Q = 0$$

...which in turn is an abbreviated form of the differential equation for an LRC circuit:

$$L\frac{d^2Q}{dt^2} + R\frac{dQ}{dt} + \frac{1}{C}Q = 0$$

And that in turn is directly analogous to the differential equation for a damped harmonic oscillator, i.e., something mechanical, not electrical: Picture an oscillating metal spring whose motion is inhibited (damped) by thick liquid. At this point we realize that when the textbook authors compare the current in an LC oscillator to water in a tank ('tank circuit') or to the motion of a swing or pendulum, these are not metaphors but direct analogies *in* nature. So there really is a kind of magic in the crystal set, far beyond what we might have been expecting.

Now the Calculus I curriculum usually includes a quick preview of differential equations, but they aren't covered seriously until you get to Calculus IV, where they become the main topic. (Why the *main* topic? Because, as hinted above, they appear to be 'the language of nature'.) It's because of the need for Calculus IV that I show such a spike at the very beginning of the Physics curve in **Figure 5** on page **38**. The spike represents a detour for our hypothetical 10-year old into one year of Pre-Calculus followed by two full years of Calculus (plus all the electronics covered above in this essay, plus the concept of amplitude modulation and rectifier circuits which I haven't bothered to include here). That's what it would take for him/her to *begin* to understand the lowly crystal set.

True, if it happens to be the pudgy finger of ten-year old Wolfgang Pauli on the tuning bead, his eyes closed blissfully the better to savor f as a function of L and C as it relates back to that second-order differential equation for simple harmonic

162. For the intervening steps that I've excluded, see the following: hypertextbook.com/physics/electricity/circuits-lrc/. For a full presentation on LC and LRC circuits, including electrical/mechanical analogies, see Serway & Jewett, pp. 1015-1021. For an interesting connection with the imaginary number i, see the discussion of LRC circuits in Nahin, pp. 127-141.

motion, perhaps the little savant chants Om and all is well. But for us mortals...

Conclusion

Stepping back from the trees to view the forest again: Am I claiming that there's no such thing as kitchen physics, only kitchen chemistry? No, the picture I see is not so dire as that. But what seems to be kitchen physics might be only the tip of an ice berg (as in the case of the crystal set radio). And even when it turns out to be reasonable kitchen physics (an example of which I will cite below), for my money the kitchen physics experiments are all one-off events that fail to coalesce. They provide me no sense of 'filling in a blank canvas', inch by inch, as kitchen chemistry does. Not to say one *must* have this lukewarm reaction to kitchen physics. I'm sure that for Dr. Frank Crawford each such experiment did indeed contribute to a steadily progressing painting in his mind, a painting of 'everything'. Thus, all through his very sober looking textbook covering part 3 of the five-part physics course at U.C. Berkeley, he surprises the reader by tossing off delightful 'Home Experiments' such as the following:

> Pour a glass of water. Add a teaspoon of milk (or less) to the water.
>
> In a darkened room, while your eyes are level with the "front" of the glass, shine a flashlight sideways through the glass, roughly left to right or better yet off by a few degrees. The blue coloration you see is analogous to that of the sky.
>
> Now move the flashlight around to the "back" of the glass, and shine it so that it is vertically centered and pointed directly at you, through the liquid in the glass. The reddish color you see is analogous to that of a setting sun. ("vertically centered" is for getting the best sunset effect)
>
> Since the liquid itself is white, both of the colors observed must have something to do with how light scatters. When the illumination is indirect, scattering is in "all directions" and blue predominates. When the illumination is straight-on, as in a sunset, there is less scattering of blue and now the red component (of the bulb's white light) dominates.
>
> — paraphrased from "Why is the Sky Blue?"[163] in Frank S. Crawford, *Waves*, p. 378

But most of us are not Frank Crawford. That's my point. So the 'painting' doesn't

163. An aside about versions: I realize that variations on this same experiment appear in many places, but it is reasonable to cite Crawford specifically as its source because he was just the sort of person who would have dreamed it up in the first place, before all the variations. Around age 10 to 12 I lived in his house, at 2440 Russell Street in Berkeley, so I recognize his style. In his personal store of home experiments, 'there's a lot more where that came from'!

get painted. Long story short: Do chemistry. Don't expect the ohm to be your path to Om.

Appendix I: Myths & Realities of Electrochemical 'Flow'

This appendix may be taken as an extended footnote to the experiment in **Chapter II** called **Avogadro's Number via Electrolysis** (pages **56**-**70**). The impetus for adding this appendix was to clarify *what* flows (or doesn't flow!) in an electrochemical cell. But a natural companion to that question is: *How* does flow occur? Accordingly, we will begin there, to set the stage, before tackling the main topic:

Question One. In an electrochemical cell, *how* does the cycle *become* an (active) cycle? Saying it another way, what gives the cycle its kick start?

Question Two. As the cycle progresses, *what* actually 'goes around' in the cell? (As we shall see in a moment, the answer is not simply 'an electron'. The story is much more involved than that.)

These are very basic questions yet the various chemistry text books I've looked at all remain silent on both. I'll hazard a guess that the silence regarding **Question One** is because "It is obvious to me as a chemist, so it never occurred to me that you would ask"; and the silence regarding **Question Two** is probably because "*That's* a bottomless pit, don't you know? Best left to our colleagues in the physics department." Not[(164)] acceptable answers!

Question One may be obvious to the chemist, but it is certainly not obvious to a newcomer to the field. In an electrochemical cell, what plays the role of the foot on a bicycle pedal or on the kick-start pedal for a motorcycle? Those mechanical examples are both cyclical, but they are not spontaneous: they require some outside force to set them in motion. The question I'm asking is what is the corresponding

164. I find it remarkable how textbook authors gloss over so much of this, as if their only goal were to hypnotize the student into believing in The Electrochemical Fairy-Tale. But since this is nearly the only place where I have a bone to pick with the Chemistry Establishment, I bury it here in an appendix, to prevent it from clashing too loudly with my message elsewhere that *the chemist walks on water*!
(The other topic that might have found its way down into this appendix is the historical 'drift' regarding the [so-called] Avogadro number [N_A] itself. But that problem is simultaneously 'less serious' but also 'more important' to know about, so I've left its discussion inside the experiment proper, as a longish digression called **Understanding Molar Mass as it relates to Avogadro, Cannizzaro, and Loschmidt**, on pages **61-66**.)

mechanism in an electrochemical cycle? (I.e., beyond merely ‘connecting up the wires’, which doesn’t count.)

Let’s begin by looking at batteries, which are introduced in science textbooks by way of their ancestor, the galvanic cell, aka electrochemical cell. By convention, this topic is parcelled out to the chemistry department, although abbreviated coverage of the topic may be found in certain physics textbooks as well. After all, electrochemistry is a subject that straddles the two disciplines, as mentioned on page **110**. Typically the student will be presented with a picture something along the lines of **Figure 114**.

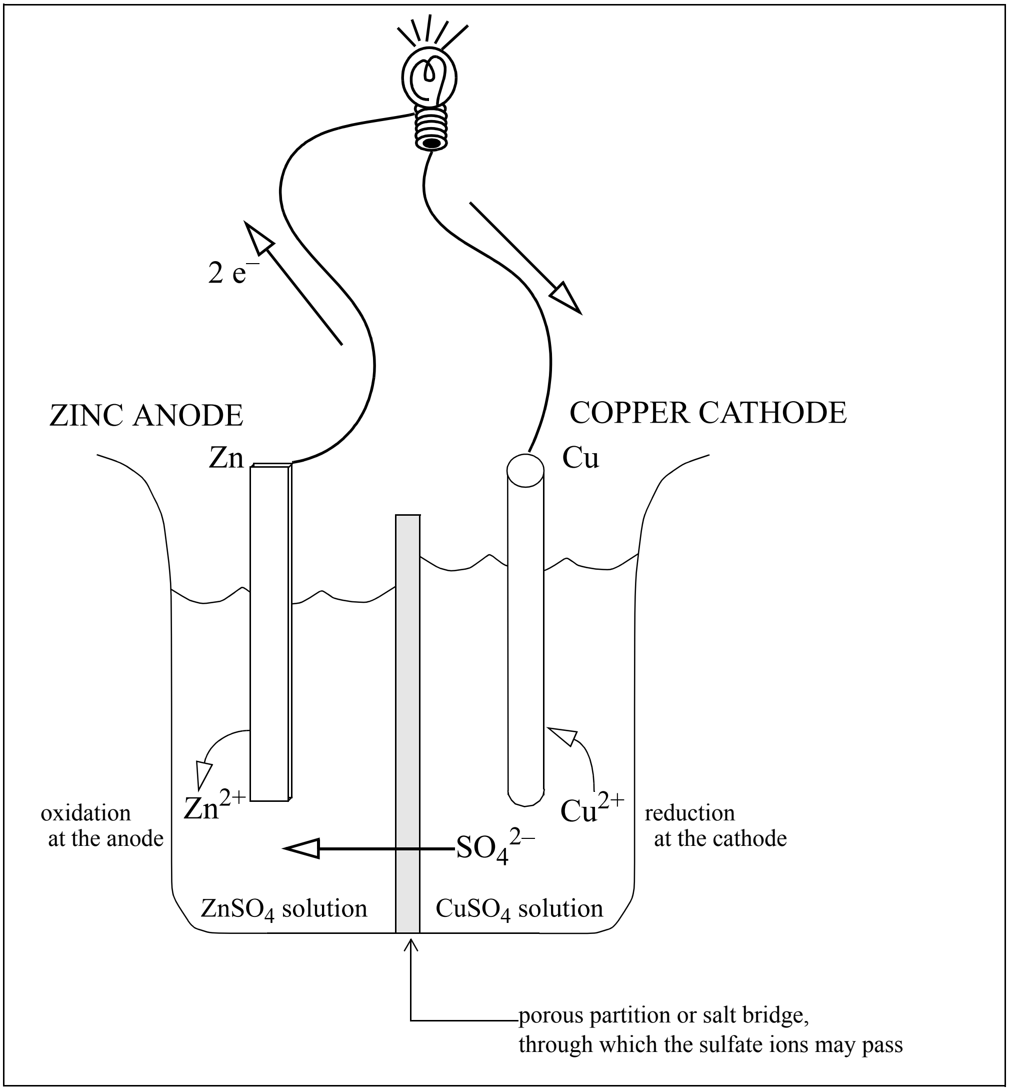


FIGURE 114: A Galvanic Cell Diagram

(For a closely related setup, see also **Figure 11** on page **58**, to which we will refer several times in this appendix.)

In **Figure 114**, two 'half-cells' are depicted, one containing a zinc strip immersed in a zinc sulfate solution, the other containing a copper rod immersed in a copper sulfate solution. The two half-cells can communicate with one another by way of a 'salt bridge' or in this picture by way of a 'porous partition'. In solution, the copper sulfate ($CuSO_4$) takes the form of copper ions (Cu^{2+}) floating independently of sulfate ions (SO_4^{2-}). The superscript '2+' indicates that each copper ion has a charge of two, relative to a neutral intact copper atom which would possess a zero charge. If such a copper ion could capture two electrons (e^-) from somewhere, it would 'reduce' to copper (i.e., become an intact copper atom with zero charge), and in the process it could also merge into the pure copper rod itself (and thus 'plate out' making the rod thicker, by the width of one atom). But this would leave an unmatched sulfate ion (SO_4^{2-}) in the solution, and that would make the solution unbalanced to the tune of two negative charges (indicated by the superscript '2–'). But if this sulfate ion were to move through the porous partition into the zinc half-cell, that would restore balance in the copper half-cell. Now the zinc side would be out-of-balance, however. This in turn could be remedied if an atom in the zinc strip were to give up two electrons (i.e., oxidize) and enter the solution as an ion (Zn^{2+}). This would leave two electrons (e^-) free to travel up into the wire and through a small light bulb, let's say, and thence to the cathode made of copper. Once inside the copper rod, these two electrons would be able to play the role of the electrons mentioned earlier, 'from somewhere', to be captured by a copper ion (Cu^{2+}) to form a neutral copper atom. And so on, in a continuous loop, with the copper rod growing visibly thicker, eventually, and the zinc strip gradually depleted.

The implicit argument is this: By following the dynamics of this cycle, step by step all the way around, you will see why the electrical circuit exists, providing energy to the light bulb or to the starter engine or whatever needs to be powered by the two wires sticking out of the battery.

My comment: True, we can see just how the cycle works. It's all so wonderfully logical, every step of the way, and the bookkeeping tidy.

Except that to my way of thinking, one crucial step is missing. An answer to: "But *why* does any of this even happen? What sets the cycle in motion?"

