

LETTERS

Create Life From Scratch? It's a Matter of Time

Howard Berg (PHYSICS TODAY, January, page 24) summarizes an impressive body of knowledge about one of the simplest living organisms, and refers to *Escherichia coli* as a "nanotechnologist's dream." Has a living organism, say *E. coli*, ever been made by humans from scratch? To sharpen the question, have humans ever taken a collection of clearly "dead" ingredients and made a clearly "alive" organism? Aside from demonstrating technical prowess, would creation of life in the laboratory be philosophically profound or trivial?

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BERG REPLIES: No free-living (independently replicating) organism has been synthesized from scratch. The possibility of doing so is still remote. The simplest case, a wall-less bacterium called *Mycoplasma*, requires DNA encoding of about 300 genes for growth under laboratory conditions.¹ The functions of about 100 of these are unknown. When isolated from nature, the species in question, *M. genitalium*, had 517 genes; compare *E. coli* at 4288. But synthesizing the DNA would not be enough: one would need to know what other components (proteins, lipids, sugars, etc.) are required and how they might be assembled.

The DNA needed to specify the bacterial virus ϕ X174 was synthesized in 1967 (enzymatically, from a viral template).² Cells of *E. coli* exposed to this synthetic DNA made new virus, giving up their lives in the process. The DNA of ϕ X174 is a single-stranded circle comprising 5386 nucleotides that encode 11 genes (several overlapping). It was sequenced in 1977.³ The intact virus is icosahedral, with a protein coat comprising 60, 60, and 12 copies of proteins specified by genes F, G, and H, respectively. But it was *E. coli*,

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with its machinery for DNA replication and protein synthesis, that made the virus.

Whether creation of life in the laboratory would be philosophically profound or not depends, I suppose, on one's philosophy. I happen to believe that life, albeit highly complex, is a matter of physics and chemistry. And I include consciousness: see Crick.⁴ So for me, it's simply a matter of time. However, such a feat would signal an enormous extension of current understanding. For a timely discussion of broader issues, see ref. 5.

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Feynman Brainwashed?

Philip Anderson's Reference Frame article "Brainwashed by Feynman" (PHYSICS TODAY, February, page 11) reminded me of a Feynman story on this very subject. Even today I find myself explaining, as Anderson does so well, why meson-exchange Feynman diagrams are not sufficient to understand the origin of the nucleon-nucleon force. But in the 1980s, when I gave the Caltech colloquium on this subject, the idea that the nuclear forces could have important nonmesonic components due to the composite character of the nucleons was considered somewhat far-fetched.

Given my youth, the controversial character of the talk, the presence in the audience of many of the professors from whom I had learned the meson exchange orthodoxy, and

Feynman's sitting in the first row of the lecture theater, I was a little anxious as I began the talk. However, after I warmed up, it went reasonably well. I closed with the punch line that not only were such new forces allowed in principle, but the calculations by Maltman and myself,¹ among others, indicated that they were dominant at short distances.

Feynman stood up to ask the first question, and the room went silent. My diagram (showing two clusters of three quarks with a pair of quarks being swapped between the two clusters) looked like meson exchange to him, so why was I claiming a new kind of force? (The similar-looking Feynman diagrams have in them time-orderings that do correspond to meson exchange.) I believe Anderson will appreciate my reply: "The problem is that you are used to thinking in terms of Feynman diagrams." In the time it took the laughter to subside, Feynman had understood everything, and proceeded to explain to the audience why it was dangerous to be "brainwashed by Feynman."

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The Matter of WIMPs

The article on weakly interacting dark matter by Barbara Goss Levi (PHYSICS TODAY, April, page 17) calls on readers to imagine a halo of dark matter "which does not participate in the galactic rotation." This is difficult to imagine, because the whole purpose of introducing the weakly interacting massive particles (WIMPs) is to explain gravitational behavior of the Galaxy. Now the reader is asked to imagine that the WIMPs themselves are not influenced by the galactic gravitational field. Maybe the intent is to assume that each particle rotates in a separate plane about the galactic center, and the average speed of the cloud is zero.

It is an interesting speculation that the angular momentum of the WIMP cloud may cancel out the total

angular momentum of the Galaxy. A further interesting idea is that maybe WIMPs are basically antimatter and will explain the abundance of matter over antimatter in the universe.

