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Exploring The Vacuum

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Abstract

The historical progress in our understanding of what actually comprises the vacuum of space is traced here, as is the presence of what has become known as the Zero-Point Energy (ZPE) in the vacuum. Two different approaches in papers by Planck have led to two different ways of looking at the ZPE and atomic phenomena, namely Quantum Electro-Dynamics (QED) and Stochastic Electro-Dynamics (SED). Towards the close of the 20th Century, new insights indicated that atomic orbit energies are sustained by the ZPE, and that the speed of light may be strongly affected by changes in the properties of space via the ZPE. The origin of the ZPE is discussed as well as some resulting implications for processes operating at the inception of the universe.

Concepts Of The Vacuum

During the 20th century, our knowledge regarding space and the properties of the vacuum has taken a considerable leap forward. The vacuum is more unusual than is commonly realised. It is popularly considered to be a void, an emptiness, or just 'nothingness.' This is the definition of a bare vacuum[1]. However, as science has learned more about the properties of space, a new and contrasting description has arisen, which physicists call the physical vacuum[1].

To understand the difference between these two definitions, imagine you have a perfectly sealed container. First remove all solids and liquids from it, and then pump out all gases so no atoms or molecules remain. There is now a vacuum in the container. It was this concept in the 17th century that gave rise to the definition of a vacuum as a totally empty volume of space. It was later discovered that, although this vacuum would not transmit sound, it would transmit light and all other wavelengths of the electromagnetic spectrum ranging from the very short wavelength gamma rays, down to radio and longer wavelengths.

Then, late in the 19th century, it was realised that the vacuum could still contain heat or thermal radiation. If our container with the vacuum is now perfectly insulated so no heat can get in or out, and if it is then cooled to absolute zero, all thermal radiation will then have been removed. It might be expected that a complete vacuum now exists within the container. Surprisingly, this is not the case. Both theory and experiment show that this vacuum still contains measurable energy. This energy is called the zero-point energy (ZPE) because it exists even at absolute zero. The ZPE was discovered to be a universal phenomenon, uniform, all-pervasive, and penetrating every atomic structure throughout the cosmos. The existence of the ZPE was not suspected until the early 20th century for the same reason that we are unaware of the pressure of 15 pounds per square inch that earth's atmosphere imposes upon our bodies; there is a perfect balance within us and without. In the same way, the radiation pressures of the ZPE are everywhere balanced in our bodies as well as our measuring devices. In this sense, the material world of atoms, molecules and energy is like a ship supported by a sea of electromagnetic waves that make up the Zero-Point Energy.

The Historical Prelude

The uncovering of the existence of the ZPE all started in the late 19th century when experiments were conducted with a special cavity radiator known as a black-body. A small hole in an opaque cavity at any given temperature is an emitter of radiation, just as a perfectly black body would be at that temperature. As a consequence, radiation from such a source is called black-body radiation. In 1893, Wilhelm Wien empirically derived a formula describing the distribution of radiant energy density (the energy per unit volume) with wavelength, but the formula deviated a little from the experimental results at long wavelengths[2]. In 1899, Otto Lummer and Ernst Pringsheim conducted accurate experiments with a cavity radiator over a range of temperatures to determine if the discrepancy was real[3-4]. The data indicated that Wien's formula was indeed slightly deficient at long wavelengths. This small deviation was confirmed by similar experiments done by Ferdinand Kurlbaum and Heinrich Rubens. In 1900 Lord Rayleigh and James Jeans theoretically derived a relationship from classical physics in a way that should have been able to describe the experimental results. Instead the graph of their equation climbed dramatically at short wavelengths resulting in what was called the "ultraviolet catastrophe". This presented a crisis. It indicated that classical theory seemed to be unable to account for some important experimental observations.

However, in 1901 Max Planck was successful in deriving a mathematical expression that fitted the most recent experimental curves for the radiation emanating from a black body. This mathematical formulation overcame the so-called "ultraviolet catastrophe" at short wavelengths, and the lesser problems with Wien's formula at long wavelengths. Planck achieved this by hypothesizing that the energy states of point particle oscillators came in discrete units rather than being continuous[5]. That is to say, radiation is not emitted in continuous amounts but in discrete bundles of energy, which are described by the product of the new constant 'h', and the frequency, 'f', of the radiation[6]. As Kuhn has pointed out, Planck remained skeptical of the physical significance of his mathematical assumption and his constant 'h' for over a decade[7]. At best, Planck thought it probably only applied to oscillators and their emitted radiation, and therefore only amounted to a slight modification of Maxwell's theory of radiation.

Planck And Einstein Infer A Zero-Point Energy

Because of his dissatisfaction, Planck in 1910 formulated his so-called second theory. In this he derived the blackbody spectral formula with a weaker quantisation assumption. His equations, published in 1911, pointed directly to the existence of a zero-point energy[8-9]. Planck's equation for the radiant energy density of a black body had the same temperature-dependent term that he had derived in his first theory. However, this new approach contained an additional (½)hf term that was totally independent of temperature and indicated a uniform, isotropic background radiation. Inspired by this development, Niels Bohr in 1913 quantised energy levels in the atom on the basis of Planck's constant 'h'[10]. Even a decade later, Bohr was careful to point out that his model of the atom agreed with classical physics when quantum numbers are high. Today that is known as the "correspondence principle"[11].