The answer, I found, in a physics text, oddly enough, not in a chemistry text: "The acid [in a voltaic cell] attacks the zinc electrode and tends to dissolve it [spontaneously]...In a cell whose terminals are not connected, only a small amount of the zinc is dissolved...If charge is allowed to flow between the terminals, say, through a wire (or a light bulb), then more zinc can be dissolved" (Giancoli, pp. 505-506). In other words, even with the wires to disconnected, there is already some spontaneous but very limited zinc/acid chemistry in progress in the isolated half-cell shown in **Figure 114** above. That's the 'kick start' mechanism I was looking for. Then, when you complete the circuit, its action becomes magnified, and runs until the electrode is used up — i.e., totally dissolved. (Less clearly, the notion of something spontaneous happening in such a cell is alluded to in Langford & Beebe, p. 151.)

Now for the electrons. Permitting ourselves to be anthropomorphic for a moment, let's ask some rude questions: How is it that the two extra electrons depicted at the anode 'know' that by travelling through the wires and intervening bulb, all the way over to the cathode, they can make themselves useful by restoring the charge balance when they marry a copper ion to form a full-fledged copper atom somewhere on the surface of the copper rod? On the submicroscopic scale, that cathode is 'several thousand miles away' from the anode. So why even go there? And at close to the speed of light, which should make each electron heavy as a planet.

A partial answer is: They don't go there, it is only 'charge transport' that travels through the metal, as discussed next.

Now for **Question Two**, the more difficult one. As I've warned the reader already on page **58**, the supposedly 'circular flow' of *electrons* as depicted in virtually every text book picture of a voltaic cell or electrolysis cell is a children's fairy-tale;(165) here I will attempt to tell a more grown-up version of the story. In lieu of the one fairy-tale, I will present five flavors of electric flow, arranged under the following three headings:

165. For instance, in Moore, p. 918 (or in Kotz, p. 835) one will find the kind of galvanic cell diagram that appears in all chemistry textbooks (and sometimes in a physics textbook). And *always* such a diagram will be accompanied by verbiage to the effect that *electrons flow through the wire from the zinc electrode to the copper electrode.*
Yes, it makes a pretty picture, I'll admit (having just followed that tradition myself in **Figure 114**), but in lieu of the lie that ' $2e^-$ ' represents 'electrons flowing through the wire', the picture should always be qualified by a discussion or by a footnote on drift velocity, or at least a *vague* inkling of how things actually work behind the deadpan facade of the symbol e^-. Presumably the symbol e^- is borrowed by chemistry from physics, where it almost always denotes a specific electron, as represented in the snapshot of a cloud chamber collision for instance, not a notion of 'abstracted negative charge in motion', which is the only way it can make sense in the electrochemistry context if followed all the way around the circuit.

A. Two kinds of *electron movement* in a cathode (or in its attached wire)

B. Two kinds of *electrical activity* in a cathode

C. Results at the macroscopic level: theory and evidence of *chemical reduction*

What kind of cell? In this appendix, I'm taking the electrolysis cell as my point of reference (i.e., the kind of cell depicted in **Figure 11** on page **58**), but the discussion pertains generally to both voltaic cells and electrolysis cells.

In **Figure 115** and **Figure 116** below, the primary movement is from top to bottom of the diagram; I do this to match the vertical orientation of a cathode or anode as depicted in a diagram such as **Figure 11** on page **58**.

Some of the large values I'll cite required some Quality Time with a calculator, the details of which I've placed near the end of this appendix, in a section called 'The side-calculations'.

A. Two kinds of *electron movement* in a cathode (or in its attached wire)

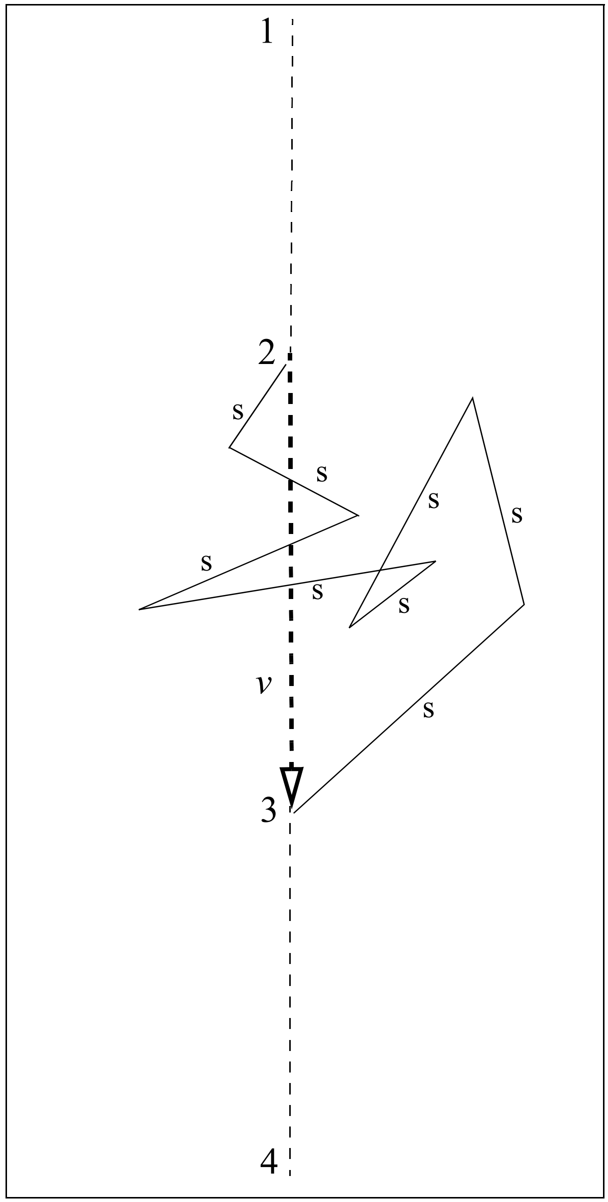


FIGURE 115: Drift Speed (s) and Drift Velocity (*v*)

Figure 115 represents the progress of one 'free electron' through the cathode in an electrolysis cell (or through the wire leading from the battery to the cathode). For the segment of the electron's journey that occurs between '2' and '3', I've provided impressionistic details of its random, zigzag path. I use the letter ‘s’ for ‘speed’ and ‘v’ for ‘velocity’. In this particular context, some physics text books are curiously vague and uncaring in their use of those two terms, treating them as if they are interchangeable. A nomenclature recommendation: What would be reasonable would be to speak of ‘drift speed’ *only* when thinking about the random zigzag motion where direction exists (vectors exist) but are ‘not important’ to us for the present purpose. Then ‘drift velocity’ would pertain to a path such as...

2---------------------->3

...which indicates the electron’s net progress in moving ‘south’ down the length of the wire or cathode.

Qualitative comparison:

The electron’s *drift speed* is FAST, but we don’t really care how fast since it is an example of the ‘drunkard’s walk’, reminiscent of Brownian movement.(166)

The electron’s *drift velocity* is SLOW, something on the order of *75 minutes to travel 1 meter*.(167) Presumably, this astonishing slowness is why all chemistry text books are allergic to the subject and simply pretend it doesn’t exist. To acknowledge its existence would be to throw a monkey wrench into all those nice neat pictures of electrochemical cells where the electrons circulate like so many trained seals, first climbing then diving and swimming, then climbing up to dive again. From the pragmatic viewpoint, ‘it doesn’t really matter’, because it all works out *as if* the fairy-tale were true, so far as many kinds of applied chemistry are concerned. (Meanwhile, there’s that goofy but entrenched business about *electron flow* [alias *actual flow*] proceeding from minus to plus, versus *conventional flow* [alias *Ben Franklin flow*], going backward from plus to minus; not to mention the fact that drift velocity proceeds ‘against the current’ of an electric field (Giancoli, p. 518). So perhaps the chemistry text book authors’ rationale might be: “Well, it’s such a mess anyway, why

166. This speed is on the order of 10^8 m/s (per Giancoli, p. 519) or 10^6 m/s (per Serway & Jewett, p. 841).

167. Depending on initial assumptions, authors of physics text books come up with very different drift velocity numbers. For example, the drift velocity of a free electron in copper is given as 1 meter per 5.5 hours in Giancoli (p. 519) while in Serway & Jewett (p. 835) it is given as 1 meter per 75 minutes. And in five such references you’re likely to see five different velocities cited, all nominally ‘for copper’. The one thing these rates have in common is that they all are *glacially slow*, and happily that’s all we care about here: a qualitative notion of how electrons move in copper wire and copper plates, to begin correcting the fairy-tale.

try to be rational about it?" Why? Because some of us care, and we care to know *before* going to unravel it all by reading a bunch of physics text books!)

Before we conclude this section, lets have a look at the term 'conduction electron' which is sometimes used as an alternate for 'free electron'. (Surprise, surprise, yet *another* goofy half-truth awaits us!) Yes, this kind of electron is 'free' and that's why it can zigzag and drift. So the term 'free' I have no quarrel with. But the alternate term, 'conduction'? That seems to imply that this special subset of the electrons are the agents by which *electricity flows through the metal*. You can see already that this is a lie, however, since their drift velocity is well below one meter per hour. The half-truth is this: Way down at the far end of the process, after that possibly mysterious thing called 'charge transport' occurs near light speed (not to be confused with 'charge transfer'), *then and only then*, does one of the 'conduction electrons' get knocked off the cathode and thus play a role in the flow of electricity, as depicted next in **Figure 116**.

B. Two kinds of *electrical activity* in a cathode

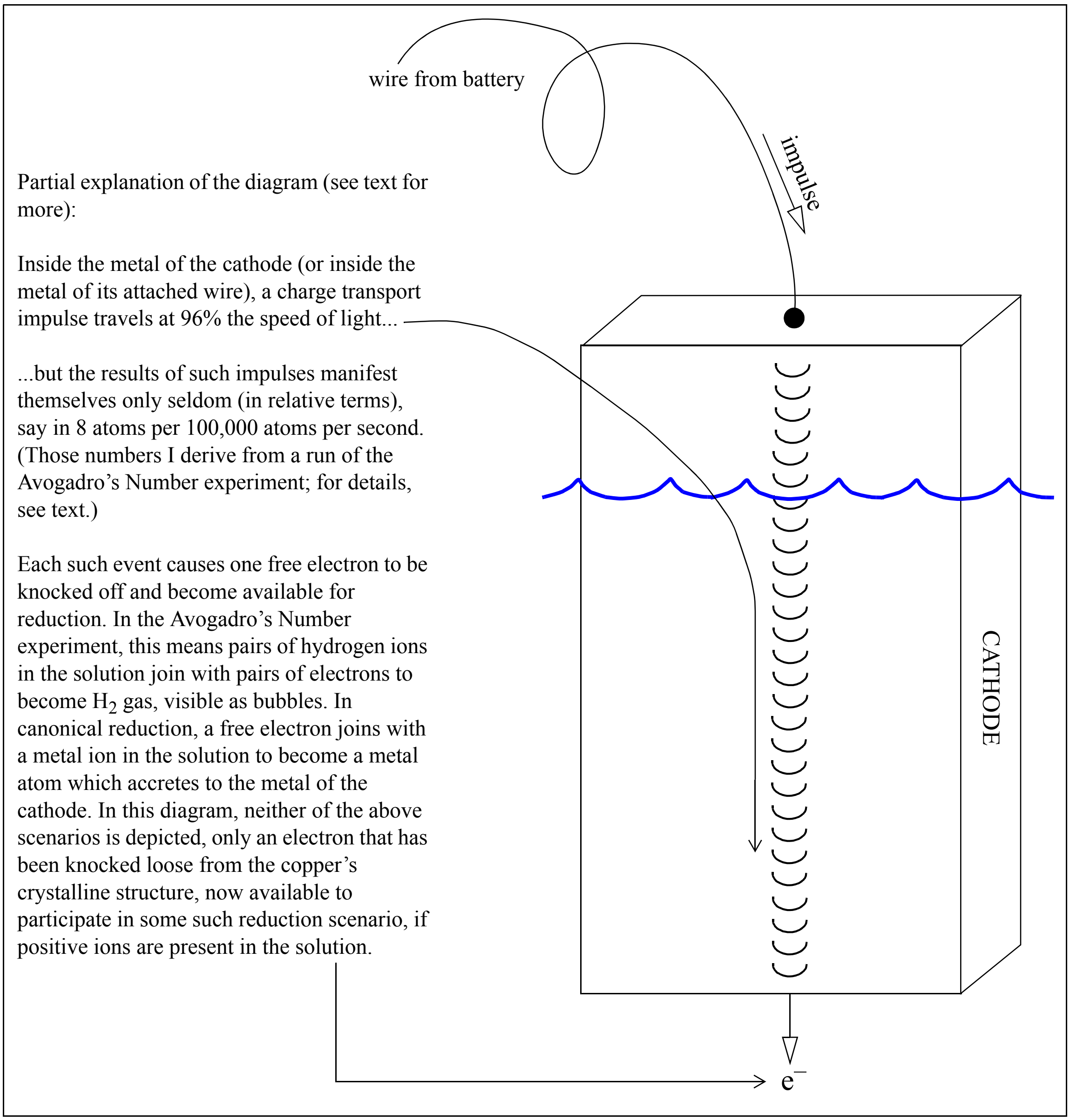


FIGURE 116: Charge Transport and Electron 'knockoff' Depicted

1. Each charge transport event moves through the (battery and wire and) cathode at approximately 96% the *speed of light*. (Thus, 'Electric flow is nearly instantaneous'.) This activity I represent by the train of 'C' shapes in **Figure 116**. These do *not* represent electrons moving through the metal of the cathode or wire. Rather, they represent a kind of shock wave, so to speak, as would occur if a table top was covered by billiard balls and you tapped a ball located at one edge, thus setting up a disturbance that induced a second ball to fall off

the opposite edge of the table. (For a table covered by actual atoms of copper, it would not be a whole atom that got knocked off the far edge, though, only the 'free electron' *belonging* to an atom on the edge, so the billiard ball analogy cannot be pressed very far.)

