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Everything for nothing

Some audacious new physics based on the fluctuations of empty space may unify the forces of nature, explain why quantum theory works and where the Universe comes from

Harold Puthoff

CLASSICAL physics tells us that if we think of an atom as a miniature solar system with electronic planets orbiting a nuclear sun, then it should not exist. The circling electrons should radiate away their energy like microscopic radio antennas and spiral into the nucleus. To resolve this problem, physicists had to introduce a set of mathematical rules, called quantum mechanics, to describe what happens. Quantum theory endows matter and energy with both wave and particle-like characteristics. It also restrains electrons to particular orbits, or energy levels, so they cannot radiate energy unless they jump from one orbit to another.

Measuring the spectral lines of atoms verifies that quantum theory is correct. Atoms appear to emit or absorb packets of light, or photons, with a wavelength that exactly coincides with the difference between its energy levels as predicted by quantum theory. As a result, the majority of physicists are content simply to use quantum rules that describe so accurately what happens in their experiments.

Nevertheless, when we repeat the question: "But why doesn't the electron radiate away its energy?", the answer is: "Well, in quantum theory it just doesn't". It is at this point that not only the layman but also some physicists begin to feel that someone is not playing fair. Indeed, much of modern physics is based on theories couched in a form that works but they do not answer the fundamental questions of what gravity is, why the Universe is the way it is, or how it got started anyway. Surprisingly, there may be answers to these seemingly unanswerable questions. Perhaps even more surprising, the answers seem to be emerging from empty space, the vacuum, the void.

In fact, according to quantum theory, the vacuum, the space between particles of matter as well as between the stars, is not empty, it is filled with vast amounts of fluctuating energy.

To understand this extraordinary idea, we will have to take a detour into the phenomenon of "fluctuations" with which quantum theory abounds. Fluctuations arise as one of the most

fundamental concepts to come out of the mathematics of quantum theory. This is the uncertainty principle enunciated by Werner Heisenberg in 1927, which says that it is impossible to know everything about a system because of what would seem to be inherent fluctuations in the very fabric of nature itself. Indeed, quantum mechanics is a statistical theory that deals with probabilities and it has some profound consequences for our understanding of reality. For instance, we cannot know the position and the momentum of an electron at the same time. If we know its momentum, or energy, accurately, then we can determine its position only probabilistically.

This "fuzziness" of positions described in terms of probability waves gives a measure of the size and shape over which an electronic orbit fluctuates in an atom. It also means that the energy of a particle or system is "fuzzy" and thus there is a slight probability of it changing, or fluctuating, to another value. In fact, a system can actually, by fluctuation, "tunnel" through an energy barrier because there is a small but finite probability of the system existing on the other side of the barrier. I shall discuss later a possible cause for such fluctuation phenomena.

The basic fuzziness of quantum theory means that there are fundamental phenomena which classical physics does not predict. For example, according to classical physics, any simple oscillator, such as a pendulum, when set in motion, comes to rest because of friction. But quantum theory predicts that such an oscillator would not completely come to rest but, instead, would continue to jiggle randomly about its resting point with a small amount of residual energy, the so-called zero-point energy.

The adjective zero-point denotes that such motion exists even at a temperature of absolute zero where no thermal agitation effects remain. Although we cannot observe the zero-point energy on, say, the pendulum of a grandfather clock because it is so minute, it is nonetheless real. In many physical systems this has important consequences. One example is the

presence of a certain amount of "noise" in a microwave receiver that can never be removed; no matter how perfect the technology.

This zero-point energy is the result of the unpredictable random fluctuations of the vacuum energy, as predicted by the uncertainty principle, which is zero in classical theory. In fact, these fluctuations can be intense enough to cause particles to form from the vacuum spontaneously, provided they disappear again before violating the uncertainty principle. This temporary formation of "virtual" particles is somewhat akin to the spray that forms near a turbulent waterfall.

Of all the zero-point fluctuation phenomena, the zero-point fluctuations of electromagnetic energy are the most easy to detect. Electromagnetic waves have standing, or travelling modes, that are a bit like the various modes of waves going along a rope that is shaken. Each set of waves has its own characteristic set of nodes and crests. It turns out that even though the zero-point energy in any particular mode of an electromagnetic field is minute (equivalent to half a photon's worth), there are nearly an infinite number of possible modes of propagation, that is frequencies and directions. The zero-point energy added up over all possible modes, therefore, is quite enormous. As hard as it is to believe, it is greater than the energy density in an atomic nucleus. And this in all of the so-called "empty" space around us.

Because the zero-point energy of the electromagnetic fields is so large, you might expect to see its effects easily, but this is not the case because its density is very uniform. Just as a vase standing in a true void is not likely to fall over spontaneously, so a vase bombarded uniformly on all sides by packets of zero-point energy would not do likewise because of the balanced conditions of the uniform bombardment. The only evidence of such a barrage of energy might be minute jiggling of the vase. Such a mechanism is thought to be involved in the quantum jiggle of zero-point motions.