Importantly, and also in 1913, Albert Einstein and Otto Stern published an analysis of the interaction between matter and radiation using simple dipole oscillators to represent charged particles, and an approach based firmly on classical physics[12]. Very significantly, they remarked that if, for some reason, such a dipole oscillator had a zero-point energy, that is, if there was an irreducible energy of 'hf' at absolute zero of temperature, the Planck radiation formula would result *without the need to invoke quantisation at all*. This important point has been proven correct since Timothy Boyer and others have made just such derivations[13, 1]. These calculations show that in fact the irreducible energy of each oscillator must be (½)hf, as Planck and Nernst correctly deduced, rather than Einstein and Stern's hf.

First Observational Proof For The ZPE

In 1916 Walther Nernst took up the indication of the ZPE's existence from Planck's second theory equation along with Einstein and Stern's proposal, and suggested that the universe may actually be filled with vast amounts of this zero-point radiation (ZPR)[14]. In effect, Nernst saw that both of these developments required an intrinsic cosmological origin for the ZPE. However, at that point the ZPE had only appeared in equations and theory; there was only no observational proof. If indeed it was cosmological in origin, then there should be some kind of observational proof for its existence from experiments that could be performed anywhere.

In 1925 that experimental evidence was obtained and the existence of the Zero-Point Energy was confirmed. The American chemist Robert Mulliken found this proof in the spectrum of boron monoxide. As he analyzed the wavelengths of these spectral lines, he discovered a slight shift from the theoretical position that these lines would have had if the ZPE did not exist[15]. What happens is that the zero-point fields slightly perturb an electron in an atom so that, when it makes a transition from one state to another, it emits light whose wavelength is shifted slightly from its normal value[16]. Some years later, a similar shift of wavelength in the microwave region of the hydrogen spectrum was experimentally established by Willis Lamb and Robert Retherford using techniques developed for radar[17]. Today, the Lamb shift of spectral lines, as the effect is now generally called, is quoted as one of the observational proofs for the existence of the ZPE. In fact, Lamb himself stated that the results of this confirmatory experiment were *"a proof that the [perfect] vacuum does not exist"* [18].

Physics Makes A Choice

It is at this point, in the mid-1920's, that the path to be followed by physics hung in the balance. It was possible that physics could have adopted the approach suggested by Planck's second theory, plus the contributions from Einstein, Stern and Nernst, in which classical theory plus an intrinsic cosmological ZPE could account for the observed phenomena. This was now backed by Mulliken's observational proof for the existence of the ZPE. The alternative was to follow Planck's first theory without the ZPE term. Four developments then occurred in four years as a result of some mathematical explorations using Planck's first theory that swung the balance.

(1). First, Louis de Broglie in 1924 proposed that, just as experiments indicate that light waves could sometimes behave as particles, or photons, depending on the measurement you make, so a particle under some circumstances might also behave as a wave. He proposed that the wavelength of a moving particle would be h/p where 'p' is the momentum of the particle and 'h' is Planck's constant[19]. (2). Next, in 1925, Max Born, Werner Heisenberg and Pascual Jordan developed quantum mechanics, with Paul Dirac formulating his own version after seeing an advance copy of their work[20]. (3). Then in 1926, Erwin Schroedinger, after musing over the significance of de Broglie's proposal for two years, proposed the wave-mechanical theory of the hydrogen atom from which the Schroedinger equation originated[21]. (4). Finally, in 1927, Heisenberg published his "uncertainty principle"[22].

The Heisenberg uncertainty principle states that the uncertainty of time multiplied by the uncertainty of the energy of a particle is closely approximated to Planck's constant 'h' divided by 2π. In a parallel way, the uncertainty of position of a particle multiplied by the uncertainty in the particle's momentum is again approximately equal to $h/(2\pi)$. This quantum uncertainty, or indeterminacy, governed by the value of 'h', imposes fundamental limitations on the precision with which a number of physical quantities associated with atomic processes can be measured. When Planck's quantum condition and Heisenberg's uncertainty principle are applied to atomic particles at absolute zero, theoretically each particle should have some residual motion and hence energy, namely the zero-point energy. After a detailed treatment of the foregoing sketch, Eisberg and Resnick go on to say *"We conclude that there must be a zero-point energy because there must be a zero-point motion ... the particle cannot have zero total energy"* [23]. A similar argument can be applied to electromagnetic fields[24]. Thus the ZPE becomes a part of this approach, but only indirectly through the uncertainty principle.

The actual origin of the ZPE on this approach has several schools of thought. One in particular is the logical result of this treatment. Since charged particles in motion emit electromagnetic radiation, this school of thought proposes that *"the sum of all particle motions throughout the Universe generates the zero-point fields"* and that in turn *"the zero-point fields drive the motion of all particles of matter in the Universe ... as a self-regenerating cosmological feedback cycle"* [16]. On this explanation the ZPE becomes an artifact of atomic particle existence. By contrast, Planck's second theory reversed this order; it directly implied that the ZPE was the cosmological entity that influenced atomic particle behaviour, and not vice versa.

Another approach to the origin of the ZPE, which contrasts with the results from Planck's second theory, is epitomized by the following comment: *"As [this equation] shows, even the lowest state has some energy, the zero-point energy. Its presence is a purely quantum mechanical effect, and can be interpreted in terms of the uncertainty principle"* [25]. Essentially this explanation says the ZPE exists because quantum laws require it. This is one reason why some physicists use to argue over whether the ZPE was a genuine entity or only a mathematical construct since it had come in indirectly via the Heisenberg uncertainty principle. By contrast, Planck's second approach predicted its presence as an intrinsic part of the universe, and hence something that potentially would govern atomic behaviour. As noted above, this prediction was experimentally verified by Mulliken and Lamb. However, by the time Lamb had performed his confirmatory experiment, quantum electrodynamics (QED) was well on the way to becoming the "standard physics" of the 20th century. In fact, since the discovery of electron spin and the Pauli exclusion principle were also made in 1925, along with Heisenberg's, de Broglie's and Schrödinger's contributions within the following two years, some felt much earlier that the complete picture could already be discerned. This is why, in 1929, Paul Dirac stated: *"The underlying physical laws necessary for the mathematical theory of a large part of physics and the whole of chemistry are thus completely known"* [26-27].