2. We also want to know: How *many* electrons get knocked off this way during a typical electrolysis procedure, and at what *rate of occurrence*? As a representative example, in our experiment called **Avogadro's Number via Electrolysis** (page **56**f.), the run lasted for 1802 seconds and involved some 6.759 x 10^{21} electrons (give or take some thousands). When you divide the second of those two numbers by the first, it works out to 3.75 x 10^{18} electrons per second: On average, that's how many electrons were 'knocked off' the cathode (to use the language of **Figure 116**) during each of the 1802 seconds (my arbitrary run time for the experiment). At first sight, 3.75 x 10^{18} appears to be 'a lot of electrons', but realize that the cathode in this case contains approximately 4.4 x 10^{22} copper atoms. And if you next work out the ratio between 3.75 x 10^{18} and 4.4 x 10^{22}, you'll see that the 'knockoff' rate turns out to be only about 8 electrons per 100,000 atoms per second — a rather slow rate, actually.

Not that the ratio immediately above 'means anything'. It's just based on an arbitrary chunk of copper that I bought at the hardware store and used as my cathode. However, for the sake of developing one's *general* sense of how big numbers play out (in small places), let's carry this investigation a bit further. To better visualize the true proportions of the process, it would help if we substituted marbles for atoms, and visualized them in a rectangular heap. Assuming a marble whose 'unit cell' edge is 20 mm long (an arbitrary choice representative of 'a large marble' or jaw breaker, if you like), then we would find the marbles stacked 27 km high (17 miles high), resting on a rectangular land mass that measures 720 km by 4,432 km (447 miles by 2,752 miles). (That's the extent of the United States from coast to coast, more or less. So the width and length of the copper strip are represented by a coast and a border of the U.S., while the thickness of the copper strip is represented by the stacked up marbles, rising 27 kilometers into the sky, and packed coast-to-coast to form an immense rectangular solid.)

Next, picture *charge transport* impulses being applied to the wall of marbles that faces on the Atlantic Ocean. Now picture the result: free electrons belonging to a certain few marbles on the west coast, four thousand kilometers away, get knocked out almost instantaneously, to the tune of 8 such 'electrons' per second for every 100,000 marbles residing in the 27 km high wall that faces the Pacific Ocean. (Here we've made a picture of the rate calculated earlier, of '8 electrons per 100,000 atoms per second'.) Returning to the reduction to hydrogen that uses up 3.75 x 10^{18} electrons per second — we see now that this is not 'a lot' after all, once it is placed in its proper context of even huger numbers. (For calculation assumptions/details, see the section below called **The side calculations**.)

C. Results at the macroscopic level: theory and evidence of *chemical reduction*

- $2H^+ + 2e^- \longrightarrow H_2$ (hydrogen bubbles appear as evidence of reduction at the cathode)
  OR
- $Cu^{++} + 2e^- \longrightarrow Cu$ (copper metal 'plates out' as evidence of reduction at the cathode, and is visible, eventually, to the naked eye, when thick enough)

Now, what was the point of all this?

For the chemistry student, the point of sections A, B, and C above is simply that '*These* two electrons' used for reduction at the cathode are not '*those* two electrons' freed by oxidation over at the anode. Granted, the fairy-tale of their being 'the same two electrons, going around in circles' is viable for many situations where the engineer wants a rough-and-ready model that will allow him/her to complete step 1 and get on with steps 2, 3, 4... of a lengthy process. All well and good. No doubt in my own activities, I've sometimes used the fairy-tale in just that way myself. But I think it's wrong to present the student *only* with the unadorned fairy-tale.

The side-calculations

Part 1: definition of the copper *unit cell*

Find volume of a unit cell for copper, assuming *fcc* (face-centered cubic) packing of the atoms as spheres, at 4 spheres per unit cell. What follows is by close analogy with the computations for a platinum unit cell in Moore, page 514:

Start by finding the mass of one atom of copper:

MM (molar mass) for copper is 63.55g.

(63.55g Cu / 1 mol Cu) * (1 mo Cu / 6.022 x 10^{23}) atoms Cu = 1.055 x 10^{-22} g

Multiply by 4 to get mass per unit cell for copper:
4 * 1.055 x 10^{-22} g = 4.220 x 10^{-22} g

Using published density for copper (8.96 g/cm^3), use density formula to find volume of unit cell:

D = M/V, so V = M/D = 4.220 x 10^{-22} g / 8.96 g/cm^3 = 4.710 x 10^{-23} cm^3

From the unit cell volume, find the length of one edge as cube root of volume:

edge = [4.710 x 10^{-23} cm^3 $]^{1/3}$ = 3.611 x 10^{-8} cm or 361 pm (confirmed by checking Emsley, *The Elements*, page 63)

From the unit cell edge, find its diagonal:

diagonal = (sq rt 2) * edge = (sq rt 2) * 361 pm = 510.53 pm

Divide the diagonal by four to find the atomic radius:

510.53 pm / 4 = 127.6 pm, say 128 pm

(We don't need the atomic radius for our purposes here; this is just a sanity check to complete the circle on all the above. The value 128 pm is confirmed in Emsley, page 62.)

Part 2: Conversion to number of copper atoms per cubic mm

Start by converting edge of unit cell from pm to mm:

361 pm * (1 mm / 10^9 pm) = 3.61 x 10^{-7} mm

1 mm^3/(3.61 x 10^{-7} $mm)^3$=1 mm^3/4.704 x 10^{-20} mm^3=2.12 x 10^{19} unit cells/ mm^3

At 4 atoms per unit cell, that makes 4 * (2.12 x 10^{19}) = 8.48 x 10^{19} atoms / mm^3 , say **8.5 x 10^{19} atoms / mm^3**

The number just calculated [BOLD] is sometimes referred to as 'the volumetric density of copper'. Now we have something that can be related directly to a piece of copper we are holding.

Part 3: Estimate the number of atoms in the copper strip (i.e., in the whole cathode)

Each piece of copper that I happened to buy at the hardware store for use as an electrode has the following dimensions approximately:

13 mm by 80 mm by 0.5 mm (the latter being its 'thickness')

Multiplying those three values together, we get a volume of 520 mm^3

Multiplying the volume by the number of copper atoms per mm^3, we have:

520 mm^3 * (8.5 x 10^{19} atoms / mm^3) = **4.4 x 10^{22} atoms in the copper strip**

Part 4: A ratio that 'doesn't mean anything' but is nevertheless interesting to contemplate as it tells us something about the rate of electrolysis (reduction)

Earlier (page 439) we calculated the number of electrons involved in the electrolysis as: 3.75 x 10^{18} electrons / second. If we divide that number by the number of copper atoms in the cathode (from Part 3 immediately above), we have:

(3.75 x 10^{18} electrons per second) / 4.4 x 10^{22} atoms = 0.000085, say 0.00008

Expressed another way: For every 100,000 atoms in the copper strip, 8 electrons per second play an active role in the process of reduction-at-the-cathode. Again, there is no 'universal truth' here, just some statistics garnered from one particular run of the experiment, some food for thought, as used earlier in the main body of this appendix.

Part 5: Picturing the copper strip as the whole United States swamped by marbles sky-high

In Part 3 we described a copper strip with dimensions 13 mm by 80 mm by 0.5 mm. If we substitute marbles for atoms to make its interior 'visible' (i.e., more easily imagined), then we wind up with a country measuring 720 km by 4,432 km, with a 'thickness' of 27.7 km, i.e., 47 mi by 2,752 mi, essentially all of the United States, and with a 'thickness' up into the sky of 17 mi. This conversion is based on an *arbitrary assumption*(168) that each marble resides in a unit cell whose length is *20 mm*. Once that assumption is made, the rest of the calculation is straightforward, albeit a bit tedious:

First we'll convert the copper strip dimensions into unit cell dimensions, picking the thickness of the copper strip (0.5 mm) as a sort of ad hoc 'unit of currency' for building up the numbers, as follows. Calculation of unit cells of copper per 0.5 mm:

(0.5 mm / 361 pm) * (10^9 pm / 1 mm) = 1,385,041 = *thickness* of the copper strip expressed in unit cell lengths

13 mm / 0.5 mm = 26 units (of our arbitrary 'currency'); now use the number:

26 * 1,385,041 = 36,011,066 = *width* of the copper strip expressed in unit cell lengths

80 mm / 0.5 mm = 160 units (of our arbitrary 'currency'); now use the number:

160 * 1,385,041 = 221,606,560 = *length* of the copper strip expressed in unit cell lengths

(Pause for a sanity check: 1,385,041 * 36,011,066 * 221,606,560 = 1.11 x 10^{22} unit cells, now as actual cubes. At 4 marbles per unit cell, we get 4 * 1.11 x 10^{22} = 4.44 10^{22} marbles total. That figure jibes with the total number of atoms in the copper strip, as calculated in Part 3 above. So it's okay to continue.)

Finally, multiply each of the three dimensions by our assumed unit cell length for a marble, which we said would be 20 mm:

(20 mm / unit cell length) * 1,385,041 unit cell lengths = 27,700,820 mm or 27.7 km (~ 17 mi)

(20 mm / unit cell length) * 36,011,066 unit cell lengths = 720 km (~ 447 mi)

(20 mm / unit cell length) * 221,606,560 unit cell lengths = 4,432 km (~ 2,752 mi)

168. I say 'arbitrary' but there was some trial and error involved since I wanted the numbers to come out in such a way that the marbles would 'cover the United States'.

Appendix J: Avogadro Again - Sequin Scale Version

Since the experiment called **Avogadro's Number via Electrolysis** (pages **56-70**) is central to my thesis, I provide a second version of it here. As regards the weighing mechanism (a gadget I call 'sequin scales'), this version is even more minimalist than the one cited above. As regards the chemicals used, this is a more ambitious (dangerous) version, no longer in the realm of kitchen chemistry, more like 'garage chemistry' or 'backyard chemistry', if you like. The idea is that one will want to be in a well-ventilated area. You'll wear goggles and gloves. And most of the time you'll stand far away from the apparatus itself since sulfuric acid is used. Not to say the sulfuric acid *vapors* are the major safety concern, but you might as well play it safe in that regard, ducking in close only at intervals, to glance at a readout on the multimeter, then writing it down elsewhere, at a safe distance. (Also be aware that a small amount of hydrogen gas will be produced, and hydrogen is flammable.)

Materials List

- A supply of concentrated sulfuric acid (H_2SO_4). This is available as 'an industrial strength drain cleaner' in hardware stores, also available in some automotive stores as 'battery acid'.
- Direct current source
  I recommend a 6V lantern battery because alligator clips can be easily attached to the spring nipples on such — no battery holder or special cable required to hook it up. (By the way, voltage is often left *un*specified in this experiment since it's all about amperage.)
- One piece of insulated wire with an alligator clip on either end. (Optionally, a second such wire to mediate the multimeter lead and the cathode, as explained in the Procedure below.)
- Two strips of copper
  Note: in this version of the experiment, you may substitute zinc, iron or nickel without changing anything else in the setup; the only thing that would need revision would be your GAM (Gram Atomic Mass) value in **Figure 13**: if using zinc, you would revise the GAM to 65.4 in lieu of 63.5, and so on, per **Appendix A: The Periodic Table**.
- One 250-mL beaker
- Small container of acetic acid (≈ vinegar) for cleaning the metal of the anode
- Small container of isopropyl alcohol (rubbing alcohol) for drying the metal

- Multimeter, preferably the kind with a built-in alligator clip at the end of each lead.
- Wrist watch or wall clock for counting minutes. (True, you'll do a gross conversion of your minutes *into* seconds later on, but you don't need a stopwatch to *count* seconds.)
- Scales for measuring copper mass loss: Before doing the **Procedure** that is illustrated by **Figure 117**, first construct and calibrate your **Sequin Scales** as described on pages **449-454**.