There are situations, however, where the uniformity of the electromagnetic zero-point energy is slightly disturbed and this leads to effects you can actually measure. One situation is when the zero-point energy perturbs slightly the spectra of lines from transitions between quantum levels in atoms. This perturbation is known as the Lamb shift, named after the American physicist, Willis Lamb. This work carried out in the late 1940s, using techniques developed for wartime radar, showed that the effect of zero-point fluctuations of the electromagnetic field was to jiggle the electrons slightly in their atomic orbits, leading to a shift in frequency of transitions of about 1000 megahertz.

Another, also named after its discoverer, is the Casimir effect—which predicts that two metal plates close together attract each other. Consider plates set at a certain distance apart. In the space between the plates, only those vacuum fluctuations for which a whole number of half-waves just spans the distance can exist, just like waves formed by shaking a rope tied at both ends. Outside the plates, the fluctuations can have many more values because there is more space. The number of modes outside the plates, all of which carry energy and



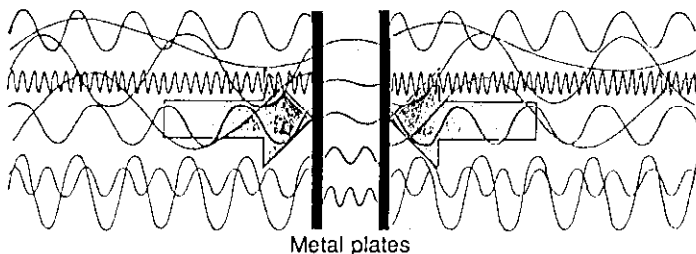
momentum, is greater than those inside. This imbalance pushes the plates together.

What does this have to do with our basic question of why the electron in a simple hydrogen atom does not radiate as it circles the proton in its lowest-energy orbit? I have considered this point by taking into account what other physicists have learned over the years about the effects of zero-point energy. I discovered that you can consider the electron as continually radiating away its energy as predicted by classical theory, but simultaneously absorbing a compensating amount of energy from the ever-present sea of zero-point energy in which the atom is immersed. An equilibrium between these two processes leads to the correct values for the parameters that define the lowest energy, or ground-state orbit (see "Why atoms don't collapse", *New Scientist*, July 1987). Thus there is a dynamic equilibrium in which the zero-point energy stabilises the electron in a set ground-state orbit. It seems that the very stability of matter itself appears to depend on an underlying sea of electromagnetic zero-point energy.

Gravity as a long-range Casimir force

As well as providing new insights into quantum theory, zero-point fluctuations also give us some insight into gravity. Einstein's general theory of relativity describes gravity well but we still do not know its fundamental nature very well. The theory is basically descriptive without revealing the underlying dynamics for that description. As a result, attempts to unify gravity with the other forces (electromagnetic, strong and weak nuclear forces) or to develop a quantum theory of gravity have foundered again and again on difficulties that can be traced back to a lack of understanding at a fundamental level. To rectify these difficulties, theorists have resorted to ever-increasing levels of mathematical sophistication and abstraction, as in the recent development of supergravity and superstring theories.

The well-known Soviet physicist Andrei Sakharov took a completely different tack to explain such difficulties. He suggested that gravity might not be a fundamental interaction at all, but rather a secondary or residual effect associated with other, non-gravitational fields. Gravity might be an effect brought about by changes in the zero-point energy of the vacuum, due to the presence of matter ("A key to understanding gravity", *New Scientist*, April 1981). If correct, you could then consider gravity as a variation on the Casimir theme, in which the pressures of background zero-point energy were again responsible. Although Sakharov did not develop the concept much further, he did outline certain criteria such a theory would have to meet—for example, predicting the value of the gravitational constant G in terms of



The Casimir effect: an imbalance in the quantum fluctuations of empty space can push two metal plates together

the parameters given by zero-point energy theory.

I have studied Sakharov's approach to gravity in detail with some positive results. A particle sitting in the sea of electromagnetic zero-point fluctuations develops a "jitter" motion, or *zitterbewegung* as German physicists have named it. When there are two or more particles, they are each influenced not only by the fluctuating background field, but also by the fields generated by the other particles, all similarly undergoing *zitterbewegung* motion. The coupling between particles due to these fields produces the attractive gravitational force. Gravity can, therefore, be understood as a sort of long-range Casimir force.

Because of its electromagnetic underpinning, gravitational theory in this form constitutes what is known as an "already-unified" theory. The main benefit of the new approach is that it helps us to understand characteristics of the way gravity works that were previously unexplained. These include why gravity is so weak; why positive but not negative mass exists; and the fact that gravity cannot be shielded because zero-point-fluctuations pervade space so cannot be shielded.