Re-Thinking The Choice

However, in 1962, Louis de Broglie published a book in which he indicated that serious consideration of Planck's alternative formulation, embracing classical theory with an intrinsic cosmological ZPE, had been widespread[28]. This initiated a re-examination of that alternative. As it turns out, this re-examination has shown that three out of the four key developments mentioned above have a very viable explanation through classical physics plus the ZPE. First, Edward Nelson published a landmark paper in 1966. The abstract states in part: *"We shall attempt to show in this paper that the radical departure from classical physics produced by the introduction of quantum mechanics 40 years ago was unnecessary. An entirely classical derivation and interpretation of the Schroedinger equation will be given, following a line of thought which is a natural development of reasoning used in statistical mechanics and in the theory of Brownian motion"* [29]. This Newtonian derivation of the Schroedinger equation using statistical mechanics provided a classical alternative to the esoteric Copenhagen interpretation of quantum mechanics.

With this impetus, Boyer, in 1975, used classical physics plus the ZPE to demonstrate that the fluctuations caused by the Zero-Point Fields (ZPF) on the positions of particles are in exact agreement with quantum theory and Heisenberg's uncertainty principle[30]. Thus the Heisenberg uncertainty relationship on this approach is not merely the result of theoretical quantum laws, but due to the fact that there is a universal perturbing ZPF acting on everything. Importantly, on this approach, Planck's quantum constant, 'h', becomes a measure of the strength of the ZPF. This situation arises directly from the additional (½)hf term in Planck's second theory that describes the ZPE. The physical reason behind all this is that fluctuations of the ZPF provide an irreducible random noise at the atomic particle level that is interpreted as Heisenberg's innate uncertainty [31-32, 1]. On this approach, therefore, the zero-point fields may be considered to be the ultimate source of this fundamental limitation with which we can measure some atomic phenomena and, as such, give rise to the indeterminacy or uncertainty of QED theory mentioned above.

Third, the question of de Broglie's wave-like behaviour of matter was addressed. This characteristic was not just a theoretical construct. The wave-like characteristics were proven to exist by the 1927 experiment of Clinton Davisson and Lester Germer where electrons were diffracted from single crystals in a way that only waves can be[33]. This experimental evidence was confirmed shortly after when George Thomson obtained similar diffraction patterns by passing electrons through powder and thin foils[34]. The problem has been to explain how particles acquire these wave-like characteristics; it is not sufficient to say that it is just a law of nature.

The answer to this problem came partly from de Broglie himself. Like Planck, he had made a second, less well-known, proposal. His thinking went along the following lines. If you equate both Einstein's equation $E = mc^2$ and Planck's $E = hf$, where 'E' is the energy of the particle of mass 'm', and where 'c' is the speed of light, you have a frequency, $f = mc^2/h$, called the Compton frequency. De Broglie felt that this frequency represented an intrinsic oscillation of the charge associated with an electron or similar particle. If he had then identified the ZPE from Planck's second theory as the source of the oscillation, de Broglie would have been on his way to a solution[35]. Haisch and Rueda noted that the electron really does oscillate at the Compton frequency in its own rest frame of reference due to the ZPE[36-37]. They point out that *"when you view the electron from a moving frame there is a beat frequency superimposed on this oscillation due to the Doppler shift. It turns out that this beat frequency proves to be exactly the de Broglie wavelength of a moving electron. ... the ZPF drives the electron to undergo some kind of oscillation at the Compton frequency... and this is where and how the de Broglie wavelength originates due to Doppler shifts"* [18].

The Two Approaches To Modern Physics

There has been a steady line of papers published using this approach with the ZPE, which has been called Stochastic Electro-Dynamics (SED) in contrast to the more standard QED. The difference between SED and QED physics has been expressed thus: *"Philosophically, a universe filled – for reasons unknown – with a ZPF but only one set of physical laws (classical physics consisting of mechanics and electrodynamics), would appear to be on an equal footing with a universe governed – for reasons unknown – by two distinct physical laws (classical and quantum). In terms of physics, though, SED and QED are not on an equal footing since ... the ratio of man-years devoted to the development of QED is orders of magnitude greater than the expenditure so far on SED"* [38].

Nevertheless, SED physics, based on the existence of an intrinsic cosmological ZPE, has been able to derive and interpret classically the black-body spectrum, the Heisenberg uncertainty relationship, the Schroedinger equation, and explain the wave-nature of matter. These were the very same factors that, interpreted without the ZPE, gave rise to QED concepts. In listing some of the successes of SED physics, it was stated that *"The most optimistic outcome of the SED approach would be to demonstrate that classical physics plus a classical electromagnetic ZPF could successfully replicate all quantum phenomena"* [32]. This requires SED physics to overhaul the 40-year head-start of the QED approach. Nevertheless, for one review of SED physics, which includes older reviews, see reference[39], with a more recent assessment by reference[35].