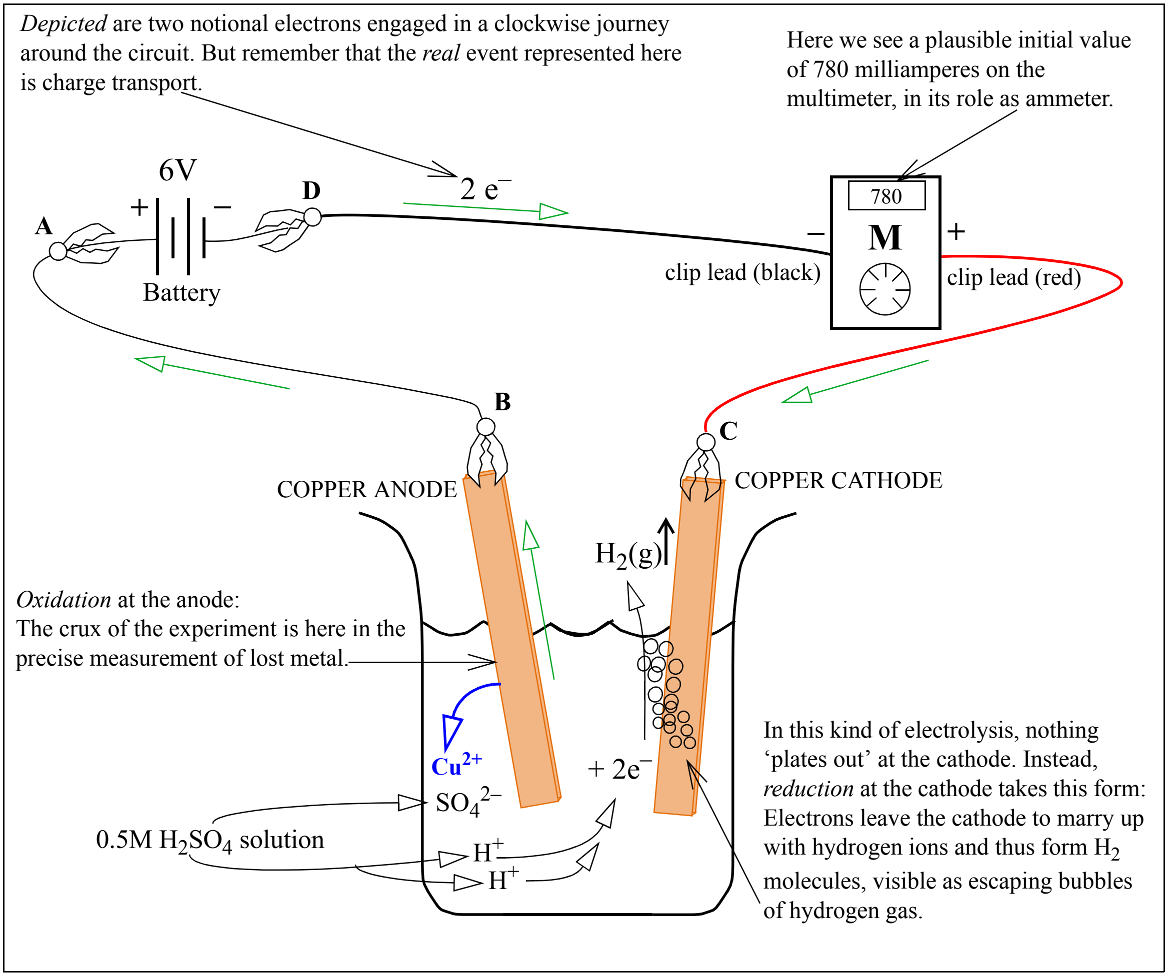


FIGURE 117: The Minimal Electrolysis Apparatus for Backyard Chemistry

Procedure

Pour water into the 250-mL beaker, to the 200 mL mark, approximately. (We just want some clearance between the lip of the beaker and the surface of the liquid, that's all.)

Add 10 mL of concentrated sulfuric acid (H_2SO_4) to the water, bringing the combined level to 210 mL. (There may be no '210 mL' line on the beaker, so just estimate the position of

210 mL total. Or think of it this way: To 3/4 cup water, add two teaspoons of the concentrated acid.) Now you have your solution. The rest of the setup is easy.

[*Note #1* for the uninitiated: If concentrated sulfuric acid is such powerful stuff, why not just dump it in *un*diluted and make the electrolysis go that much faster, eh? Short answer: Because nothing much would happen. Slightly longer answer: Yes, the 98% concentration stated on the label sounds hugely impressive, and so it is in cleaning a drain, for instance. But the product must be combined with (much more) water to become a genuine, active acid in this context. It's a dramatic example of 'less is more'.]
[*Note #2* for the uninitiated: While conceptually we may think we are 'diluting the concentrated acid' never do this literally. Rather, always '*add acid*' as indicated above. Never add water *to* an acid. Horrible things can happen.]
[*Special Note* for the confirmed chemistry geek: The 96% or 98% concentration of 'industrial strength sulfuric acid' translates to something on the order of 18M molarity. And what we're aiming for here is something in the vicinity of a 0.5 M solution. According to published tables, 54.3 mL concentrated sulfuric acid with 1L water gives a 1M solution. So, 28 mL in 1L or 7 mL in 250 mL should give a 0.5M solution. I've very crudely rounded the latter two values, up to 10 mL and down to 200 mL.]

Clean(169) one of the two copper strips by dipping it in the acetic acid (vinegar). Rinse it in water, then dip it in the container of alcohol. Place it on a paper towel to dry. When dry, weigh it to the nearest toothpick or sequin (≈ 1/2 or 1/3 of a toothpick). This copper strip is the one that will be the anode (see **Figure 117**).

Attach alligator clip A to the positive terminal of your power source, as indicated in **Figure 117**. At the other end of that wire, attach alligator clip B to the copper strip that you cleaned and weighed.

Immerse the copper strip in the beaker.

169. Given the low level of precision that we're shooting for, the cleaning and drying step probably has no appreciable impact on the result. But vinegar and rubbing alcohol are household items, nothing special, so why not perform these steps pro forma, for practice at least?

To the other copper strip, attach the positive lead[170] from the multimeter (probably red), using its built-in alligator clip, labeled C. Immerse this second copper strip in the beaker.[171]

Prepare a table for recording times and ammeter (multimeter) readings.
Since this version of the apparatus is built without a variable resistor to control (smooth out) the amperage, we must cope somehow with varying amperage during the run of the experiment, where 30 minutes duration is recommended, and 17 minutes is the minimum. The workaround is to record sample values along the way and later average them. Here is one of many possible approaches that should work: For every three-minute period, jot down a rough, impressionistic average of the half-dozen values you've seen on the display during those three minutes. Then, when you're finished, take the arithmetical mean of the ten values you've written down for the 30-minute run. (Example: 780 + 830 + 810 + 785 + 820 + 855 + 895 + 915 + 950 + 995 milliamps, summed and divided by ten is 863.5mA or 0.86A as the average, using two significant figures. But one significant figure is probably appropriate here: 0.9A.)

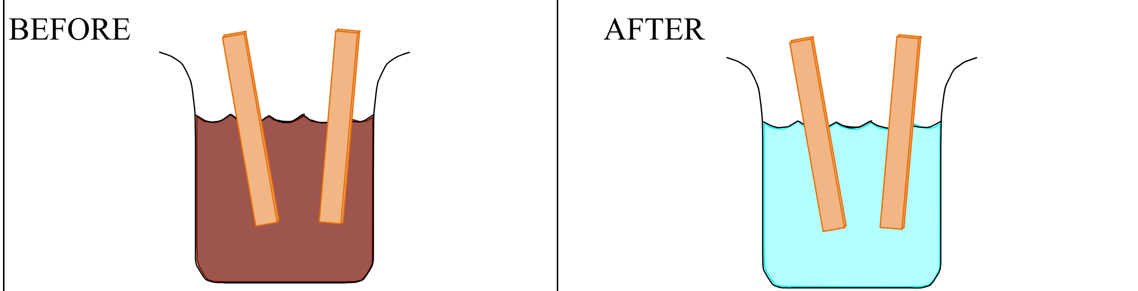
Complete the electrical circuit by attaching the negative lead from the multimeter (probably black) to the negative terminal of the battery (at D in **Figure 117**), and switching on the multimeter box.

At the conclusion of the 30-minute run, disconnect the battery and remove the anode (the copper strip depicted on the left in **Figure 117**). Carefully detach its alligator clip. Rinse the anode by dipping it in the container of alcohol again. As before, dry it on a paper towel, then weigh it to the nearest toothpick or sequin.

(This is the moment of truth in two senses: First, this is where you find out if you have plausible results — something like the change depicted in **Figure 118**, and something on the order of 0.4 g difference for the before and after weighings of the copper. This, along with an average amperage between 0.8 A and 0.9 A, should put

170. If it is not clear which is the positive lead and which the negative on your multimeter, don't worry about it. Even if you attach the leads 'backwards' it just means the number on the display will have a minus sign prefixed to it. Ignore the sign and treat the displayed number as positive amperage. No harm done.
171. Try to arrange it so the 'clip lead' from the multimeter is above the surface of the liquid. If you're concerned about the lead coming into contact with the acid and possibly being ruined by the reaction, use an intervening wire with (cheap) alligator clips in-between the multimeter and the copper strip.

you in the ballpark. And it's a moment of truth in the following sense as well: Do you feel anything resembling a 'connection' to the atomic realm? Lest we forget, *that's* the whole point of the exercise, since far better values for N_A can readily be obtained elsewhere these days.)



At first, the mixture of water and H_2SO_4 will be colored by the dark brown dye that is routinely added to the latter by its commercial distributors.

At the end of the experiment, the muddiness will have cleared up, and the water will now possess a delicate cyan tint, created by the accumulation of copper ions (Cu^{2+}) at the anode, a visual representation of the lost mass!

FIGURE 118: Before and After Views of the Electrolysis Solution

Sequin Scales

Rationale: This 'sequin scale' version of the experiment is actually the one I did first, before the 'carat scale' version on pages **56-70** above. In building and describing a set of 'sequin scales', one of my two motivations originally was to beat the system, as it were, and to avoid the cost of an analytical scale, priced in the \$1,500 to \$3,000 range. Later I realized that such a device would be overkill. Also, I wanted to try something safer and more 'domestic' than sulfuric acid. Hence the new version above.

My 'sequin scales' are a variation on the standard 'ruler scales' idea (as described at www.science-projects.com/Scales.htm, for example). I've taken the idea in a specific direction where we care only about discovering the weight of a given object (e.g., a strip of copper), not about 'measuring out a substance' (e.g., 4 grams of a powder), and where we can achieve a resolution of 'one sequin' as I call our smallest unit of measure.

Materials for constructing the scales, concise version:
A ruler and pencils; a few coins; and a supply of toothpicks and sequins. That's *it.*

Materials for constructing the scales, verbose version:

- 1 foot-long ruler with inches and/or centimeters preprinted on it. This will be the balance.

- 3 pencils or ballpoint pens (all three identical, e.g., No. 2 pencils or Bic® pens). Either pencils or pens will do so long as the design is *hexagonal*, to prevent rolling on the table.
- 1 index card (3x5 or 5x7), or a similar piece of heavy paper. This will be the base, under the fulcrum.
- 2 identical nickels (5¢ coins)
  By 'identical' we mean coins minted within the past 4 or 5 years, in which case they've probably experienced negligible wear and can be assumed to still match their 5.000 g mint specification. This part is crucial: If *worn*, the coins will be of *no use* in this context!
  (For reference, here some other standard weights: dime: 2.200 g; penny: 2.500 g; quarter: 5.700 g, per http://www.usmint.gov/about_the_mint.)
- toothpick supply
  E.g., a box of Diamond® toothpicks, regarded as the 'standard' for toothpicks, each weighing 100 mg (supposedly).[172] If you can find flat toothpicks, these are better, as the rolling around of round toothpicks can be aggravating in this context. It appears that for a given manufacturer, the round and flat varieties are made with the same weight.
- sequin supply
  One package of sequins or confetti or 'gold stars' or miniature buttons — *any* light uniform object such that the combined weight of several of them will approximate the weight of one toothpick. For example, using small sequins, the Dimensional Analysis (alias 'Unity Factors') might work out this way:

$$\boxed{\frac{100\text{ mg}}{\cancel{1\text{ toothpick}}} * \frac{\cancel{1\text{ toothpick}}}{5\text{ sequins}} = \frac{100\text{ mg}}{5\text{ sequins}} = 20\text{ mg /sequin}}$$

  Or, with medium-sized sequins (one-half inch diameter), it might be close to a simple 2:1 ratio, so that each sequin would represent 50 mg (= 0.050 g), approximately.