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LEVI REPLIES: When I wrote that weakly interacting massive particles (WIMPs) do not participate in the galactic rotation, I was not implying that WIMPs do not experience a gravitational field. They do. However, WIMPs move in more or less random orbits in a spherical volume, in contrast to the organized motion of the majority of stars in our Galaxy, which rotate in a flattened disk. The WIMPs are not likely to collapse into a disk, as most of the stars have; they collide so infrequently with one another (their mean free path is greater than the diameter of the Galaxy) that they have no mechanism for shedding energy and collapsing into the flattened pancake-shaped disk.

As for the question of whether WIMPs might be antimatter, we have several reasons for concluding that they are not: First, the amount of matter in WIMPs is much larger than the ordinary matter in the universe. Second, antimatter would exist in the form of antiprotons and positrons, and they would annihilate ordinary matter, with a spectacular and highly visible gamma-ray background. Finally, such antimatter would be charged, would interact with photons, and hence would not be "dark."

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The Universe in a Glass of Beer

The mystery of the cosmological constant has been with us for a long time,¹ and has recently been said to be the most perplexing puzzle in contemporary physics.² Ever since it was introduced by Einstein in 1917, debate has continued as to whether it really exists or not; and if it does, why is it so small? Although Einstein and other theorists came to regard it as unnecessary, in the face of mounting evidence that the universe was expanding rather than stationary as was originally thought, the cosmological constant has been

resurrected in recent years to help explain—along with the concept of "dark matter"—the apparent motion and structure of the universe. And although some theorists in modern times have tried to prove that it is either zero or extremely small (see, for example, ref. 3), recent evidence from high-redshift supernova studies strongly suggests that it not only exists but contributes at least twice as much as ordinary matter to the critical density required for a flat universe (see *PHYSICS TODAY*, June 1998, page 17).

The question remains, however, as to why the constant is as small as it is rather than huge or even infinite as standard field theory would seem to indicate (*PHYSICS TODAY*, March 1989, page 21). That is, if one assumes that it is due to the vacuum field that permeates all of space (*PHYSICS TODAY*, July 1999, page 81) and sums the zero-point energies of all the field modes, the result would be an infinite energy density and the universe would have curled up upon itself long ago. Because this has not happened, it has been assumed that something either limits the number of field modes or causes them to largely cancel out. Attempts to impose limits, however, have still yielded results up to 120 orders of magnitude too large, while arguments that have been advanced for the field modes to cancel in some way have largely seemed untenable. Therefore, to help resolve this dilemma, I would like to put forth the following suggestion.

If we think of the vacuum as a fluid of uniform energy density, then a small "bubble" formed within it should "rise" toward the "surface" much like a bubble would in a glass of beer. If the bubble were to arise from a quantum fluctuation in the vacuum of space, it would move at an ever-increasing rate toward the boundary of the universe (if it is indeed bounded) due to the slightly unbalanced Casimir forces acting upon it (that is, the pressure of the vacuum). This suggests that a kind of cosmic Archimedes principle is at work in what might be called a Casimir-driven universe, causing space itself to expand at an ever-increasing rate. Whether the universe is finite and bounded as is a glass of beer is not yet known, but if it is, this model should account for the observed behavior of the expansion rate, at least in general terms. It may also lessen the need for "dark matter" (unless you're having a Guinness) and help achieve the

"mass without mass" suggested recently by Frank Wilczek (*PHYSICS TODAY*, November 1999, page 11; January, page 13) as a desirable consequence. In any case, it would not be the first time such a model has proven useful in physics (and probably not the last) and the thought that we live in a universe that is something like a light pilsner is not a bad thought at all.

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Elegance: Keeping it Simple and Testable

David Mermin, in his recent *PHYSICS TODAY* article (March, page 11), gave an interesting commentary on elegance in physics. I have to agree with his remarks—and perhaps we need to inquire further about why this strange concept has become so elevated in our discourse. Here I am guided, for one, by the statement of Einstein's in his little book on relativity, from 1916, which Mermin touches on. In translation, Einstein's original sentences read:

"In the interest of clearness, it appeared to me inevitable that I should repeat myself frequently, without paying the slightest attention to the elegance of the presentation. I adhered scrupulously to the precept of that brilliant theoretical physicist L. Boltzmann, according to whom matters of elegance ought to be left to the tailor and the cobbler."

I think that Boltzmann's statement as quoted by Einstein casts this idea of elegance into a true light. It is, as Mermin suggests, largely a subjective judgement—and as Boltzmann implies, perhaps as changeable as the fashions behind our choice of clothing and shoes.

The fact is that we scientists really are not respected in society for our elegance, though we might have artistic aspirations. A doctor is respected and valued for saving lives, and that is all. A scientist is respected and valued for having a glimpse of truth, and that is all. We test the truth of scientific theory in experiment. If no experiment is possible, then the science is