

Quantum Fluctuations of Empty Space:  
A New Rosetta Stone in Physics?

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In a recent article in the popular press (*The Economist*, January 7, 1989, pp. 71-74) it was noted how many of this century's new technologies depend on the Alice-in-Wonderland physics of quantum mechanics, with all of its seeming absurdities.

For starters, one begins with the observation that classical physics tells us that atoms, which can be likened to a miniature solar system with electron planets orbiting a nuclear sun, should not exist.

The circling electrons should radiate away their energy like microscopic radio antennas and spiral into the nucleus. But atoms do exist, and multitudinous other phenomena which don't obey the rules do occur.

To resolve this cognitive dissonance physicists introduced quantum mechanics, which is essentially a set of mathematical rules to describe what in fact does happen. But when we re-ask the question, "why didn't the electron radiate away its energy?" the answer is, basically, "well, in quantum theory it doesn't."

It's at this point that not only the layman but some physicists can begin to feel that someone's not playing fair. I say only some physicists because the majority of working physicists are content simply to use quantum rules that work, that describe (if only statistically) what will happen in a given experiment under certain conditions.

These are the so-called "logical positivists" who, in a philosophical sense, are like the news reporter whose only interest is the bottom line.

There are nevertheless individuals here and there who still want to know why the electron didn't radiate, why Einstein's equations are in this form and not another, where does the ubiquitous zero-point energy that fills even empty space come from, why quantum theory, and perhaps the biggest question of all, how did the universe get started anyway?

Surprisingly enough, there may be answers to these seemingly unanswerable meta-level questions. Perhaps even more surprising, they seem to be emerging, as a recent book title put it, from *Something called Nothing* (1), or to put it more correctly, from empty space, the vacuum, the void.

To comprehend the significance of this statement, we will have to take a detour into the phenomenon of fluctuations with which quantum theory abounds, including the fluctuations of empty space itself.

Before the advent of quantum theory, physics taught that any simple oscillator such as a pendulum, when excited, would eventually come to rest if not continuously energized by some outside force such as a spring. This is because of friction losses in the system.

After it was recognized that quantum theory was a more accurate representation of nature, one of the findings of quantum theory was that such an oscillator would in fact not come to total rest but rather would continue to "jiggle" randomly about its resting point with a small amount of energy always present, the so-called "zero-point energy."

Although it may not be observable to the eye on your grandfather clock because it is so minute, it is nonetheless very real, and in many physical systems has important consequences.

One example is the presence of a certain amount of "noise" in a microwave receiver that can never be gotten rid of, no matter how perfect the technology. This is an example which shows that not only physical devices such as pendulums have this property of incessant fluctuation, but also fields, such as electromagnetic fields (radio waves, microwaves, light, X-rays, etc.).

As it turns out, even though the zero-point energy in any particular mode of an electromagnetic field is minute, there are so many possible modes of propagation (frequencies, directions) in open space, the zero-point energy summed up over all possible modes is quite enormous; in fact, greater than, for example, nuclear energy densities. And this in all of so-called "empty" space around us. Let us concentrate on the effects of such electromagnetic zero-point fluctuations.

With such large values, it might seem that the effects of electromagnetic zero-point energy should be quite obvious, but this is not the case because of its extremely uniform density.

Just as a vase standing in a room is not likely to fall over spontaneously, so a vase bombarded uniformly on all sides by millions of ping pong balls would not do likewise because of the balanced conditions of the uniform bombardment.

The only evidence of such a barrage might be minute jiggling of the vase, and similar mechanisms are thought to be involved in the quantum jiggle of zero-point motion.

However, there are certain conditions in which the uniformity of the background electromagnetic zero-point energy is slightly disturbed and leads to physical effects.

One is the slight perturbation of the lines seen from transitions between atomic states known as the Lamb Shift (2), named after its discoverer, Willis Lamb.

Another, also named for its discoverer, is the Casimir Effect, a unique attractive quantum force between closely-spaced metal plates.

An elegant analysis by Milonni et. al. at Los Alamos National Laboratory (3) shows the Casimir force to be due to radiation pressure from the background electromagnetic zero-point energy which has become unbalanced due to the presence of the plates, and which results in the plates being pushed together.

From this it would seem that it might be possible to extract electrical energy from the vacuum, and indeed the possibility of doing so (at least in principle) has been

shown in a paper of that same name by Robert Forward (4) at Hughes Research Laboratories in Malibu, California.

What does this have to do with our basic questions? Let's start with the question as to why the electron in a simple hydrogen atom doesn't radiate as it circles the proton in its stable ground state atomic orbit.

This issue has been re-addressed in a recent paper by the author, this time taking into account what has been learned over the years about the effects of zero-point energy. (5) There it is shown that the electron can be seen 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, and an assumed equilibrium between these two processes leads to the correct values for the parameters known to define the ground-state orbit.

Thus the ground-state orbit is set by a dynamic equilibrium in which collapse of the state is prevented by the presence of the zero-point energy. The significance of this observation is that the very stability of matter itself appears to depend on the presence of the underlying sea of electromagnetic zero-point energy.

With regard to the gravitational attraction that is described so well by Einstein's theory, its fundamental nature is still not well understood. Whether addressed simply in terms of Newton's Law, or with the full rigor of general relativity, gravitational theory is basically descriptive in nature, 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 by and large have resorted to ever-increasing levels of mathematical sophistication and abstraction, as in the recent development of supergravity and superstring theories.