Granularity:

So, we're talking about resolution on the order of 20 mg in the former case, or 50 mg in the latter case, either of which looks hopelessly crude compared to the usual textbook requirement ("...to the nearest 0.0001 g on an analytical balance"); nevertheless, as we'll see, it turns out to be just the ticket for the specific task at hand, viz., to get a visceral sense of what Avogadro's number means, by estimating it

172. But I find the weight of a toothpick to be 110mg (0.11g). However, for the sake of cleaner looking examples, I've maintained the fiction of '100mg' in the text. Similarly, the sequins I have on hand seem closer to 0.03g than to 0.02g, but I use the latter number in the examples.

to the same level of precision as achieved by its initial estimators, Maxwell *et al.* (see list on page **69**).

Calibrating the balance:
Rulers are manufactured many different ways, often with significant asymmetry. Thus, if you take the 6-inch mark as the center of a given ruler, then place your two identical nickels perfectly symmetrically near its two ends, say centered on the 1/2-inch mark and 11-1/2 inch mark respectively, your scales will likely *not* be in balance. A typical configuration that *is* balanced would be something irregular-looking, such as '7/16-inch and 11-1/2 inch'. Once you've discovered these two points, test your hypothesis by swapping the positions of the two coins. (They should still balance.) Then make a note of the two marks as these will be your 'targets' for placement of weights and samples later.

Sequin Arithmetic Example

	THE EXOTIC UNITS	THEIR CONVENTIONAL EQUIVALENTS
Copper strip mass before electrolysis	1n + 7t +4s	5.000 g +0.700 g + 0.080 g = 5.780 g
Copper strip mass after electrolysis (see **Figure 119** and **Figure 120**)	1n + 4t +1s	5.000 g +0.400 g + 0.020 g = 5.420 g
Difference (= mass lost to electrolysis)	0n + 3t +3s	0.000 g +0.300 g + 0.060 g = 0.360 g

Legend for the table above: n = nickels (5¢ coins), t = toothpicks (standard),
s = sequins (small)

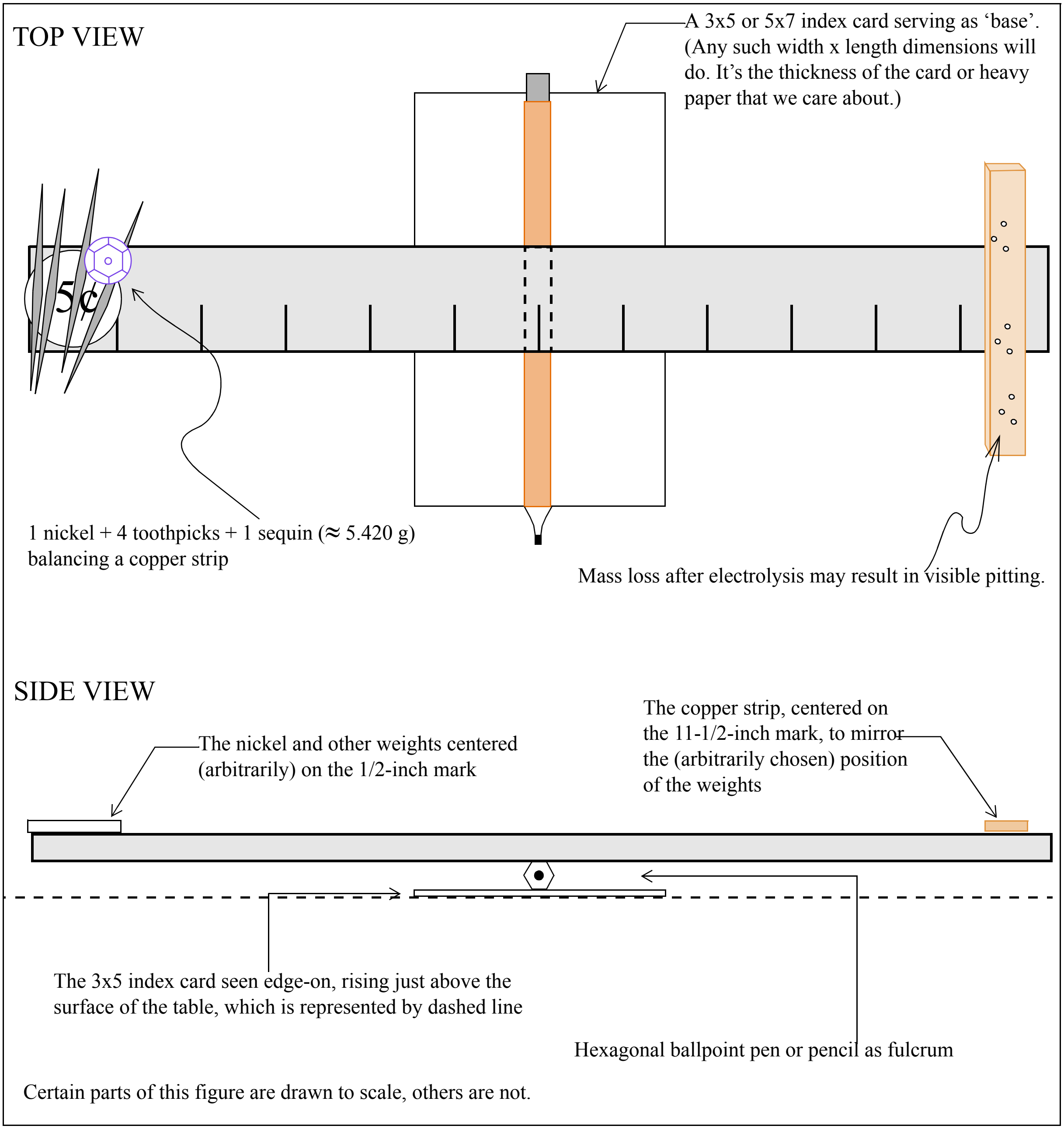


FIGURE 119: Sequin Scales (loaded to illustrate the Sequin Arithmetic Example)

Note: I reverse engineered the example above so that it would come into the ballpark of 0.3551 g, the difference in an online sample calculation (posted by Dr. Anne Marie Helmenstine at chemistry.about.com/cs/generalchemistry), while still missing 0.3551 by an amount that seemed realistic given the premise of 20 mg resolution (granularity).

Using the nickel alone, one can check results by exploiting the relation A * m_1 = B * m_2, as illustrated in **Figure 120** and the ensuing discussion.

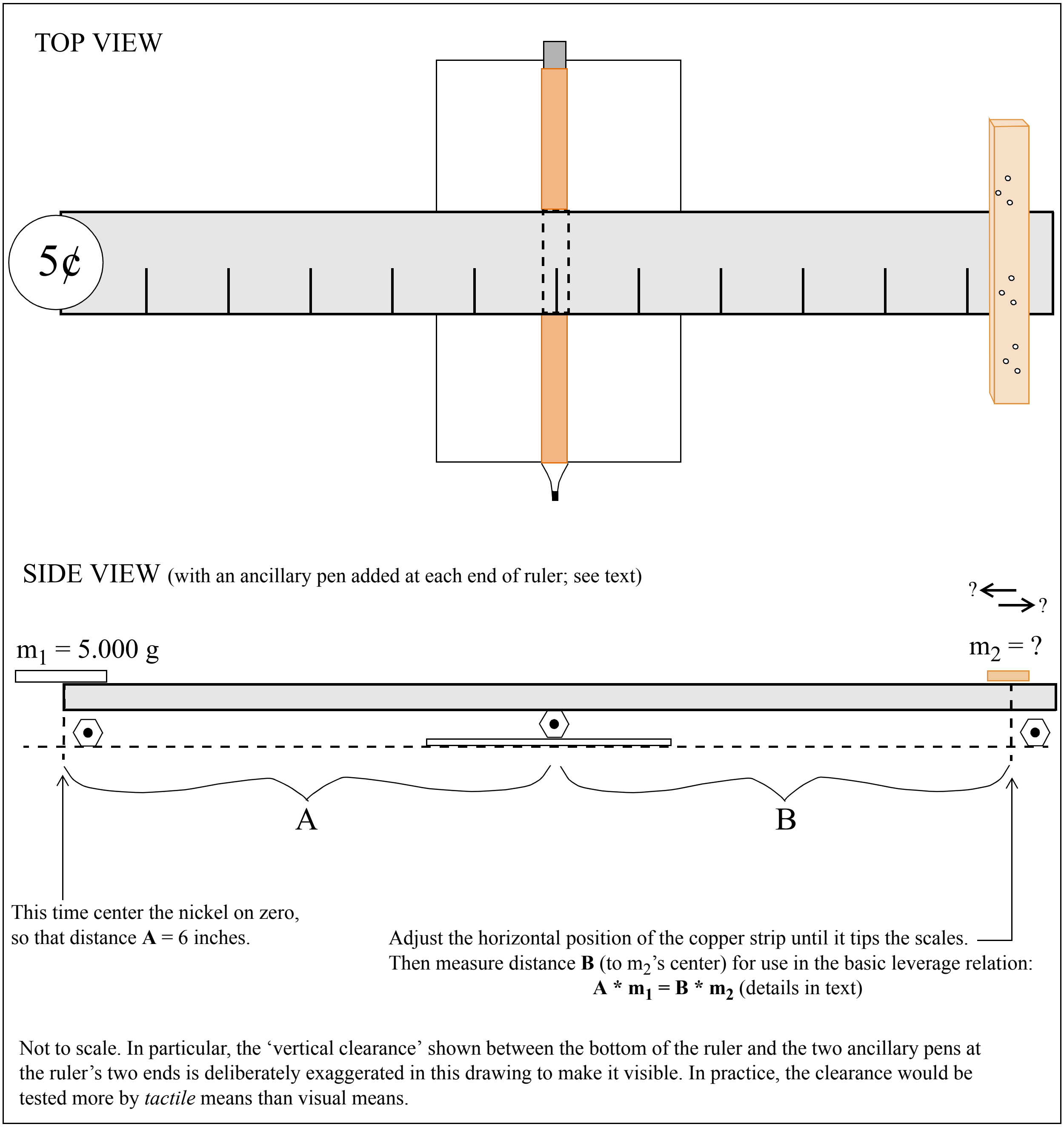


FIGURE 120: Leveraging Leverage as a Check On Your Reading

By trial and error, nudge the copper strip left and right until you've found the point where it (just barely) tips the scales. To have a better idea of where that point is exactly, do this:

Obtain two additional ballpoint pens (or pencils) identical to the one serving already as fulcrum. Try sliding each in turn under a far end of the ruler. Because of the 3 x 5 index card used as a base, sliding *both* pens *freely* underneath (shown in the **Figure 120** SIDE VIEW only) will be possible only when the scales have been balanced very finely, say on the order of 0.01 g to 0.02 g precision, which is comparable to that of a digital carat scale. (Technique: Discovery of the ideally balanced condition is done more by *tactile* means as by visual means: when you attempt to slide one of the two ancillary pens underneath, either there will be a slight friction or bump against the ruler or not.)

Measure distance B. Suppose the measurement for B is 5-9/16 inches, i.e., a point just to the east of the 11-1/2 inch mark used in **Figure 119**, expressed in this context with six inches subtracted from it: 11-9/16 inches minus 6 inches = 5-9/16 in or 5.5625 in.

The general leverage relationship for distances and masses is: $A * m_1 = B * m_2$

Distance A is assumed to be 6 inches. So, translating the general formula into specific terms for this case, we have: $6 \text{ in} * 5.000 \text{ g} = 5.5625 \text{ in} * m_2$.

Solving for m_2, by this method the weight of the copper strip would appear to be:

$$m_2 = (6 \text{ in} * 5 \text{ g}) / 5.5625 \text{ in} = 5.39 \text{ g}$$

Point of reference: By the method shown earlier in **Figure 119**, we concluded that the weight of the copper strip was about 5.42 g. Perhaps a safer number to report would have been the average of 5.42 g and 5.39 g, which we could round off to 5.4 g — a number less likely to raise the objection of 'too many significant figures' given the (actual or perceived) crudeness of the Sequin Scales. But in the ensuing calculation (the main event at last!), we will stick with (an implied value of) 5.42 g, for the sake of consistency with earlier sections.

Sample Calculation of Avogadro's Number from Electrolysis Data

Part 1: Atoms of Copper (see Figure 13 on page 66)

Total charge passed through the electrolysis circuit:

$q = I * t = 0.601 \text{ amp} * 1802 \text{ s} = 1083 \text{ coul}$

where 0.601 amp is the mean average of maybe a dozen readings and 1802 seconds is roughly 30 minutes, the duration of the run.