As a result of these developments, some physical phenomena now have two possible explanations, one from the QED approach, another from SED physics. The explanation that is used is a matter of aesthetics, since the mathematics of both give the same answers. Nevertheless, SED physics has the advantage that it is often more easy to conceptualize and avoids some of the more esoteric mathematics of QED theory. Despite these advantages, and despite the fact that SED physics is perfectly respectable, SED physicists are currently in a minority so the QED approach is considered "standard", while SED physics is yet to be fully formalized.

Introducing The Zero-Point Energy

Although arising for conceptually different reasons, the ZPE is therefore an integral part of both QED and SED physics. For the moment, let us follow SED physics which considers the vacuum at the atomic or sub-atomic level to inherently contain the turbulent sea of randomly fluctuating electro-magnetic fields or waves of the ZPE. These waves exist at all wavelengths longer than the Planck length cutoff [40]. At this length, about 10^{-33} centimetres, the vacuum itself breaks up and becomes granular in a way discussed later. Thus the vacuum itself provides a natural cutoff wavelength for the ZPE. At the macroscopic level, however, the vacuum is smooth and even featureless since these all-pervasive zero-point fields (ZPF) are homogeneous and isotropic throughout the cosmos. Indeed, the flow of radiation is on average the same in all directions, so there is no net flux of energy or momentum perceived by an observer. Furthermore, observation shows that this zero-point radiation (ZPR) must be Lorentz invariant and look the same to two observers no matter what their relative velocity is[1]. This Lorentz invariance is only obtained with an energy density proportional to the frequency cubed, precisely what Planck's equation from his second theory predicted.

Note that this Lorentz invariance makes the ZPF crucially different from any of the 19th century concepts of an ether[41]. The old ether concept indicated that an absolute velocity through the ether could be determined. However, the Lorentz invariant condition indicates that the zero-point radiation will look the same to all observers regardless of their relative velocities. Nevertheless, even though relative velocities through the ZPE cannot be detected, accelerated motion through the ZPE can be detected as the addition of a thermal radiation spectrum to the unchanged ZPE spectrum. In other words, an observer accelerating through the vacuum would see themselves surrounded by radiation like that from a hot object; the greater the acceleration, the hotter the radiation[42, 1]. However, an extremely high acceleration (10^{21} g's) is required to give a radiation bath temperature rise of only 1 degree Kelvin. This mathematical relation connecting acceleration through the ZPE and temperature was discovered independently by Paul Davies[43] and William Unruh[44]. The phenomenon is now called the Davies-Unruh effect.

The Energy In The Vacuum

The magnitude of the ZPE is truly large. It is usually quoted in terms of energy per unit of volume or energy density. Well-known physicist Richard Feynman and others[45] have pointed out that the amount of ZPE in one cubic centimetre of the vacuum "*is greater than the energy density in an atomic nucleus*" [31]. Indeed, it has been stated that: *"Formally, physicists attribute an infinite amount of energy to this background. But, even* *when they impose appropriate cutoffs at high frequency, they estimate conservatively that the zero-point density is comparable to the energy density inside an atomic nucleus"* [16]. In an atomic nucleus alone, the energy density is of the order of 10^{44} ergs per cubic centimetre.

Estimates of the energy density of the ZPE therefore range from at least 10^{44} ergs per cubic centimetre up to infinity. For example, Jon Noring made the statement that *"Quantum Mechanics predicts the energy density [of the ZPE] is on the order of an incomprehensible 10^{98} ergs per cubic centimetre."* Prigogine and Stengers also analysed the situation and provided estimates of the size of the ZPE ranging from 10^{100} ergs per cubic centimetre up to infinity. In case this is dismissed as fanciful, Stephen M. Barnett from the University of Oxford stated: *"The mysterious nature of the vacuum [is] revealed by quantum electrodynamics. It is not an empty nothing, but contains randomly fluctuating electromagnetic fields ... with an infinite zero-point energy"* [46]. In actual practice, recent work suggests there may be an upper limit for the estimation of the ZPE at about 10^{114} ergs per cubic centimetre imposed by the Planck length cutoff[40]. Paul Davies put the estimate slightly higher: *"about 10^{110} joules per cubic centimetre"* [42]. The realization that the Planck length cutoff existed also provided QED physicists with a reason to accept the ZPE as a real rather than just a virtual entity. Without the cutoff wavelength, the energy density of the ZPF goes to infinity and so, unlike most real fields, it could not be integrated mathematically in the QED equations[47].

In order to appreciate the magnitude of the ZPE in each cubic centimetre of space, consider a conservative estimate of 10^{58} ergs/cc. Most people are familiar with the light bulbs with which we illuminate our houses. The one in my office is labelled as 150 watts. By comparison, our sun radiates energy at the rate of 3.8×10^{26} watts. In our galaxy there are in excess of 100 billion stars. If we assume they all radiate at about the same intensity as our sun, then the amount of energy expended by our entire galaxy of stars shining for one million years is roughly equivalent to the energy locked up in one cubic centimetre of space. The physical vacuum is not an empty nothingness.

Evidence For The Existence Of The ZPE

Experimental evidence soon built up hinting at the existence of the ZPE, although its fluctuations do not become significant enough to be observed until the atomic level is attained. For example, the ZPE can explain why cooling alone will never freeze liquid helium[25, 48]. Unless pressure is applied, these ZPE fluctuations prevent helium's atoms from getting close enough to permit solidification[15]. In electronic circuits, such as microwave receivers, another problem surfaces because ZPE fluctuations cause a random "noise" that places limits on the level to which signals can be amplified. This "noise" can never be removed no matter how perfect the technology.

