

THE UNIVERSE AT LARGE

C-to-Z Physics

by VIRGINIA TRIMBLE

In which we explore 24 issues to which some part of physics other than B may be relevant. Each item includes a puzzle or thought question. Some of these are meant to be taken seriously, if not as physics, then perhaps as sociology.




C IS FOR CLUSTER. You may be thinking of a few atoms or molecules, clinging perilously together, and the question of how many does it take before they belong in *Physical Review B* rather than *A*. Somebody once told me the answer to this is 6–10. I, however, am thinking of clusters of stars. The physics is plain old Newtonian gravity, and the computer programs that imitate clusters are called *N*-body simulations, at least by their friends. You may or may not be surprised to hear that clusters of point masses reveal “emergent properties” that could not have been guessed from integrations of 2- or 3-body systems. These get names like gravithermal oscillations, dynamical friction, and violent relaxation. Curiously, these cluster properties also start to show up when you have 6–10 particles. What, if anything, does this coincidence mean?



D IS FOR DNA. We all have heard the story of how X-ray crystallography provided a critical hint leading to the double helix structure. That is, the physics came at the beginning. Now here they are sequencing the genome by chemical methods and occasionally deducing what a particular sequence does by the very biological method of seeing what happens to an organism when one of the sequences is changed or deleted. This feels backwards to closet reductionists, and we expect some day a second epoch of triumphant physics, when it will become possible to work forward again from some particular molecular bond to some particular malady or mercy. Any takers for a bet on when this might happen?



E IS FOR EARTHQUAKE FORECASTING. And a sad story it is. When first I taught introductory geophysics, in the warm afterglow of the rapid conquest by mantle convection, seafloor spreading, and plate tectonics, there were a whole flock of warning signs. These included uplift of land around faults, changes in the rate of microseisms and in their *p*-wave velocities, radon in wells, changes in the electrical conductivity and helium content of soils, and even animal behavior, lightning flashes, and what my grandmother used to call “earthquake weather”. And they all made sense, in terms of laboratory behavior of stressed granite and expectations for quakes occurring along different kinds of faults. The



general idea is that the stressed rock swells, lifting up the land and leaving empty pores that slow the p -waves and make the rock harder to break. Then ground water flows into the pores, concentrations of dissolved gases rise, the waves speed up again, the rock softens and begins to slip, and . . . “drop” as the teacher used to shout in earthquake drills in the Los Angeles public schools. The lightning and distressed dogs were effects of piezoelectricity (also a laboratory phenomenon). There was even a success story, in the form of a five-hour warning of a February 1975 quake in Haicheng (NE China) that permitted evacuation and significant saving of lives.

Probably much of this is still true, but it has proven so nearly useless in practical contexts that even the most optimistic government agency (a Japanese one) has pretty much stopped funding projects in earthquake prediction per se. Is there any plausible explanation of Gram's earthquake weather? The only information I have is that she was right about Tehachapi (1952). But then she also bought stock in Minute Maid frozen orange juice shortly before every American discovered that it was absolutely essential to drink the stuff for breakfast every morning, or all your teeth would fall out.



IS FOR FRACTAL. Some things are (coast lines, so they say) and some are not (spider webs). The astronomical community has, of late, expended considerable sums in page charges arguing whether the distribution of galaxies, clusters, and voids in the Universe is best described as a fractal with dimension D about 1.2. The alternative is homogeneity on sufficiently large scales, and the problem has been that surveys did not envelop quite enough space to tell the difference. The Sloan Digital Sky Survey (and other projects) will soon remedy this. A more serious problem will then stand out more starkly: how can the Universe have made the matter be as clumpy as it is while leaving the microwave background radiation as smooth as it is? This issue of the formation of large-scale structure is arguably the most important unsolved problem in modern astrophysics. Which

topology (meatballs, honeycombs, sponges, or something else) gravitational processes prefer to produce is one aspect of it. Meanwhile, if you can't help with the key question, did you know that mandelbrot is also edible? (This is the sort of culturally-biased item that should never appear on an IQ test.)



