

students a sense of how those atoms can hook together in different ways to provide different functions. Here, qualitative thinking serves us well.

We never suggest using explanations before phenomena, but we do insist on providing the tools by which explanations can follow phenomena. The explanations can follow the phenomena after the basic ingredients have been learned. If more physics than was taught in ninth grade is needed in, say, a biological process, then by all means invite in the physics teacher. This will enrich the physics that was learned at an admittedly low level and encourage the taking of advanced physics courses after the three-year sequence. The same scenario can be applied for the chemistry that biologists must know.

In all of this, we must not forget the objective: to bring the science way of thinking to all high-school graduates. I believe doing so will in no way hurt future scientists or engineers. The curriculum should be rich enough to give them the advanced courses that can profitably build on the firm, conceptual, and process-rich sequence I am trying to describe.

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An Earlier Bar to Rescaling Units

Solomon Golomb, in his letter to *PHYSICS TODAY* (October 2001, page 12) has proposed that physical quantities—for example, time and temperature—be expressed in logarithmic scales, preferably based on the decibel system widely used by engineers.

Years ago, the late Lewi Tonks and I made the same proposal,¹ but specifically for measures of pressure or vacuum. We proposed to use the common logarithm (base 10) of the absolute pressure in bars, and to name the unit step on that scale “one boyle.” We noted that “one deci-boyle,” one-tenth of a boyle (about 12%), would be a fair measure of the precision with which extremely high or low pressures are measured in all but the most precise work. Our paper referred to similar earlier proposals and mentioned a table of constants to be added to 10 times the logarithm of pressures expressed in various units (for example, torr,

inches of mercury, psi, and atmospheres) to convert them to the deciboyle scale. It also gave a list of examples ranging from the lower limits of the ionization gauge (–140 dB) to the pressure at Earth’s center (65.61 dB).

Besides the *Nature* article, our proposal was presented to the American Society of Mechanical Engineers at their winter meeting in 1964² and was described to and discussed by readers of the trade journal *Research/Development*.³ Predictably, there were various alternative proposals. When readers were polled by the journal, 43% favored “retaining the present system”—whatever that is!—while 41% favored some form of logarithmic scale. Not all of the 41%, however, favored our designation of the bar as the base of the scale. Many said that we already have a logarithmic system in the prefixes (milli, micro, and so forth). We responded to them at length in the March 1966 issue, noting “an irrational component of conservatism in such matters, which has been noted and deplored by most students of creativity.”³

To my knowledge, that was the first proposal to apply the decibel system to other than acoustic measurements, and the only one I have been aware of before Golomb’s letter. I am unaware of any formal action on our proposal.

I wish Golomb more success with this proposal than we had 35 years ago!

References

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3. G. C. Baldwin, L. Tonks, *Research/Development*, F. D. Thompson Publications, Inc., February 1965, and comments in the issues of September 1965 and March 1966.

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Is The Universe’s Expansion Accelerating?

A Search and Discovery article titled “Farthest Supernova Strengthens Case for Accelerating Cosmic Expansion” (*PHYSICS TODAY*, June 2001, page 17) deals with the present state of a central question in

cosmology: whether or not the expansion of the universe is accelerating. The article cites the most recent observational data in support of this thesis. The overriding concomitant question is what is the cause for the acceleration, and the search for an answer has become a major area of research. It seems fairly well agreed that inclusion of the cosmological constant Λ in the Einstein equations provides an excellent *description* of the expansion and its acceleration. But, its *interpretation* is open to question.

The majority opinion is that the term $\Lambda g_{\mu\nu}$ is a vacuum energy—the “dark energy.” This view was initiated by particle theorists¹ in search of a solution to the problem posed by the absence (apart from the Casimir effect) of any observable zero-point energy. This zero-point energy is computed to be 120 orders of magnitude greater than the observed values for Λ . So the attitude is that the observed value is an *effective* value and must be composed of the zero-point energy and compensating sources; hence, the preoccupation with dark energy and quintessence.

There is, however, a minority opinion that quintessence is inappropriate. The Einstein equations in canonical form are

$$R_{\mu\nu} - \frac{1}{2}Rg_{\mu\nu} + \Lambda g_{\mu\nu} = -\kappa [(\rho + p)u_\mu u_\nu + pg_{\mu\nu}].$$

With Λ transferred to the right-hand side to be a species of energy, the equations are

$$R_{\mu\nu} - \frac{1}{2}Rg_{\mu\nu} = -\Lambda g_{\mu\nu} - \kappa [(\rho + p)u_\mu u_\nu + pg_{\mu\nu}].$$

There is a profound difference in principle between these two ways of writing the equations. John Wheeler has put it this way: The gravitational field equations are simply geometry = mass-energy. Is $\Lambda g_{\mu\nu}$ geometry or is it energy? There are strong, theoretical, a priori arguments that it is purely geometric.

The Einstein tensor is $G_{\mu\nu} \equiv R_{\mu\nu} - \frac{1}{2}Rg_{\mu\nu}$, and it serves exceedingly well in all noncosmological situations. Its importance motivated close scrutiny of its structure by Albert Einstein's colleagues. The Einstein tensor is a second-rank tensor constructed solely from the metric tensor and its first and second derivatives. It is linear in terms of the second differential order and has a vanishing covariant divergence.

Study of the Einstein tensor's structure was begun as early as 1917 by H. Vermeil. The most recent result in this area of study is a theo-

rem constructed by David Lovelock,² which severely delimits its form. He has shown that, if the field equations are to be derived from a variational principle, then in a four-dimensional space, the only type (2,0) tensor density whose components satisfy $A^{ij} = A^{ij}(g_{ab}, g_{ab,c}, g_{ab,cd})$ with $A^{ij}{}_{;j} = 0$ is given by $A^{ij} = \sqrt{g} [R^{ij} - \frac{1}{2}g^{ij}R] + \Lambda \sqrt{g} g^{ij}$.

Although accumulating evidence for an accelerating expansion is leading to a general acceptance of $\Lambda g_{\mu\nu}$ as a proper term in the Einstein equations, this evidence has not erased the original stigma due to Einstein's characterization of it as “the biggest mistake of my life.” It is not generally accepted that Λ is part of the geometry. However, to burden Λ as the vehicle for solving the zero-point energy problem is questionable. The introduction of quintessence is uncomfortably reminiscent of the introduction of ether in the 19th century. Zero-point energy is a purely quantum phenomenon and its “problem” will be solved in the context of a quantized theory of gravitation.

The behavior of the cosmos seems to be that of a de Sitter space. Recall that the simplest vacuum solution of the Einstein equations without Λ is a Minkowski spacetime; if Λ is included, it is a de Sitter spacetime. Recall further that, in a vacuum de Sitter spacetime, a particle at a distance $\vec{x}$ from the origin is subject to a force $\vec{F} = mc^2\Lambda/3 \vec{x}$. Any attempt at solving astrophysical-cosmological problems must accept from the beginning that $\Lambda g_{\mu\nu}$ is “geometry.”

References

1. For a comprehensive exposition of this view and its implications, see S. M. Carroll, <http://arxiv.org/abs/astro-ph/0004075>.
2. D. Lovelock, *J. Math. Phys.* **13**, 874 (1972); D. Lovelock, H. Rund, *Tensors, Differential Forms, and Variational Principles*, Dover, New York (1989), p. 314.

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A Moment of Gravity

In a note entitled “An Optical Stretcher” in Physics Update (PHYSICS TODAY, November 2001, page 9), the term “center of gravity” is incorrect. The correct term is “center of mass.” Gravity has nothing to do with conservation of momentum.

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