There is other physical evidence for the existence of the ZPE proving that it is not just a theoretical construct. One such piece of evidence is something called the surface Casimir effect, predicted Hendrik Casimir, the Dutch scientist, in 1948 and confirmed nine years later by M. J. Sparnaay of the Philips Laboratory in Eindhoven, Holland[1]. The Casimir effect can be demonstrated by bringing two large metal plates very close together in a vacuum. When they are close, but not touching, there is a small but measurable force that pushes them together. An elegant analysis by Milonni, Cook and Goggin explained this effect simply using SED physics[49]. Given that the ZPE consists of electromagnetic waves, then as the metal plates are brought closer, they end up excluding all wavelengths of the ZPF between the plates except those for which a whole number of half-waves is equal to the plates' distance apart. In other words, all the long wavelengths of the ZPF are now acting on the plates from the outside with no long waves acting from within to balance the pressure. The combined radiation pressure of these external waves then forces the plates together[16, 32]. The same effect can be seen on the ocean. Sailors have noted that if the distance between two boats is less than the distance between two wave crests (or one wavelength), the boats are forced towards each other.

The Casimir effect is directly proportional to the area of the plates. However, unlike other possible forces with which it may be confused, the Casimir force is inversely proportional to the fourth power of the plates' distance apart[50]. For plates with an area of one square centimetre separated by 0.5 thousandths of a millimetre, this force is equivalent to a weight of 0.2 milligrams. In January of 1997, Steven Lamoreaux[51] reported experimental verification of these details within 5%. Then in November 1998, Umar Mohideen and Anushree Roy reported that they had verified the theory to within an accuracy of 1% in an experiment that utilized the capabilities of an atomic force microscope[52].

Although it is also discussed below in terms of QED concepts, the surface Casimir effect neatly demonstrates the existence of the ZPE in the form of electromagnetic waves. Interestingly, it has been pointed out that there is a microscopic version of the same phenomenon. In the case of closely spaced atoms or molecules the all-pervasive ZPF result in short-range attractive forces that are known as van der Waals forces[15, 31-32]. It is these attractive forces that permit real gases to be turned into liquids[15]. (When an 'ideal' gas is compressed, it behaves in a mathematically precise way. When a real gas is compressed, its behaviour deviates from the ideal equation[53]).

Paul Dirac And The Vacuum

In 1928, Paul Dirac formulated the relativistic quantum mechanical theory of the electron because the Schroedinger equation only worked for slow-moving objects. His equations for fast-moving electrons had both positive and negative solutions. The negative solution indicated that electrons existed with a negative total relativistic energy, a somewhat unusual notion. Rather than discard the negative solution to his equations as unrealistic, Dirac followed the idea through in 1930 with an ingenious concept[54]. If a continuum of negative energy levels existed, then electrons moving from positive energy levels into the negative levels would emit a photon of light as their excess of energy was given up. However, this was not observed, so Dirac went one stage further. He noted that electrons obey the Pauli exclusion principle in which only one electron can exist in every quantum state. He therefore postulated that all negative energy states were already filled. Consequently, the vacuum consisted of a "Dirac sea" of an infinite number of electrons filling all the negative energy levels, while the positive energy levels were empty.

The possibility then existed of exciting an electron in a negative energy level to an unoccupied positive energy level by the absorption of a photon of light. This left a hole in the negative electron energy level, which would have all the characteristics of a positive electron or positron[54]. Thus the concept of electron-positron pairs was born. Two years later, Carl Anderson discovered the first positron during cosmic ray research. Then, in 1933, Blackett and Occhialini obtained the first cloud chamber photos of electron-positron pair production[55], while later that same year Thibaud and Joliot observed the radiation from pair annihilation and proved that the mass of the positron was equal to that of the electron[55]. In 1955, a team led by Owen Chamberlain and Emilio Segre generated the first proton-antiproton pairs, experimentally establishing the concept of particle-antiparticle pairs[56].

However, this prediction of particle-antiparticle pairs by Dirac came as a result of trying to overcome the problem of negative energy in the equations. Dirac's view of the vacuum resulted from this. There are those who still hold to the "Dirac sea" model for the vacuum, but as Henning Genz, professor of theoretical physics at the University of Karlsruhe, Germany stated: *"The infinite sea of electrons in the Dirac vacuum, with their negative energy and their infinite charge, cannot be the answer. They don't even figure in the actual quantum field theory of electrons. They are neither real nor observable; they are an artifact of an evolving theory"* [57]. Even more recently, in the Spring of 2002, Mark Hindmarsh, lecturer in quantum theory at the University of Sussex, pointed out: *"this picture of a negative energy 'sea' of electrons leaves much to be desired. Bosons, particles with integer spin such as the photon (spin 1) and the pion (spin 0), do not obey the Pauli Exclusion Principle and yet they still have negative energy states. Thus there can be no Dirac sea picture and we are left where we were before. It is only if we abandon simple wave mechanics and turn to quantum field theory that we find a satisfactory resolution of this problem"* [58]. Indeed, in quantum field theory, particles and antiparticles appear from the outset on an equal footing, and no negative energy states or negative probabilities occur.

The ZPE And Virtual Particles

Nevertheless, experimental evidence had now established the existence of particle-antiparticle pairs that annihilate giving up any excess energy. These concepts proved useful to understanding the vacuum and *"they help us as we put together our image of the actual vacuum. We glean from [Dirac] that every particle has its antiparticle of opposite charge and that particle plus antiparticle are nothing but an excitation of the vacuum ... Conversely, we saw that every real particle-antiparticle pair can annihilate into a pure energy excitation of the vacuum"* [57]. By way of elaboration, let us suppose for a moment that there is nothing in the vacuum; no matter or radiation at all. According to the Heisenberg uncertainty principle, there is an uncertainty in the amount of energy such a vacuum could contain. On average, the energy may be zero, but there will always be a slight uncertainty in this energy. This small uncertainty allows a non-zero energy to exist for short intervals of time. This period of time is defined by $h/(2\pi)$ divided by the uncertainty in the energy.