IS FOR GLOBAL WARMING. A paper in the March 15, 1999, issue of *Geophysical Research Letters* announced that 1998 had been the warmest year since 1001 or thereabouts. The relative contributions from sunlight, atmospheric effects, and heating by vigorous discussion were not estimated. There is, in any case, a cleaner example of global warming elsewhere in the solar system. The atmosphere of Neptune's moon Triton has increased its scale height since it was imaged by Voyager 2 in 1989. Since the value of local g hasn't dropped, T must have gone up. The best bet is increased insolation at the south polar cap, resulting from a tilted rotation axis being carried around as Neptune orbits the sun. If so, the warming is part of a cyclic pattern and will reverse itself in 50 years or so. Arguments for cyclic patterns on Earth have also been made, especially by people who study activity cycles on stars like the sun. Astronomers can afford to wait to be sure. Can terrestrial policy makers?



IS FOR HUBBLE, the only astronomer to make *Time Magazine's* March 1999 list of greatest scientists and thinkers of the 20th century. A complete list of his accomplishments would be quite long. But his two most fundamental contributions, the recognition that those fuzzy things in the sky are other galaxies like our own (his word was “nebulae”; Shapley preferred “galaxies”) and the discovery that they and we are moving apart from each other at speeds proportional to separations, both grew directly out of his careful studies of variable stars, especially Cepheid variables. He was, in other words, more a hedgehog than a fox. Progress in science surely demands both

kinds of approaches, but, at least in modern astronomy, there does not seem to be much room for hedgehogs, who run the risk of being described as “the world’s foremost expert on dynamics of triple galaxies” or “on rapidly oscillating Ap stars” (but only because nobody else is interested in them). On the anti-science side, one should probably add two more classes, the science writer “who misunderstands many things” and the crank, “who misunderstands one big thing” (often quantum mechanics or general relativity). And I hasten to include myself in the former class, at least for this issue of the *Beam Line*.



IS FOR ISING MODEL. And, according to the obituary in the March 1999 issue of *Physics Today*, the eponymous Ernst remained unaware of the importance and wide applicability of his 1924 thesis work for about a quarter of a century. Can you think of any branch of physics where this could happen today? Kruskal coordinates in general relativity (a way of seeing around the Schwarzschild horizon) also went incompletely appreciated by the inventor for some time, but that too was many years ago.



IS FOR JANSKY. He was, quite by chance, the world’s first radio astronomer. Seeking sources of short-wave interference to communications for Bell Laboratories, he found emission from the center of our Milky Way. “Shortwave” back in 1931 meant 14.6 meters. Jansky soon turned to other Bell-oriented problems, leaving the field (literally, for both the New Jersey and Illinois installations) to Grote Reber, who was the *only* radio astronomer between 1937 and 1946. Bell Labs and serendipity re-entered the picture, as you undoubtedly know, in 1965, with the discovery of the 3K cosmic background radiation by Arno Penzias and Robert Wilson, who were also concerned about communication problems. We have all heard (and perhaps tried to make) the case for curiosity-based, as well as focused or applied,

research. The lesson of Jansky, Penzias, and Wilson is that starting out to work on a practical problem does not preclude learning things that even your purest colleagues will find interesting.



IS FOR KUIPER BELT. The Dutch-born Gerard P. Kuiper, long headquartered in Arizona, was for a decade or two nearly the only senior planetary astronomer active in the United States. His belt was a hypothetical one of potential short-period comets, located outside the orbit of Neptune, but closer to us than the Oort cloud of potential long-period comets. The first object with a Kuiper belt orbit turned up in 1993, and some dozens are now known. As the number increased, solar system astronomers began to ask whether Pluto might have begun life in the belt and have been perturbed to its present orbit thereafter. And, went on kibbitzers, was Pluto even entitled to be called a planet at all?

This quibble met head on with the more serious question of “what is a planet?” that has arisen from the discovery of Jupiter-size companions to many nearby stars (so far only one per star). At least three answers are possible, with definitions in terms of mass (between brown dwarfs and asteroids), composition (some segregation, like the earth’s iron core and the rocky centers of the Jovian planets), or formation process (in a disk around a central mass that is in the process of becoming a star). Naturally, the only definition we can apply outside our solar system is the mass criterion, least interesting of the three.