Note: one ampere = 1 coulomb/second, so 1 coul = one amp-second

Number of [notional!] electrons that passed through the electrolysis circuit:

q / charge-per-electron = 1083 coul /(1.602 x 10^{-19} coul/electron)
= 6.759 x 10^{21} electrons

Atoms of copper lost from the anode = copper ions gained in the solution
= number of electrons halved: 6.759 x 10^{21} electrons (1 Cu^{2+} / 2 electrons)
= 3.380 x 10^{21} Cu^{2+} ions gained in solution = 3.380 x 10^{21} Atoms of Copper

Part 2: Mass Lost

Mass lost at anode: combined weight of 3 toothpicks + 3 small sequins ≈ 0.360 g (This is a piece of pretend data, as detailed in the **Sequin Arithmetic Example** above. But all the other values cited are from the real data per Dr. Helmenstine's posting, although we've done extensive regrouping, relabeling, and reordering of the computational steps.)

Part 3: The Estimate

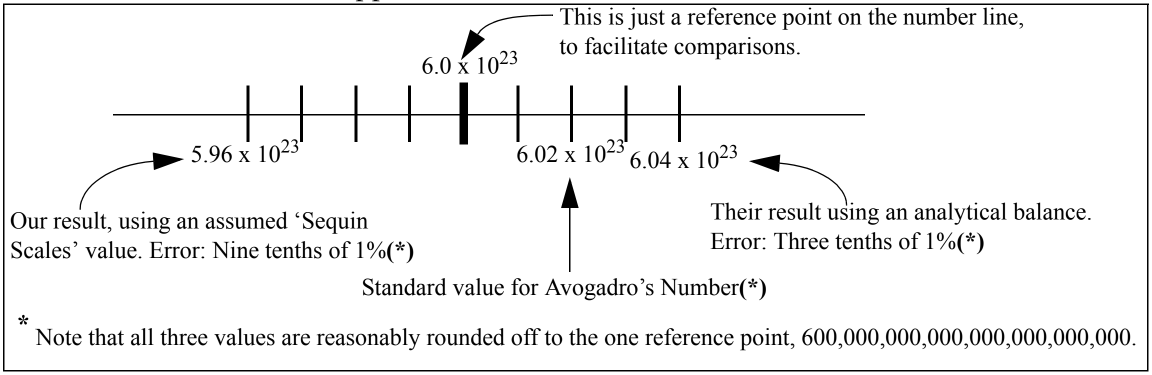
D = (B * C) / A (<== referring to Figures **12-13** on pages **65-66**)
D = 63.5 g * 3.380 x 10^{21} / 0.360 g = 5.96 x 10^{23} copper atoms per 1 whole GAM for copper

The specific result immediately above we then generalize to this:

5.96 x 10^{23} atoms per 1 GAM for *any* element

That's our estimate of N_A. (In passing, note that the so-called Avogadro's *number* is really a *ratio* of something-to-one, just as the 'number *pi*', so-called, is really a ratio of 3.14-to-one.)

And this is where it would appear on a number line:



Thus, with a modest 20 mg resolution (assuming 5 small sequins to one 100 mg toothpick), we came reasonably close to the famous number.

And even if we had limited our weights to whole toothpicks, and allowed *no* sequins at all (i.e., taking toothpicks as our 'significant figures'), we still would have obtained a reasonable result. For instance, in my own run of the experiment, I recorded an initial weight of 1 nickel + 7 toothpicks (= 5.700 g) and final weight of 1 nickel + 3 toothpicks (= 5.300 g), for a quick-and-dirty difference of 0.4 g. Plug 0.4 into the formulas above (in lieu of 0.360), and it gives you an estimated N_A of 7 x 10^{23}. For more perspective on this, see the list of values on page **69**.

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as fiction. Even his small cadre of admirers seem to miss the point, assuming he writes funny stories about robots. No, he writes *non*fiction about *human beings*. Always. In a sense, he is the *only* one who knows how to write about them.

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Comment: Professional mathematicians rip Wallace's rambling, jerky 'history', both for content and for its irritating style. My take: *If* Wallace could have been clear on his identity as an outsider, then it might have worked. But Wallace was confused about his identity, sometimes playing the outsider card (successfully, I would say), but more often talking down to the reader, after doing a quick vaudeville change into the purple fluttery robes of a Math Establishment Envoy. In *general*, I'll go along with the critics' assessment that Mr. Clegg's *Infinity* (same year, 2003) is more reliable and more readable. But neither should Wallace be discounted out of hand. I found some of his 'outsider' insights unique and valuable (quite in harmony with my own drubbing of the Mathematics Priesthood in Chapter V and Appendix C). Moreover, when we come to the very crux of the matter — Cantor's aleph-null ($\aleph_0$) and the power set — I find Wallace's exposition (p. 266-268) slightly more coherent than Clegg's attempt (pp. 184-185). That was a pleasant surprise.

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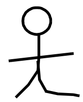
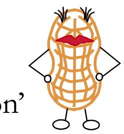
Woolf, Virgina. *Mrs. Dalloway* (Harcourt 1981, 1925) 197 p.

Wu, C.S. [Wu Jian-xiong] 吳健雄 *et al*. "Experimental test of parity conservation in beta decay," *Physical Review* 105 (1957) 1413.

Zee, A. *Fearful Symmetry: The Search for Beauty in Modern Physics* (1986) 322 p.

Zill, Dennis G. *A First Course in Differential Equations* (1979, 1993) 541 p.

Author’s Colophon

Here I will say a few words as myself  , no longer as ‘the proton’  of Chapters **III** through **VII**. I hope the device was mildly entertaining — my attempt to offer the viewpoint of a subatomic visitor. But the idea had its practical side, too: We humans are caught like flies on a paper called the macroscopic realm. Living here ‘in the middle’ is both a blessing and a curse. It is a blessing for allowing us to sit, as it were, at the 50-yard line from which vantage point one can peer both up and down the scale toward the VERY small and the VERY large.[173] It is a curse because it predisposes us to equate macroscopic with normal, macroscopic with real, macroscopic with alive, and so on. Speaking as ‘the proton’ allowed me to illuminate, for a moment, the weaknesses of that provincial way of thinking.

My talking proton device had a pedagogical aim as well: Out of habit, many textbook authors still dispose of the proton as a plain sphere, failing to mention the variants shown in **Figure 21** on page **78**. In addition, we have the business about

173. But the neat analogy of the 50-yard line (in a 100-yard stadium) soon makes us suspicious: Surely chance will have landed us at something more like the 40- or 60-yard line, not smack on the center-point of God’s great ruler? Circa 2010, on one end of the spectrum we have the radius of the cosmos estimated at 10^{28} cm and the radius of a quark estimated at 10^{-16} cm. In the rough and ready manner of a physicist, one says that we humans are ‘one-centimeter’ creatures (or even zero-centimeter creatures, for that matter; a spooky thought!) Then, using absolute values and a simple proportion, we could try refining our estimated stadium position as follows: $x = (16 * 100) / (28 + 16) = 36$-yard line. Or, doing it with more style and accuracy, one could say: “The universe is about as much larger than the whole solar system as man is larger than the proton”; Kenneth Ford, p. 33. (He wrote that in 1963, when 10^{28} cm and 10^{-14} cm were the accepted points of reference, rather than 10^{28} cm and 10^{-16} cm, respectively. This makes no material difference in the rough picture that Ford draws for us, though. That’s his elegant version of our ‘36-yard line’.) This business of being skewed left is more than just a few digits on an exponent; it has implications for how we may react with or ‘commune’ with objects at the atomic level; see the Koch Machine and Twenty Degrees of Separation on page **254**.

'neutron decay' versus 'proton birth' on page **100**: that passage started out life as a footnote to help the lay reader understand an annoying quirk of physics-speak; later I expanded it into a short essay covering 'proton eternity' and proton awareness for everyday living, so to say. Generally, I felt the need for something like an extraterrestrial(174) visitor (the proton) to make various observations that would be judged impolite or unthinkable in a normal context — where the whole mathematics culture is off-limits, for example.

Admittedly, the Copernicanesque inversion that I harp on (by multiple references back to **Figure 24** on page **82**) is a bit much. If it strikes the reader as being dangerously close to the lunatic fringe, I can't complain since it strikes me too as *outré* — sometimes. But let's not forget its source of inspiration: a perfectly sane question posed by Schrödinger: Why are we so big? (My paraphrase; for his actual words, see the section that begins on page **18** above.) For him, the question holds engaging technical challenges, inviting one to work the answer out in terms of biology and physics. For me, the question leads in another direction, to a Zen glimpse of the world inverted and seen 'correctly' for the first time ever: How normal an atom is, how absurdly huge and slow we are. Then, as if the sentence in Schrödinger weren't electrifying enough, along come Dawkins and Wong with their talking Taq who has his own 'independent' rationale for turning our world on its head and identifying humans as a mere fancy froth (see page **81** above). Although Wong's idea is worked out on a different scale, it is still essentially the same as mine: There is something, dramatically smaller than humans, that seems so fundamental and real and eternal that it casts doubt on human 'importance' and legitimacy. Together, these two closely related visions become compelling, and never mind how crazy they might sound:
(a) Schrödinger (when read 'correctly' with emphasis on the epiphany about atoms)
(b) Dawkins and Wong (read directly, as a wake-up call regarding the Eternal Bacterium)

For me, the inescapable message in each case is: Humans are simply too big to be real. (And while this viewpoint doesn't quite jibe with Buddhism or Hinduism, it

174. By the way, my own viewpoint is almost that remote, being that of a sinologist: Ph.D. in Chinese language and linguistics, Harvard University, 1975. (My three years of chemistry and calculus came much later, via course work at Century College and University of Minnesota, 2003-2007.)

certainly is not incompatible with those philosophies. Either of them could easily accommodate it.)

If I'm not able to persuade the reader of my overall philosophy (with atoms at the center), I hope at least to stimulate new kinds of thinking about chemistry in a less grandiose vein: Washed up on the shores of time, looking back on the romantic interests of a lifetime, one might come to a gloomy conclusion: "Now they are faded memories. And I suppose all that loving and lusting was just chemistry, anyway." Meaning: "None of it was real; it was all an illusion generated by our hormones and pheromones. And now it's gone. What a bleak final act for the play." But this is easily turned around to a chemico-centric viewpoint as follows: "Of course it was chemistry, since EVERYTHING is chemistry!" There follows, in this case, only a wistful rumination, not a black depression. (Thinking of Dr. Freud and his advocacy for 'normal misery' as distinct from self-destructive neurosis.)

The reason for this colophon: There was a price to pay for the 'talking proton' device used in Chapters **III -VII**: Several topics originally planned for the main body of the text simply couldn't be cast in the proton's voice. They would not have been plausible concerns of a subatomic visitor, bemused by bipeds. Hence their migration down into an appendix or into this colophon.

For example, there is a thread of social criticism, prominent in **Appendix G: Time's End (1967) and Garbage World (1992)**. Note, however, that this thread is not about 'changing the world'. People of my generation saw and felt the vibe of flower children transforming the planet — but there was *no* such transformation, really; that's the point. Consequently, we have a hard time believing that humankind will ever change deeply all at once; only by glacially slow increments, if ever. In this book, the social criticism is only for clarifying one's situation, not sounding the trumpets. The book's agenda is not social reform but the development of coping skills: it's a self-help book, if you like, for coming to terms with one's (counterfeit) existence at the macroscopic scale, where Garbage World is just one of several challenges, along with the implications of **Figure 24**b on page **82**.

Here is a related loose end to tie up: Why, in the title, do I allude specifically to Copernicus? Do I aspire to an Intellectual Revolution? I am trying to coin yet another journalistic decade name (as listed in **Figure 27** on page **93**)? No, I fall back on the name Copernicus as a convenient shorthand, that's all, to sidestep the inelegance of, say, 'a major paradigm shift'. And there is no intent to start a

Revolution per se. Rather, as with the late quartets of Beethoven, the intent is to get down on paper an idea that will eventually have its day and might even seem inevitable in retrospect. And when the 'shift' does come, it should involve nothing disruptive to society at large, only some private psychological pain, one person at a time. Pain, but also relief, as outlined in the next paragraph, which might have been entitled, 'On the enigma of caring-not-caring for humanity'.

The dominant message of this book might be framed as follows: "Atoms are the Blood and the Life, while we are mere machines, at best; phantoms, at worst." But my impetus for trying to articulate and expand on that message for 500 pages is (paradoxically, one might say) a desire to help my fellow humans find the way forward, find a way to come to terms with the modern world. With Mother Nature given credit where credit is due (even for horrific things such as spiders, scorpions, supermachines and Garbage World), one is relieved of having to fret over, "Where did humankind go wrong?" or "Why does God permit such Evil?" All those kinds of question.