Because of the equivalence between matter and energy from Einstein's famous formula, these small energy fluctuations will produce particle-antiparticle pairs that exist for a short time and then disappear. This allows the average properties of the universe to be maintained. Because of their ephemeral existence, they are called virtual particles. Consequently, from Heisenberg's uncertainty principle alone, QED requires the vacuum to be filled with virtual particle pairs flipping in and out of existence like a sort of quantum foam. Indeed, virtual photons also pop in and out of existence as they are emitted and then absorbed by various particle processes. The QED approach assigns much of the vacuum energy density to these virtual particles. Because of this incessant activity on the atomic scale, the vacuum has been described as a *"seething sea of activity"* [15], or *"the seething vacuum"* [16].

It is important to note that the SED approach inevitably requires virtual particles to exist also. Since the whole universe is filled with the electromagnetic ZPE at a high energy density, Einstein's relationship demands that this energy be inter-convertible with mass. In order to maintain conservation of electronic charge, any such particulate matter that condenses out of the intense local fluctuations of the vacuum fields at the atomic level must be in the form of particle-antiparticle pairs. An energetic photon of light may also raise the local energy threshold high enough to allow a virtual electron and positron pair to form, annihilate, and emit the photon again. In this sense, the SED approach has replaced the "Dirac sea" of electrons with the electromagnetic ZPE.

It is in this context of virtual particle pairs existing in the vacuum that another important step forward was made in June of 2001 by Takaaki Musha of Yokohama, Japan. He pointed out that if the ZPE allowed the formation of virtual particles, then the formation of virtual tachyons was also logical. His subsequent analysis demonstrated that the Cherenkov radiation from these virtual tachyons had the same spectrum and mass density as the cosmic microwave background radiation[59]. This is a completely consistent approach to the whole topic of vacuum characteristics while simultaneously holding some serious implications for cosmology.

The origin of the Casimir effect can now be discussed in QED terms since this can best be done in the context of virtual particles and/or photons on that model. It will be recalled that this approach assigns all particles with a wavelength. As a result, the physics demands that only those virtual particles whose wavelengths can fit a whole number of times into the gap between the Casimir plates will appear there. The rest are excluded. Consequently, the vacuum energy density between the plates will be less than the energy density outside, so the plates are forced together. A similar line of argument can also apply to the virtual photons between the plates. It can thus be seen that both the QED and SED explanations are viable alternatives. However, SED uses the intrinsic electromagnetic waves of the ZPE directly, while QED uses virtual particles (and/or photons) that have arisen from the vacuum fluctuations that may be attributed to the action of the Heisenberg uncertainty principle. However, no matter which way it is explained, this discussion of the Casimir effect has important implications that only became apparent in the early months of 1990.

The ZPE And The Speed Of Light

These important implications arise since the vacuum energy density between the Casimir plates was lower than outside as a result of the exclusion of the longer wavelengths of the ZPE and some virtual particle pairs. In February and March of 1990, Klaus Scharnhorst at the Humboldt University in Berlin, and Gabriel Barton of the University of Sussex in Brighton, England investigated the effects of this lower energy density more thoroughly. Scharnhorst used QED theory to calculate what happens to light travelling between the Casimir plates. He states in his Abstract that any change in vacuum energy density *"in the simplest terms consists in causing a change in the velocity of light"* [60]. Scharnhorst elaborated: *"This is simply the result of the change in the vacuum structure enforced by the plates"* [61]. He concludes: *"In the simplest terms the impact of the plates on the propagation of light in the vacuum between them can be described by saying that they cause a change (more precisely a raising) in the velocity of light for electromagnetic waves propagating perpendicular to the plates…"* [60].

Barton also used quantum interaction laws, but took a somewhat different approach. He states*: "But (as known from the Casimir effect) the intensity of the zero-point field between parallel mirrors is less than unbounded space, which for light normal to the mirrors entails a refractive index n < 1 and speed c/n > c, as Scharnhorst has recently found by other arguments"* [62]. Barton concluded: *"One could say that between parallel mirrors, even at zero temperature, there is a disturbance of the electromagnetic field, and it is as if between the mirrors, the energy density of the electromagnetic field were less than zero. So it seemed to me that if a positive energy density makes light go slower, then, in a sense, a negative energy density, such as you have between mirrors, would make light go faster"* [61].

In commenting in Nature on the outcome of the investigation, Stephen Barnett led into the discussion by stating that *"The source of this surprising development is the mysterious nature of the vacuum as revealed by quantum electrodynamics. It is not an empty nothing but contains randomly fluctuating electromagnetic fields and virtual electron-positron pairs with an infinite zero-point energy. Light propagating through space interacts with the vacuum fields, and observable properties, including the speed of light, are in part determined by this interaction"* [63].