So, if we have an explanation for non-radiating atomic ground states and for gravity, do we know where the electromagnetic zero-point energy comes from in the first place? There are two schools of thought. One is that it is just simply a part of the boundary conditions of our Universe like, for example, the background radiation left over from the big bang. The other is that the zero-point energy is generated by the quantum-fluctuation motion of the charged particles constituting matter. Recently, I have calculated the possibility of the latter. I assumed that zero-point fields drive the motion of particles, and that the sum of all the motions of the particles throughout the Universe, in turn, generate the zero-point fields in the form of a self-regenerating feedback cycle, not unlike a cat chasing its own tail.

This self-consistent approach yielded the correct values for the zero-point field. Thus, the zero-point fields observed at any given point are due to random radiation arriving from particles throughout the Universe that are themselves undergoing zero-point motion ("Where does the zero-point energy come from", *New Scientist*, 2 December 1989). These self-regenerating zero-point fields also produce the familiar properties of quantum theory, such as fluctuation phenomena and the uncertainty principle, for example. This means that it might be possible to model many aspects of quantum theory on the basis of self-consistent, random interactions between



particles and the zero-point fluctuation fields they generate.

Although a knowledge of zero-point fields emerged from quantum physics as that subject matured, Timothy Boyer at City College in New York took a contrary view. In the late 1960s, he began asking what would happen if we took classical physics as it was and introduced a background of random, classical fluctuating zero-point fields. Such fields would presumably have originated in the initial random processes of the big bang and then by regeneration as I have just described. Could such an all-classical model reproduce quantum theory in its entirety, and might this possibility have been overlooked by the founders of quantum theory who were not aware of the existence of such a fluctuating background field?

Boyer began by tackling the problems that led to quantum theory being introduced in the first place, such as the blackbody radiation curve and the photoelectric effect. His upstart, neoclassical approach reproduced the known quantum results one by one. This approach is called stochastic electrodynamics (SED), in contrast to quantum electrodynamics (QED). Indeed, Peter Milonni at the Los Alamos National Laboratory in the US noted in a review of the Boyer work that if physicists in 1900 had thought of taking this route, they would probably have been more comfortable with this

classical approach than with Max Planck's hypothesis of the quantum. One can only speculate as to the direction that physics would have taken then.

The list of topics successfully analysed using the SED approach, which produce the same results as when the QED approach is used, has now been extended to include the harmonic oscillator, Casimir and van der Waals forces and the thermal effects of acceleration through the vacuum. Out of this work emerged the reasons for such phenomena as the uncertainty principle, the fluctuating motion of particles, the existence of van der Waals forces even at zero temperature, and so forth, all shown to be due to the influence of the unceasing activity of the random background fields.

There are also some notable gaps in the development of SED; for example, deriving Schrödinger's equation, which is the basic equation describing the dynamics of particles, as yet turns out to be an intractable problem. Several researchers are confident, however, that this obstacle can be overcome. Until then, though, it remains an open question whether quantum theory as we have come to know it will be entirely replaced by a refurbished classical theory in the near future. But regardless of the final outcome, the successes to date of the SED approach, by its highlighting of the role of background zero-point fluctuations, means that when the final chapter is written on quantum theory, field fluctuations in empty space will be accorded an honoured position.

And now to the biggest question of all, where did the Universe come from? Or, in modern terminology, what started the big bang? Could quantum fluctuations of empty space have something to do with this as well? Edward Tyron of the City University of New York thought so in 1973 when he proposed that our Universe may have originated as a fluctuation of the vacuum on a large scale, as "simply one of those things which happen from time to time". This idea was later refined and updated within the context of inflationary cosmology by Alexander Vilenkin of Tufts University, who proposed that the universe is created by quantum tunnelling from literally nothing into the something we call the Universe. Although highly speculative, these models indicate that physicists find themselves turning again and again to the void and fluctuations therein for their answers.

Those with a practical bent of mind may be left with yet one more unanswered question. Can you find mundane applications for this emerging Rosetta Stone of physics? Will it be possible to extract electrical energy from the vacuum? Robert Forward at Hughes Research Laboratories in Malibu, California has considered this possibility. Could the engineer of the future specialise in "vacuum engineering" as the Nobel laureate Tsung-Dao Lee has put it? Could the energy crisis be solved by harnessing the energies of the zero-point "sea"? After all, the basic form of zero-point energy is highly random and tends to cancel itself out, so if a way could be found to bring order out of chaos, then, because of the highly energetic nature of the vacuum fluctuations, relatively large effects could be produced.

Given our relative ignorance at this point, we must fall back on a quote given by the Soviet science historian Roman Podolny when contemplating this issue. "It would be just as presumptuous to deny the feasibility of useful application as it would be irresponsible to guarantee such application." Only the future can reveal the ultimate use to which humans will put this remaining fire of the gods, the quantum fluctuations of empty space. □

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Further reading "The classical vacuum", *Scientific American*, Timothy Boyer, August 1985, p 70; "Is the Vacuum really empty?", *American Scientist*, Walter Greiner and Joseph Hamilton, March-April 1980, p 154; *Something Called Nothing—Physical Vacuum, What is it?*, Roman Podolny, Mir, 1986.