Taking a completely different tack when addressing these difficulties in the sixties, the well-known Russian physicist Andrei Sakharov put forward the somewhat radical hypothesis that gravitation might not be a fundamental interaction at all, but rather a secondary or residual effect associated with other (non-gravitational) fields.  
(6)

Specifically, Sakharov suggested that gravity might be an induced effect brought about by changes in the zero-point energy of the vacuum, due to the presence of matter.

If correct, gravity would then be understood as a variation on the Casimir theme, in which background zero-point-energy pressures were again responsible.

Although Sakharov did not develop the concept much further, he did outline certain criteria such a theory would have to meet such as predicting the value of the gravitational constant  $G$  in terms of zero-point-energy parameters.

The approach to gravity outlined by Sakharov has recently been addressed in detail, and with positive results, again by the author. (7)

The gravitational interaction is shown to begin with the fact that a particle situated in the sea of electromagnetic zero-point fluctuations develops a "jitter" motion, or ZITTERBEWEGUNG as it is called.

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, and the inter-particle coupling due to these fields results in the attractive gravitational force.

Gravity can thus be understood as a kind of long-range Casimir force. Because of its electromagnetic underpinning, gravitational theory in this form constitutes what is known in the literature as an "already-unified" theory.

The major benefit of the new approach is that it provides a basis for understanding various characteristics of the gravitational interaction hitherto unexplained.

These include the relative weakness of the gravitational force under ordinary circumstances (shown to be due to the fact that the coupling constant  $G$  depends inversely on the large value of the high-frequency cutoff of the zero-point-fluctuation spectrum); the existence of positive but not negative mass (traceable to a positive-only kinetic-energy basis for the mass parameter); and the fact that gravity cannot be shielded (a consequence of the fact that quantum zero-point-fluctuation "noise" in general cannot be shielded, a factor which in other contexts sets a lower limit on the detectability of electromagnetic signals).

As to where the ubiquitous electromagnetic zero-point energy comes from, historically there have been two schools of thought: existence by fiat as part of the boundary conditions of the universe, or generation by the (quantum-fluctuation) motion of charged particles that constitute matter.

A straightforward calculation of the latter possibility has recently been carried out by the author. (8)

It was assumed that zero-point fields drive particle motion, and that the sum of particle motions throughout the universe in turn generate the zero-point fields, in the form of a self-regenerating cosmological feedback cycle not unlike a cat chasing its own tail.

This self-consistent approach yielded the known zero-point field distribution, thus indicating a dynamic-generation process for the zero-point fields.

Now as to the question of why quantum theory. Although knowledge of zero-point fields emerged from quantum physics as that subject matured, Professor Timothy Boyer at City College in New York took a contrary view.

He began asking in the late sixties what would happen if we took classical physics as it was and introduced a background of random, classical fluctuating fields of the zero-point spectral distribution type. 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?

(First, it is clear from the previously-mentioned cosmological calculation that such a field distribution would reproduce itself on a continuing dynamic basis.)

Boyer began by tackling the problems that led to the introduction of quantum theory in the first place, such as the blackbody radiation curve and the photoelectric effect. One by one the known quantum results were reproduced by this upstart neoclassical approach, now generally referred to as Stochastic Electrodynamics (SED) (9), as contrasted to quantum electrodynamics (QED).

Indeed, Milonni at Los Alamos noted in a review of the Boyer work that had physicists in 1900 thought of taking this route, they would probably have been more comfortable with this classical approach than with Planck's hypothesis of the quantum, and one can only speculate as to the direction that physics would have taken then.

The list of topics successfully analyzed within the SED formulation (i.e., yielding precise quantitative agreement with QED treatments) has now been extended to include the harmonic oscillator, Casimir and Van der Waals forces and the thermal effects of acceleration through the vacuum, to name a few.

Out of this work emerged the reasons for such phenomena as the uncertainty principle, the incessant fluctuation of particle motion, 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 failures in SED, such as transparent derivation of something as simple as Schrodinger's equation, which turns out as yet to be an intractable problem.

Therefore, it is unlikely that quantum theory as we have come to know it and love it will be entirely replaced by a refurbished classical theory in the near future.

Nonetheless, 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 honored position.

And now to the preeminent 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 also?

Well, Prof. Edward Tryon of Hunter College of the City University of New York thought so when he proposed in 1973 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." (10)

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 tunneling from literally nothing into the something we call our universe. (11)

Although highly speculative, these types of models indicate once again that physicists find themselves turning again and again to the Void (and the fluctuations thereof) for their answers.

Those with a practical bent of mind may be left with yet one more unanswered question. Can this emerging Rosetta Stone of physics be used to translate such lofty insights into mundane application?

Could the engineer of the future specialize in "vacuum engineering?" Could the energy crisis be solved by harnessing the energies of the zero-point sea?

After all, since the basic zero-point energy form is highly random in nature, and tending towards self-cancellation, if a way could be found to bring order out of chaos, the, because of the highly energetic nature of the vacuum fluctuations, relatively large effects could in principle be produced.

Given our relative ignorance at this point, we must fall back on a quote given by Podolny (12) when contemplating this same 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 Mankind will put this remaining Fire of the Gods, the quantum fluctuations of empty space.

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