You have a wide choice of questions here: Is Pluto a planet? (Yes, because it has been one for 60-some years if for no other reason.) How do you get things from the Kuiper and Oort zones into the inner solar system? How do you get giant planets as close to their stars as most of the extra-solar-system discoveries? (three-body processes all). And, when you have taken care of those, should you drink your champagne on December 31, 1999, or 2000? (Both please, as Pooh said).



L IS FOR LIGHT YEAR. The serious issue here is how to think about, and perhaps more important, how to explain about, enormously large or small numbers and entities. The methods that appeal to us tend to involve logarithmic steps and nearly always fail. Watching “Powers of Ten” has no effect on students’ tendency to ask, “Are there any other galaxies in our solar system?” And I have completely given up on trying to disabuse a very dear and well-educated friend of the notion that visiting Egyptian antiquities carries one most of the way back to the Big Bang. Allan Sandage (the only person who can really claim to have been a student of Edwin Hubble) see “H”) says that he always thinks of an elliptical galaxy as being about the size of a football. My mental time ribbon is always about 18 in. long, but the markers can be anything from Gyr to hours, depending on the problem at hand, and moving between scales is a sort of zoom lens process. Incidentally, light years are a very bad unit to start with, since they inevitably suggest time rather than distance. The astronomers’ unit is the parsec.



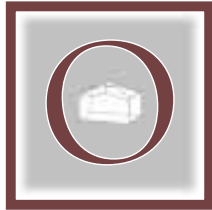
M IS FOR MAGNETOSTRICTION. It makes perfectly good sense (rotate domains into alignment with an imposed field and you will surely open up cracks between them), and the phrase “110 to 130 or 140 micro-inches per inch” will live in my ears all my life. It probably applies to some ferrite, and of course micrometers per meter would say the same thing with political correctness. Now consider the following system(?):

Make 5–10 micron-sized particles of three different magnetostrictive materials with different curves of expansion versus field strength. Coat them with something brittle and encapsulate with a solution of some substance with which each of the three materials will react to form a different-colored product (preferably red, yellow, and blue). Coat a thin layer of the capsules on film or paper. Encode a color image as a scan (like a TV scan) of

electric currents that will produce different levels of magnetic field when the current passes through a micron-sized probe that can be moved across the surface of the film or paper. The three field levels must, of course, be those such that the three kinds of materials will break their brittle coatings in order from weak to strong, interact with the surrounding solute, and produce a colored image made of dots smaller than normal visual resolution (again like TV or a dot-matrix printer). Believe it or not, this actually worked after a fashion. My father patented it and tried to sell it for years. (This is the sort of background that really makes one appreciate tenure!). The engineering question is this: A new technology, when it first appears, is never as good as the one that has been in use for years for the same general purpose. Is there any reliable way to recognize the small subset of new methods that are eventually going to be better than existing ones? Probably not, or we would all have gotten rich on xerography, chips, or frozen orange juice.



N IS FOR NOCTILUCENT (“night shining”) CLOUDS. These are the highest clouds found on earth. Formed at about 80 km, they catch the last rays of the setting sun when it is as much as 9 degrees below the horizon for a ground-based observer. (Draw the picture and persuade yourself that $\cos^{-1} 6400/6480$ is bigger than you thought it was.) Particles collected in situ consist of ice mantles on cores containing iron and nickel and probably derived from evaporated meteors. Proper cloud stuff is, of course, built around terrestrial dust seeds. The official puzzles are (a) how does the water vapor get up this high? and (b) why are the clouds confined to a narrow height range around 80–85 km while the trails of disintegrating meteors extend far above and below? My own private puzzle (which probably involves some branch of physics other than atmospheric and meteorology) is: Why did the only person I ever knew who worked seriously on noctilucent clouds have a secret clearance and refuse to talk about them?