In thinking about the contradiction that I've saddled myself with, I am reminded of a remark V.S. Naipaul makes about Indian writers when they take a Western form and have "some trouble with it" (quoted in Jussawalla, p. 43). In all of R.K. Narayan's books, Naipaul finds one message: that the human condition is not important, since all existence is a delusion, a dream.[175] Thus, Naipaul regards it an 'oddity' that Narayan can write novels about people as though human life matters, while holding to that 'deeper pessimistic rejection of a concern with men'. Those acquainted with Naipaul as a *British* author, in a direct line of descent from Conrad, the master, will realize how far outside the circle of all such *Indian* novelists Naipaul would place himself (his own distant Indic roots notwithstanding). At least as of 1977, the date of the transcribed conversation, this would have been his stance. And in general I am sympathetic to Naipaul's acerbic, eagle-eyed view of the world. But in this particular case, he seems so busy showing up his Indic cousin as a kind of foolish stray sheep whose exotic myopia causes him to "[not] quite understand what the novel is for" that Naipaul deprives himself of a valuable insight. (Given Naipaul's level of intelligence, this deprivation may be willful rather than obtuse, but still we find it irksome, his dismissal out of hand of a whole subcontinent and all their 'wrongheaded' novels.) Anyway, the point is this: R.K. Narayan's 'oddity' is

175. See R.K. Narayan, *The Vendor of Sweets*, pp. 138 and 176, for example.

exactly my own oddity that I've pursued with both eyes open. It's a paradox, yes, but hardly a mistake.

Late in the project, I learned the name Lucretius when an editor at alliviy.net expressed surprise that I had made no reference to the epic, *On The Nature of the Universe*. Acknowledging the lapse, I retrofitted references to Lucretius on pages **18**, **98** and **110**, to paper over my ignorance. It occurs to me now, in the wake of the Naipaul/Narayan discussion immediately above, that there is more than a passing resemblance between the task Lucretius undertook and my own — not so much on the technical or philosophical side (where my kind of 'atomism' is more radical than his) but on the ethical side: To some critics, his epic is a (tedious) retrospective on Greek atomism, but a closer reading shows that his impetus is ethics, not the promotion of an atomistic philosophy per se: It's all in the cause of *helping his fellow Romans* make sense of their lives in a time of extreme turmoil and cynicism. (See the Introduction by John Godwin, especially pp. ix, xxvii and xxviii; and note that Lucretius was a contemporary of Cicero, famous for "O tempora! O mores!") Similarly, while my motive at one level may be to praise the chemistry ethos or to critique the mathematics culture, from another perspective the ultimate aim of all my analyses is philosophical and ethical, i.e., *altruistic* — all the mean-sounding remarks about 'bipeds' notwithstanding.

"But how does *Bach* wind up in these pages?" one may ask. For months this troubled me, too. Enough to consider moving that material out of Chapter **VII** and down into a new appendix. Then one day I remembered Hofstadter's *Gödel, Escher, Bach*. If Bach had a place in that book, why not here, I decided. Note that the primary topic of the Epilogue (Chapter **VII**) is the soul, with music as *one* possible window upon its domain; so there's a thread of logic there, at least. (Another window, close at hand to many of us, is the business meeting: Every now and then I'm able to look around the table during such a meeting and see a 'circle of souls' instead of 'people'. Try it sometime for yourself. You might have an epiphany.) But why introduce the Bach Arithmetic Paradox (page **197**) in the Proton's voice, specifically? Because I've tried out the idea on some very intelligent associates (and over a very long period, dating back to my first counterpoint exercises at Los Angeles City College in 1961!), only to be met with blank looks of incomprehension. So the idea truly is alien, it seems, more suited to the Proton's voice than my own.

Another loose end: In **Chapter III: Letter from a Proton**, by applying such broad generalizations as TAINTED vs. PURE (page **98**), was I not setting myself up for the embarrassment of glaring exceptions? Yes. For instance, in **Understanding Molar Mass as it relates to Avogadro, Cannizzaro, and Loschmidt** on page **61**f (which was a necessary detour from our experiment called **Avogadro's Number via Electrolysis**, page **56**f) we find ourselves staring at some warts on the very nose of chemistry — specifically, at a certain brand of vague quasi-circularity that I tend to associate with physics and math; but there it is, raising its ugly head in chemistry, too, rather thwarting one's notion that chemistry is the PURE one. We had better say chemistry is *relatively* PURE on balance, but certainly not above reproach. In this connection, see also **Appendix I: Myths & Realities of Electrochemical 'Flow'** where I document another peccadillo.

Whence the PATHOLOGICAL, dangling like a miscarried fetus at the very bottom of **Figure 29** on page **95**? It was an article by the astrophysicist Bekenstein (2003) that served as the irritant grain of sand that induced me to write a book-length manuscript on information theory during the period 2003-2005. But the more I studied academic information theory (as tested against my own 20 years' experience as a database architect and programmer), the more outlandish and *unworthy* of a book it seemed. In the Bekenstein article, it was p. 1 in particular that vexed me. To this day, I don't know whether to laugh or cry when I look at that page, with its chatty, inane question, "How much information does it take to describe a whole universe?" First, the topic has to be "How much data..." not "How much information..." Why? Because when pressed even an astrophysicist will admit he has no clue what the word 'information' means — only an unaccountable passion for talking about 'information' whenever it isn't there and especially if he believes it is hiding from him inside a black hole.(176) But even if stated correctly, using the modest word *data* in lieu of *information*, still it would be an impudent question. Moreover, the article never really addresses the primary topic (how much of whatever is needed to *describe* such-and-such) as promised; instead, it focuses on an implicit subtopic, data storage, singing the praises of chip miniaturization, and thus ignoring the elephant on the table: "How much [data] would it take...?" (For a

176. There are signs that the Mad Hatter's Tea Party may be ending: One takes heart from a 6/21/07 news item indicating that scientists at Case Western Reserve University have begun to question the very premise of a black hole itself. Source: http://sciencenow.sciencemag.org/cgi/content/full/2007/621, "No More Black Holes?"

glimpse into the patent idiocy of such an idea, recall the reference on page 189 about describing one *raindrop*, never mind "a whole universe"!)

Next, while still on page 1 of his article, Bekenstein takes us on a Blitzkrieg tour of information theory and thermodynamics, supposedly for the purpose of defining the technical terms 'bit' and 'entropy'. Granted, no-one could say much about those two subjects if induced (by the editor or by himself) to fit his remarks onto a single page. Still, I find irksome the particular *way* they attempted and so bungled the feat: Before seeing the byline, one would bet his last dollar that such garbage must have been written by a brash young ignoramus, not by the Grand Old Man of astrophysics himself. Welcome to the new *Scientific American*.

Speaking of astrophysics, I should now follow up on my promise (under the heading FOOLS RUSH IN... on page 96) to address the Big Bang Nucleosynthesis argument for studying cosmology. From the Big Bang Nucleosynthesis standpoint, one would pursue cosmology precisely *because* one had adopted the atom-centric view that I advocate (or some variation on it). First, a quick review: The notion of the Big Bang was put forth by George Gamow in 1946, at which time he also proposed that all 92 elements had been synthesized during the first few minutes of the Big Bang. The current, heavily revised theory is that only hydrogen, helium, lithium, and beryllium were formed in the Big Bang, which soon lost the ultra-high temperature needed to continue nucleosynthesis; only after star 'furnaces' formed did the synthesis resume, millions of years later, at which point the heavier atoms, carbon through uranium, were created, chiefly in the death throes of stars (Singh, p. 389). The term 'stellar nucleosynthesis' was introduced to distinguish the latter process. To dramatize it, Carl Sagan once said:

> "If you want to make an apple pie from scratch..."
> [dramatic pause, during which he leans down by an open oven door and the camera zooms in to linger on his trademark grin] "...you must first create the universe."(177)

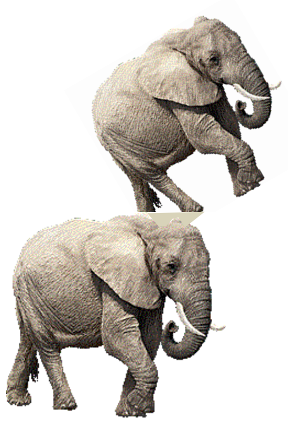
That's an admittedly enchanting and memorable vignette, with its undeniable truth that even apple pie is a kind of stardust. But for someone with limited time (viz., any of us bipeds, who live a very short time *and* at a glacial pace), this flattering stardust dream is also a distraction, a luxury one can ill afford.

Here is an admittedly abstract analogy: Suppose you are a mathematician

177. Cosmos, PBS TV, November 23, 1980. [source: www.imdb.com/name/...]

investigating the nature of two transcendental numbers, say e and π. (As noted in **Chapter V**, I personally don't buy the religious orthodoxy that places e and π on twin pedestals, but let's forget my bias for the moment and accept the popular viewpoint that these transcendentals are the Holy Grail.) A *valid* property of π would be its transcendental nature. An indirect, *pseudo*-property of π might be the specific algorithm and chip set in a computer that helped you find its 400th decimal place yesterday. (I.e., there are countless roads *to* that 400th decimal but only the one correct value for the 400th decimal place itself.) In this analogy, then, the transcendental numbers would be the atoms, and someone's hypothetical obsession with how the innards of a 68xxx chip can generate their digits would be cosmology. True, someone somewhere had better be the expert on the algorithm and someone else had better be the expert on how that chip was designed, but generally, in most contexts, the mathematician would not want to get lost trying to micromanage all those computer science details that went into the design and manufacture of the computer. He/she has better things to contemplate, such as: What does it *mean* if you raise e to the π^{th} power, or raise π to the e^{th} power?

According to current Big Bang theory, atoms were created in such-and-such a way; but the salient point is that atoms *can* exist and *will* exist given the proper context, nor will something *different* get cooked up in the stellar furnace. Once you comprehend that all roads lead to the atom as the object of interest, why spend time with campfire stories about the composition of the gravel on some hypothetical far distant segment of the road to which one can never travel for verification? It may be that 'back to the stars' is where you yearn to travel, figuratively; but it's basic chemistry that will take you there, not the campfire stories of cosmology.



Now it is time to address two elephants, elephants who are a sibling pair, stacked acrobat-wise on the dining-room table, let's say.

Elephant One:

Half of this volume is occupied by a Theory of Information.

Why allow it?

Elephant Two:

This volume tries to cover 'too much'. Isn't that sort of grand effort passé, *verboten*, to be written only on an asylum wall?

In Defense of Elephant One:

In 2003, after reading the *Scientific American* article mentioned earlier, as I wrestled with the chimera of 'information entropy', I developed an interest in (real) entropy, and thus in (real) thermodynamics, which led me by a back door to chemistry (at the same time that my daughter was leading me to chemistry by the front door, as recounted below). Subsequently, during the period 2003-2005, even as I was *writing* a book on 'information theory' (the materials that evolved later into Chapter **VI** plus appendices B, D and E of this volume), I was *thinking* already about chemistry and the book that I would write from an entirely different angle during the period 2006-2010 (namely, all the other parts of the present volume). The crux of the matter: There is an intimate, organic, continuous linkage between the (nearly) disowned mother-book and its child-book on chemistry, with no convenient place to snip the umbilical cord. Thus (with the imagery of mother and womb now inverted) appears a full-fledged treatise on Theory of Information tucked away inside a volume devoted to chemistry (and devoted likewise to the debunking of both 'Information Theory' and 'information' itself, as outdated cultural artifacts).

Beyond the organic linkage that resists severing, there is a 'public service' aspect. At my age one is inclined to cast false modesty to the winds and say it straight: I am the *right one* for the job of writing a (true) Theory of Information. I have the chops for it. Therefore, from a certain perspective, I owe it to someone out there not to abandon the project — never mind that I have serious qualms about the bus itself, even if I'm the one driving the bus for a time. That 'someone out there' would be the true believer, determined to keep seeking the Holy Grail of Information, come what may. Clearly, several or many such 'someones' exist.

This odd situation is not without precedent. Over the years, there have been many occasions when Bob Dylan was asked by the media to explain himself generally or to redeem himself specifically in the eyes of an alienated faction of his public (after he forsook 'nice' acoustic folk for 'mean' electric rock; after he forsook 'smart' leftist rock for 'dumb' right-wing Christian; and so on). How could he?! Here's how. Most memorably, in looking back on the folk phase, he offered perspective to this effect:

> I never actually said I *believed* in all that.
> It was just a *scene* that I wanted to be in.
> And I knew I could do it *better* than anyone else.

My paraphrase of certain remarks attributed to him in the film *I'm Not There*. The film is a liberally mixed cocktail of fact and fiction, yes; but those remarks sound dead-on, their subtext being: "So let's stop talking about what or whom I might have abandoned or betrayed. That's a non sequitur."