Lightspeed And Virtual Particles

In this context, there are important results from a further analysis done in 1995 on the speed of light in 'modified vacua', including the Casimir vacuum. The Abstract of the analysis reads in part: *"Whether photons move faster or slower than c depends only on the lower or higher energy density of the modified vacuum respectively"* [64]. The analysis concluded that for all vacua *"It follows automatically that if the vacuum has a lower energy density than the standard vacuum, [lightspeed] v >1, and vice versa",* where the notation v = 1 denotes the current speed of light. The reason given by the analysis for the change in lightspeed is that *"Modifications of the vacuum that populate it with real or virtual particles … reduces the speed of massless particles [light photons]. The opposite situation, e.g. the Casimir vacuum, corresponds to modifications of the vacuum that* *eliminate virtual modes and, consequently, their would-be scattering. The speed of massless particles is, then, increased."*

Barnett picks up on this point and explains further: *"Scharnhorst and Barton suggest that a modification of the vacuum can produce a change in its permittivity [and permeability] with a resulting change in the speed of light. ... The role of virtual particles in determining the permittivity of the vacuum is analogous to that of atoms or molecules in determining the relative permittivity of a dielectric material. The light propagating in the material can be absorbed ... [but] the atoms remain in their excited states for only a very short time before re-emitting the light. This absorption and re-emission is responsible for the refractive index of the material and results in the well-known reduction of the speed of light"* [63]. Barnett concludes: *"The vacuum is certainly a most mysterious and elusive object…The suggestion that [the] value of the speed of light is determined by its structure is worthy of serious investigation by theoretical physicists."*

Lightspeed And Vacuum Energy Density

It should be noted that Barton considered the magnetic properties of space (the permeability) as well as the vacuum's electric properties (the permittivity) in his calculations, and both are uniformly affected by the Casimir process at all wavelengths. Scharnhorst's treatment confirms this as it also revealed that there is no dispersion in this process. This made it possible for Barnett to comment in Nature: *"Scharnhorst and Barton …[show that] with the apparent increase in the velocity of light, the phase, group and signal velocities will therefore all increase by about the same amount"* [63].

Also of significance is Barton's comment: *"But between mirrors the intensity of the zero-point oscillations of the Maxwell field is less than in unbounded space, a familiar conclusion confirmed experimentally by the Casimir effect; and the same ... reduction in intensity entails a proportionate drop of the refractive index below unity ($\Delta n<0$)"* [62]. In fact Barton shows that the permittivity, ε, and permeability, μ, of the vacuum between the plates (or mirrors) are both proportional to the Casimir vacuum energy density, U. This may also be discerned from classical electrodynamics whose equations show the converse, namely that, if other factors are unchanged, then generally energy densities are proportional to both the permittivity and the permeability individually [65]. Therefore, since permittivity, ε, and permeability, μ, are uniformly affected by the Casimir process, then light speed, c, is inversely proportional to both individually since

$$c^2 = 1/(\varepsilon\mu) \qquad \text{so it follows that} \qquad c \propto 1/\varepsilon \propto 1/\mu \qquad (1)$$

where the symbol ($\propto$) is used to mean "is proportional to". Therefore, since the permittivity and permeability are individually proportional to the vacuum energy density, U, it follows that

$$c \propto 1/U \qquad (2)$$

These conclusions may also be derived from a more classical approach. If the energy density of an electromagnetic field is given by U, with E and H being the electric and magnetic intensity of the field of a plane wave, then the standard equation reads[66]:

$U = ½ (\varepsilon E^2 + \mu H^2)$ so that $2U = (\varepsilon E^2 + \mu H^2)$ (3)

Here ε and μ are the electric permittivity and magnetic permeability of free space respectively. However, this equation for a plane wave is only equivalent to one third of the total energy density allowing for all possible directions of propagation[67]. Therefore, the quantity U must be divided by 3. Furthermore, since it is standard to put[68]

$\varepsilon E^2 = \mu H^2$ (4)

then it follows from (3) that

$U/3 = \varepsilon E^2 = \mu H^2$ (5)

Equation (5) can be re-arranged to give the result

$\varepsilon = U/(3E^2)$ and $\mu = U/(3H^2)$ (6)

Let take these equations and apply them exclusively to the intrinsic properties of the vacuum. In this case the fabric of space is reacting in such a way that the electric permittivity of free space can be described as being equal to $U/(3E^2)$ while the magnetic permeability of the vacuum is given by $U/(3H^2)$. Since we are dealing here uniquely with the properties of the fabric of space, the energy density, U, can only refer to the energy density of the Zero-Point Fields. In like manner, E and H must be referring specifically to the average electric and magnetic intensities of those Zero-Point Fields. If the electric and magnetic results from (6) are now multiplied together, we have:

$\varepsilon\mu = U^2/(9E^2H^2) = 1/c^2$ (7)

where the last step in (7) comes from equation (1). This leads to the conclusion that the properties of the vacuum govern lightspeed, c, in such a way that

$c = 3EH/U$ (8)

where U is the energy density of the ZPF with E and H being the average electric and magnetic intensities of that field. Thus the proportionality derived more heuristically in (2) can now be stated as an equality.

In other words, the overall result from the whole Casimir discussion is that lightspeed is inversely proportional to the energy density of the vacuum. Therefore, if the energy density of the ZPE changes, an inversely proportional change in the speed of light will occur. This relationship appears to be an inherent property of the vacuum in which the intrinsic energy density in the fabric of space and the velocity at which this intrinsic energy propagates are inversely related.

The ZPE And Atoms

Before discussing the fabric of space and the origin of the ZPE, one further development must be mentioned that occurred in 1987. According to classical physics, if the atom is like a miniature solar system, then the circling electrons should radiate away their energy, spiral into the nucleus, and the whole structure disappear in a flash of light. This problem exists because electronic charges undergoing acceleration radiate energy according to classical physics. Well, this spiral of annihilation does not happen to the orbiting electron, and in order to resolve the problem the mathematical rules of quantum mechanics were applied. These rules restrain electrons to particular orbits, or energy levels, in which no energy is radiated unless the electrons jump from one orbit to another. These quantum concepts work well and give all the right answers. However, there are some physicists for whom the fundamental question of why the orbiting electron does not radiate energy remains unresolved. They felt that a quantum law or rule is one thing; a real physical explanation is another.