O IS FOR ORTHORHOMBIC, one of the seven possible crystal systems. From most to least symmetric, these are cubic (with three symmetry directions, all cell edges equal, and all angles equal 90 degrees), rhombohedral, hexagonal, tetragonal, orthorhombic, monoclinic, and triclinic (with no symmetry directions, no equal edges, and no right angles). I once, for a high school science project, carved them all out of Styrofoam, made cell edges out of pipe cleaners, and grew seven examples from saturated solutions (most of which would not today be allowed in any high school). I wondered at the time why there weren't at least a few other possibilities, for example, one that might be called "biclinic" with a single 90 degree angle. The high school chemistry teacher did not understand the question, and I did not understand father's answer. Explanations (suitable for bears of very little brain) from knowledgeable readers would be appreciated. If you happen also to be puzzled, a substitute question is: How would you pronounce orthorhombic if it didn't have the second "h"?



P IS FOR PLUMBER, which Einstein is reputed to have said he would have chosen to be if he had it all to do over again. The expanded version of the story has the plumbers' local immediately sending him a union card. Normal plumbing, as you may have noticed, works best in the laminar flow mode, standard in pipes up to a Reynolds number around 2000 and sustainable with care up to perhaps 100,000. Incidentally, conduction is no more satisfactory than turbulence in the household context: the bathroom floor gets nice and warm, but nothing happens when you turn the tap.

Turbulence and convection are important in a whole range of astronomical contexts, from star formation to the poorly-understood neutrino-driven convection that is supposed to eject the stellar envelope in the kind of

supernova that happens when an iron core collapses to a neutron star (see S). Neither the efficiency of energy transport nor the spectrum of eddy scales can be calculated except by simplifying the problems beyond recognition. Thus you can choose from an enormous number of residual questions, with or without these two: (a) given that all critical dimensionless numbers are supposed to be of order unity, isn't there some way of redefining the Reynolds number to make $Re_{crit} \approx 1$? (b) can you name even one theoretical physicist who never in his life tried to calculate $1/137$ from something else?



Q IS FOR QED, which might mean Quod Erat Demonstrandum or Quantum Electrodynamics. The former QED, at least to those of us with an old-fashioned "falsifiability" criterion for what constitutes a meaningful scientific hypothesis, has no place in physics. The latter clearly does, at least until another quintet of geniuses comes up with something better (the inventors having said they never meant it to last forever). It also gives me an opportunity to tell a previously unrecorded Feynman story. At a fall 1965 Caltech party (celebrating you know what), a few of us gave him a black plastic box, then readily available at novelty stores. It had a metallic toggle switch sticking out of the top of its 4x4x6 inch volume, some eccentric gears on the bottom, and (one deduced) batteries inside. You placed it on a table and displaced the switch. The box rocked and shook and groaned for a minute or two. Then the top opened, a small green hand came out, returned the switch to the original position, and disappeared back inside, leaving the box quiescent. The recipient contemplated this for some time and then declared (you must imagine the voice and accent for yourself), "Yes. It's very interesting. And I can see that it's very useful. But I'm not quite sure what it's useful for. Sort of like quantum electrodynamics." Was it by design or chance that QED stands for these two very different concepts?



R IS FOR RHEOLOGY, the Society of which is the smallest of those associated with the American Institute of Physics (am not sure why; the subject sounds important). The name is also the youngest, apparently first appearing in print in 1929 on the title page of the *Journal of Rheology*. There was enough disagreement about the name that a professor of Latin was coopted the next year to declare it the most suitable choice. Scientists are constantly having to invent names and acronyms. The April 1 issue of the *New England Journal of Medicine*, on my desk as I write this, has an editorial entitled “Annexinopathies—A New Class of Diseases.” Naively, I was expecting a yet more complex variant on Munchausen’s syndrome by proxy.* In fact, annexins are a class of 20 or more proteins with repetitive domains, with which many physiologically unpleasant things can go wrong. The topic for consideration here is what we can do to keep down the incidence of new words and acronyms, or at least to make them as transparent as possible. I have a specific suggestion for acronyms: Don’t. It is almost never necessary. Of course you don’t want to repeat “Submillimeter Common-User Bolometric Array” twice in every paragraph. But with a little thought, you can use the complete name once every page or two, and then cycle among “the array,” “the bolometer,” “our submillimeter device,” and so forth, at least until the other users are not just common but many. For new words, you will receive conflicting advice. Purists will forbid the mixing of Latin, Greek, and Anglo-Saxon. My own prejudice is that ready interpretation and self-evident pronunciation are much more important. This brings us back to rheology, because there are also devices called rheometers, and which syllable gets the accent