There is a logical objection to consider quickly in passing: This book is, itself, a typical product of the Information Age, and in my opinion, at least, it contains unusual 'information' that can benefit the hypothetical 'someone' mentioned above. From that admission, it might seem that I am talking out of both sides of my mouth. However, in this context I am using the term 'information' only as it pertains to the earthling's narrow view of things. Meanwhile, like it or not, there *is* a cosmic angle on 'information' and it is from that perspective that I've spent a considerable effort debunking the phrase 'Information Age' in **Chapter VI: The Riddle of Information 'Glurth' (in an Information Age)**, because the earthling notion of 'information' is so grotesquely wrongheaded and deficient.

In Defense of Elephant Two:

Too 'ambitious'? As explained immediately above, I started out with a very narrow goal: To refute a few pages of nonsense written by Beckenstein for a magazine. But then came my 11,000-word refutation of Norbert Wiener (now Appendix D), and a 32,000-word treatise of my own, showing what the first true Theory of Information might look like if the nascent field were ever approached seriously (now Appendix E). And still the investigations grew in many directions, quite naturally and organically, the short explanation being that chemistry is the central science, thus connected to 'everything'.

There is an Escherian twist at play, too, joining the two elephants: Even though 'information theory' is itself a bogus field, when you try to study it seriously you are led soon enough to thermodynamics, a respectable field, ensconced on the border between chemistry and physics. By that logic, Appendix B belongs in this volume, since it provides an overview of thermodynamics. However, all the writing and lavish illustrations contained *in* that appendix started out life as part of the earlier project, the (nearly) abandoned book about 'information theory'.

But enough fooling around. Let's get to the point: The world still needs thinkers who try to wrestle 'everything'. The conventional wisdom is that those days are long gone. Because of hyper specialization (there are book-length treatises on each of several organometallic compound, e.g.), no one person can claim to have a panoramic view. It is quite literally impossible. Here's what I say to that impossibility: A few of us crazies must keep trying anyway. Otherwise, humanity has transformed itself recently from the species that thinks into just another insect population. If everyone is toiling away at his/her specialty, for Big Science or in the genomics lab, and no one dares to lift her head and think anymore about the intellectual landscape, we are in fact an insect society adrift with no rudder, a cloud of genius gnats flying in formation, with nowhere to go. So I won't apologize, only acknowledge that what I've attempted is unfashionable and slightly daft.

Uncle Tungsten:

In the introductory part of Chapter **IV**, I justify the long detour into physics in terms of the overlap between physics and chemistry. True enough. But there was also a personal reason for putting physics in the limelight: Between age 6 and age 17, I found myself in nine different rented apartments in Berkeley, with my nomadic single mom. There was one period when we actually became acquainted with one of our many landladies and landlords: That would have been the years 1953-1955 when I was age 10-11, and our address was 2335 Russell Street, if memory serves. That was Frank Crawford's house with part of the upstairs rented out to us. For that brief period I had, in effect, a father. He taught me how to ride a bicycle, how to find the Pole Star, and how to sing "Row Row Row Your Boat" as a two- or three-part round. But my most vivid memories of him revolve around his efforts to interest me in science. These efforts included everything from instruction in algebra (since it was not taught to sixth graders in those days) and a homemade cloud chamber(178) and radio-receiver breadboard kits for Christmas to paperbacks by George Gamow and guided tours of the Bevatron just then under construction in the Berkeley Hills, at the very dawn of the whole bubble-chamber epoch (cf. Galison p. 346 and Crease p. 274).

For more about Frank Crawford, see the lambda decay reference on page **140**. Now that I'm aware of the context, it is natural for me to wonder if my erstwhile landlord would have been revulsed or excited by the general *idea* of a parity violation, as he did his lambda experiment so close on the heels of Madame Wu and Leon Lederman. The person I remember from 1955 had a temperament very close to that of Richard Feynman (if you take away the competitive edge and the flashiness, leaving only the unquenchable passion for teaching, sharing). Recall that the only one quoted as being 'very excited' by the prospect of parity violation, i.e., by the possible *downfall* of parity, was Richard Feynman. Frank Crawford's reaction would

178. The subatomic world seems so vivid and real to me in large part thanks to this early experience of seeing cosmic ray tracks in the cloud chamber he constructed on our living room floor. An important detail: We were looking at actual cosmic rays; otherwise, what kind of 'experience' could it have been? Yet these days 90 percent of the cloud chamber postings on the internet assume that one will buy a needle with radioactive lead on the tip as one's 'alpha source' to force vapor trails to appear. Is it really *that* difficult to build a cloud chamber good enough to detect cosmic rays? Thinking that perhaps it is, I cite the cloud chamber from a negative perspective on page **32**. But there is another possible explanation for the knee-jerk inclusion of an 'alpha source' in the setup: Could this be yet another aspect of the dumbplexity malady? (See page **7**.) In other words, why bother waiting patiently for real cosmic rays when you can have instant gratification by forcing a bunch of vapor trails on demand, from a speck of radioactive lead on the tip of a needle? One could make a legalistic argument that a local alpha particle is 'just as real as a cosmic ray'. But that would miss the point — the romance and drama of the actual cloud chamber experience.

surely have been similar, pleasantly out of step with the party line: excitement, not revulsion.

Fast forward from 1955 to 1961: Having no clue about the historical significance of the procedure, I dutifully heat some reddish-orange powder in a test tube, because this is part of the curriculum of the chemistry class at Berkeley High School that year. It is a class that I dread for some reason — especially that word 'Avogadro' and the huge number it stands for, which seems only grotesque, arbitrary, absurd, to my delicate teenage 'sensibility' (which I recognize in retrospect as garden-variety Teenage Brain Chemistry syndrome.)

The grade I received was probably a C, possibly a charitable B–, although an F might have been more like it. Still, the simplicity and beauty of *that* experiment (= the HgO experiment that appears on page **76** above) *did* stay with me for years — fondly remembered for decades, in fact, as "the alchemical magic of extracting mercury from powdered cinnabar [not!]"(179) — and it planted the seed for later interest. Consequently, when my sixteen-year old, Alison, said to me in 2003, "You really should take the chemistry course over at Century College," something clicked. And that set the stage for Frank Crawford's enthusiasm to have its proper effect on me, after a 50-year hiatus: At age 60 I learned calculus and became a chemistry major, and recognized Dr. Crawford as having been my own Uncle Tungsten.(180)

179. For years, I treasured some of that reddish-orange powder in a vial, alchemist style, supposing that I had my own purloined supply of 'cinnabar'. Now I realize that cinnabar designates HgS, the red of Chinese lacquer, not HgO, which is known simply as mercuric oxide. But regarding the color of the two substances, there exists some general confusion not of my making: In certain books one encounters the flat statement that HgS is red while HgO is yellow-orange. Dig deeper, though, and you find confirmed your suspicion that HgO exists in both an orange form *and* a red form. After all, Lavoisier himself makes a perfectly clear reference to "red specks of mercury calx" (HgO) appearing on the surface of his liquid mercury (assuming the translators from French haven't all perversely conspired to write 'red' instead of 'yellow-orange'). And certainly the powder they provided to us at Berkeley High School in 1961 was an extraordinarily beautiful shade of reddish-orange, nothing like 'yellow-orange'. *Definitely reddish-orange*, *Definitely reddish-orange*, one can imagine Dustin Hoffman chanting in the film, *Rain Man*, as he rocks (or rather, 'does rocking', to say it the Asperger way). And yes, it *is* a comfort.

180. See Oliver Sacks, *Uncle Tungsten: Memories of a Chemical Boyhood* (2001).

A glimpse of the future, or wishful thinking?

In some remote future, Freshman Chemistry will supplant (or at least join) Freshman English as one of the crucial first steps in *anyone's* education. Or not: There is no law that says we won't be as benighted 500 years from now as we are today, but in imagining Freshman Chemistry as the new cornerstone of all education I am exercising my right to be cautiously optimistic.

Do I mean that in a technocracy, our educators should gradually elevate the status of the sciences relative to the humanities, since the latter have only limited value in a technocracy? No. A drift in that direction may indeed be under way already, requiring only another few decades to be confirmed. By contrast, the change I envision would be more of a tectonic shift in the educational landscape, requiring perhaps three or four centuries of preparation before it could even be attempted without a chorus of sneers and laughter. On the path that I hope for, college educators would one day recognize basic chemistry as the crown jewel of their system, yes, but in doing so they would *not* adulate 'science-and-technology', rather warn against that mealy-mouthed term as a co-opting tool of Industry. Far from being an affront to the humanities, the Freshman Chemistry class I hope for would count as a new and better *kind* of humanities class.

Acknowledgements

My family consists of two daughters, one on the east coast, the other on the west coast. Alison I've mentioned already in the Author's Colophon immediately above, in connection with my own Uncle Tungsten, the physicist Frank S. Crawford. Tangee I'll thank now for the telephone conversations, my one thread of connection to the outside world while focused for nearly a decade on this work.

I am grateful to coworker Peter Stucki for introducing me to the writings of Stanislaw Lem and Jorge Borges; for better or worse, Mr. Stucki is also the immediate 'cause' of this volume, which began with my reaction (less than gruntled) to an article he showed me in *Scientific American* (Bekenstein 2003). Many thanks to Paul Krause (another coworker at Medtronic, Inc.) for offering suggestions on a very early manuscript — materials which evolved into Chapter **VI** plus Appendices B, D, and E of the current volume. Thank you to yet another coworker, Fred Wahlquist, for pointing out Hofstadter's Foreword to Doris Schattschneider's book on M.C. Escher (whence 'sewing-machine Bach' on page **311** above). Thank you to yet another Medtronic coworker, Scott Edinger, for "The gotcha is..." (his trademark phrase) which I employ as the theme for all the variations in Appendix B.

For the proverbial 'encouraging word' I am indebted to Jane Mackay (at janemac.net) in connection with an early round of proofing for Chapter **III**. Her kind remark about that chapter gave me the strength to finish updating the four ensuing chapters that were not yet fully and consistently recast in the Proton's voice.

More recently, thanks are due to the editors at allivy.net for proofing of the final manuscript (plus copy-editing in Chapter **I**; elsewhere the writing remains ragged, I realize).

The important insight about 'science and technology' on page **27** (echoed on page **482**) I owe entirely to a remark of Azar Nafisi that I chanced to hear once on the radio as she expounded her philosophy.

Graphics credits: The foundational picture that becomes a fractional mole on page **49** is a royalty-free image from animal.x0.com; the elephant image(s) on page **477** are likewise from animal.x0.com. (The cover and the illustrations numbered 1 through 120 I home-brewed using Adobe FrameMaker, a generalized authoring tool whose graphics capabilities are a notch or two below Adobe Illustrator. As mentioned on page **78**, my **Figure 21** is based on one by Gerald Miller. The tomatoes in **Figure 10** are from Google Images. The source for part of **Figure 22** is discussed in footnote **57**, page **122**.)

In imitation of Danchin (see page **15** above), I will now attempt a summing up: This book is pessimistic: it argues that we are glorified *viruses* duped by our own lust for dumbplexity into believing the triple illusion of Life, Information and Progress. This book is optimistic: it shows that Brahman has graced us with methods of communion with the *atom*, the one genuine life-form.

Conal Boyce
St. Paul
June 2010

On Punctuation Conventions: There is a popular punctuation style in which one avoids single-quotes, letting double-quotes do the work for all situations, with period dots and commas placed inside the closing quote. I adopt the roughly ‘opposite’ convention favored by linguists and by others who deal with technical subjects: I use single-quotes as my mainstay, and with the period or comma, if any, placed *outside* the closing quote mark. Why? Essentially for the same reason a semicolon or colon is left outside the closing quote in whatever convention: Because one wishes not to be made ill by the sight of content and punctuation obscenely commingling! Meanwhile, double-quotes I reserve for special situations, e.g., to mark a complete quoted utterance or passage, or to flag a mere notion or a some other unusual usage. A borderline example occurs on page **273**, where I place the term ‘richness’ in single quotes. This indicates that I am in the process of defining it as a technical term (even though it still carries *some* overtones that might suggest a more impressionistic flavor, as though I had placed it in double-quotes). Also, I favor the technical writers’ convention whereby every member of a series is marked by an explicit comma, even *if* it happens to be followed by the word ‘and’: like “...j, k, x, and y”. (The point here is to avoid even the shadow of a doubt about ‘x and y’ versus ‘x’ and ‘y’, i.e., the question of whether they are being regarded as separate entities or as a single, combined entity.)

Errata:
Comments/corrections welcome at conalboyce@gmail.com. My intention is to post revised pdf versions of the book from time to time at conalboyce.com.

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