*Munchausen’s syndrome (named for the mythical baron) is pretending to be sick or making yourself sick to get attention. The “by proxy” version is, most often, making your children sick for similarly horrifying reasons. NEJM tries to get its issues into the hands of subscribers a few days before the cover date when associated articles will appear in the popular press.

presents the same set of problems as are encountered in kilometer versus thermometer (etc.). Presumably a “kilometer” as most often pronounced would be the same as an “odometer,” and no, I don’t know anyone who puts the stress on the third syllable there, either.



S IS FOR SUPERNOVAE. Type I events occur among population II stars and Type II events occur among population I stars. This sounds like a major failure of the principle advocated under R, but is really just bad luck. Worse luck, we are pretty sure we understand the physics of Type I events (explosive fusion of about a solar mass of carbon and oxygen to iron-peak elements) but have never seen even one example of the supposed progenitor systems (massive pairs of white dwarfs in short-period orbits); while for Type II events we see lots of progenitors (massive stars) but have not been able to model the physics that ejects the stellar envelope and produces the luminosity, spectrum, and expanding gas cloud that we see.



T IS FOR TENOR. I once read, stated as gospel, that the present shortage of outstanding tenors was a direct result of the increasing height of European and American men and their correspondingly longer vocal cords. This is the simplest possible sort of physics (see also X), and if it is right, the situation is likely to get worse. There are, on average, physiological differences between tenors and basses and between sopranos and altos that you can study for yourself.

We start by assuming that you are already aware of the differences between sopranos plus altos and tenors plus basses. Now examine the next large choir you see, and try to figure out which section is which. Position of the hair line among the men and shoulder breadth among the women are good places to start. There are probably



average height differences as well (though a small sample can be driven off-scale by a single Placido Domingo or Joan Sutherland). The lab assignment for this paragraph is to find as many differences as you can and attempt to formulate hypotheses to account for their correlation with vocal range. That's the easy part. Now try to test said hypotheses without getting into SERIOUS trouble. The serious aspect of this (not often of concern to physicists except obviously members of AAPM) is what constitutes "informed consent" for human experimental subjects and should it be regarded as a sufficient condition?



U IS FOR UFOs. Astronomers probably see more things in the sky we can't identify than the general run of humanity, if only because we spend more time looking at it. That we (and you) are pretty sure that the vast majority of them are not space ships sent by other civilizations, but are not always able to explain very clearly why to others, is another aspect of the general problem (see "L") of making clear the difference between a million and a billion. Teddy Bullard once said that the most important thing scientists had learned from World War II was the difference between a thousand dollars and a million dollars and what you could do with each (He meant that most scientists had never had access to either before.). Perhaps that is the right approach? Five million dollars will buy you enough gasoline to drive your car the distance to Mars at its closest to us. Five billion dollars worth of gas would take your car much less than 1 percent of the distance to the very nearest star.




V IS FOR VISION. The physics sounds simple—a couple of fairly imperfect lenses placed to provide a bit of parallax and detectors for wide-band, three-color photometry. But, when it comes to a functioning system, the physics-specified components are apparently neither sufficient nor necessary. On the sufficient side, readers of

Oliver Sacks will recall that attempts to commission the system late in life all more or less fail. (Does this mean there is a critical period in childhood for learning to see as there is for learning language?). On the necessary side, I know first hand how easily one dispenses with the parallax. You may well have seen, or read about, Edwin Land's experiments in reproducing what seemed to be a full range of colors with only two wavelength bands. And, indeed, a good many dichromats discover their disability(?) only by chance and well beyond childhood.

The late Fritz Zwicky of Caltech once got so annoyed with a colleague about assignment of a color to some star that he ordered a set of the Ishihara plates and insisted that everybody connected with Mt. Wilson and Palomar Observatories take the test. Sure enough, a couple of staff members were at least partly color blind and had never realized it. Based on that sample and some later ones, I have often wondered whether astronomers (only the men, of course!) are more likely to be color-challenged than the general run of humanity. And, if so, is there some physics-based biological reason for it?



W IS FOR W URSAE MAJORIS, WOLF-RAYET, AND W VIRGINIS STARS. Don't be surprised to find three interesting classes under one letter. We could easily have gone from A (AB Aurigae, an example of massive, pre-main-sequence objects with emission lines) to Z (ZZ Ceti stars, pulsating white dwarfs) with stellar prototypes alone. Each has associated puzzles, or we would not bother to name the class. The W UMA's are binaries whose component atmospheres touch, yet manage to maintain different temperatures. How they do it, and even how they get into this pickle (protostars are big; W UMA's cannot have formed with their present separations) "requires further work." The Wolf-Rayet stars are massive and considerably evolved. What is more, they have managed to discard most of their remaining hydrogen and show surfaces made of helium and carbon. Not all massive stars are allowed to do this or we



would see no Type II supernovae, with strong hydrogen lines in their spectra. How does a given star decide what to do?

The W Vir stars are the low-mass old analogs of young, massive pulsating variables called Cepheids. Confusion between the two at one time led astronomers to appraise the Universe as a factor of at least two more compact in space and time than it is. Models still do not well describe observed relationships between stellar masses and pulsation periods, especially where two or more modes are excited in the same star.



IS FOR XYLOPHONE. The standard question in this territory is, “Can you hear the shape of a drum?” meaning, roughly, how close is the connection between the geometry of a membrane (or a string, plate, or air column) and

the power spectrum of frequencies it emits when excited. The answers “yes” and “no,” that is, close and not so close, have both appeared in recent years in articles at the *Scientific American* or *Physics Today* level. The real answer, though, has to be “That’s the wrong question.” Otherwise, my “A” would sound more like Menuhin’s than it does. One of the lessons of music synthesizers is that what we hear is not just a power spectrum. Electronic keyboards can call out some remarkably unkeyboardlike sounds, but they are not really very xylophone-like or violin-like either, let alone Menuhin-like. Today, traditional and nontraditional instruments are being built to produce predictable sounds, so there must be progress. Alternate questions for non-acousticians include: Can you pronounce Chladni’s name so he would recognize it? or, Does one dare admit to liking Fritz Kreisler better?



IS FOR YTTERBY, the smallest town to have four elements named for it (in fact the only town). They are erbium, terbium, yttrium, and ytterbium. Three of the four are rare earths, or lanthanides, and the fourth falls

immediately above lanthanum. You will not need an interpreter for that sentence. But when did you first hear of the periodic table, when come to appreciate its enormous power, and (recently much discussed in California) when should our children be admitted to the same privilege? I have heard this issue debated by councils, boards, and committees of several learned societies. A large majority says, “Oh, I must have been 9 or 10, and third or fourth grade would be about right for my kids.” But other people’s kids should wait until high school at the earliest, and maybe even then only if they are college bound. Perhaps, but did we understand the periodic table because we were destined to become scientists, or did we become scientists partly because somebody took the trouble to explain the periodic table to us? NOW go to your local school board meeting.



IS FOR ZENITH. No deep mysteries here. It is the point of sky directly over your head and derived (“obscurely” according to the *New Complete Oxford English Dictionary*) from the Arabic *samt al ras* (“path over the head”). The astronomical point to ponder is the enormous skill of 19th century astrometrists, who managed to identify aberration of starlight, to measure parallaxes of an arc-second or less, and to recognize that the perihelion of Mercury’s orbit was advancing faster than expected, all without photographic emulsions to record the images they saw.

You were perhaps expecting “syzygy,” but, as you see, it starts with an “s,” means conjunction, roughly, and, according to a recent introductory text, is more used by crossword puzzle designers than by astronomers. Incidentally, if you don’t already own one, the new edition (in one volume, printed nine pages on one) of the Compact OED is a good investment, even at the open market price of \$295. I suspect, though, that it is not much fun to read if you actually need the magnifier they provide.