A paper published in May 1987 shows how the problem may be resolved[69]. The Abstract summarizes: *"the ground state of the hydrogen atom can be precisely defined as resulting from a dynamic equilibrium between radiation emitted due to acceleration of the electron in its ground state orbit and radiation absorbed from the zero-point fluctuations of the background vacuum electromagnetic field…"* In other words, the electron can be considered as continually radiating away its energy, but simultaneously absorbing a compensating amount of energy from the ZPE sea in which the atom is immersed. In a similar way, a child on a swing gets a push just as the swing starts to slow down, and a resonance is set up between the period of the swing and the frequency of the pushes. So the orbiting electron also gets resonantly timed pushes from the ZPE that keep it going. This had been explained earlier in a parallel, but even more enlightening way as part of a course on stochastic processes applied to physics. The statement was made[47]: *"With somewhat more quantitative estimations, Boyer [70] and Claverie and Diner [71] have shown that if one considers circular orbits only, then one obtains an equilibrium radius of the expected size [the Bohr radius]: for smaller distances, the electron absorbs too much energy from the [ZPE] field…and tends to escape, whereas for larger distances it radiates too much and tends to fall towards the nucleus."*

Although the electromagnetic ZPE was considered in the case of the 1987 paper, as in other SED treatments, an important statement was made in conclusion. It read: *"Indeed, for the problem considered here, in the corresponding QED treatment the Heisenberg equations of motion in operator form are formally identical to the equations in this text, and quantum-mechanical ensemble averaging leads to the same results. Thus, the SED treatment and conclusions presented here are reproduced without change in the corresponding QED treatment"* [69]. In other words, both QED and SED maths give the same result, ensuring its validity. This development was considered sufficiently important for New Scientist to devote two articles to the topic[72-73]. The first of these was entitled *"Why atoms don't collapse."*

This title introduces the final paragraph of that original paper, which carries an unusual significance. It reads: *"Finally, it is seen that a well-defined, precise quantitative argument can be made that the ground state of the hydrogen atom is defined by a dynamic equilibrium in which the collapse of the state is prevented by the presence of the zero-point fluctuations of the electromagnetic field. This carries with it the attendant implication that the stability of matter itself is largely mediated by ZPF phenomena in the manner described here, a concept that transcends the usual interpretation of the role and significance of zero-point fluctuations of the vacuum electromagnetic field"* [69]. In a word, it appears that the very existence of atoms and atomic structures depends on this underlying sea of the electromagnetic ZPE. Without the ZPE all matter in the universe would undergo instantaneous collapse. Under these circumstances, some understanding of the origin of the ZPE itself becomes important.

Discerning The Origin Of The ZPE

As noted earlier, the actual origin of the ZPE has several schools of thought. *"The first explanation ... is that the zero-point energy was fixed arbitrarily at the birth of the Universe, as part of its so-called boundary conditions"* [16]. A second school of thought proposes that *"the sum of all particle motions throughout the Universe generates the zero-point fields"* and that in turn *"the zero-point fields drive the motion of all particles of matter in the Universe ... as a self-regenerating cosmological feedback cycle"* [16]. On this second explanation the ZPE and atomic particles both require the existence of each other. However, if there is even a hint that all matter in the universe is likely to undergo collapse without the ZPE, it becomes difficult to envisage how atomic structures emerged in the first place by the feedback mechanism. On this basis it would seem that something more fundamental is required as an origin for the continuing ZPE, even though the feedback mechanism may perhaps sustain the ZPE once formed. To that end, a consideration of the conditions pertaining at the inception of the universe may be worth investigating. In order to do this effectively, it is important to realize that there is another aspect of the physical vacuum that needs to be introduced.

The "Granular Structure" Of Space

When dealing with the vacuum, size considerations are all-important. On a large scale the physical vacuum has properties that are uniform throughout the cosmos, and seemingly smooth and featureless. However, on an atomic scale, the vacuum may be described as turbulent. Indeed, it is in this realm of the very small that our understanding of the vacuum has increased. The size of the atom is roughly 10^{-8} centimetres, while the size of a fundamental atomic particle, such as an electron, is about 10^{-13} centimetres or less. It is at this level that the turbulence of the ZPE is acting on matter. However, as the scale becomes smaller, very little happens until a major change occurs near the scale of the Planck length (1.616×10^{-33} centimetres), which may be designated as L*. In 1983, F. M. Pipkin and R. C. Ritter pointed out that *"the Planck length is a length at which the smoothness of space breaks down, and space assumes a granular structure"* [74]. Under a sidebar that reads *"Breakdown of smoothness of spacetime at Planck length"* Misner, Thorne and Wheeler comment that this lack of smoothness *"give[s] space at [L*] distances a 'multiply connected' or 'foamlike' character"* [75]. Here, then, we are dealing with the very *"fabric of space"* itself. This term is used by Brian Greene, professor of physics and mathematics at Columbia University, to describe the structure of the vacuum at the Planck length[76]. It is from this 'granular structure' making up the 'fabric of space' that an origin may be found for the ZPE.

Introducing Planck Particles

This 'granular structure' of space, to use Pipkin and Ritter's phrase, is considered to be made up of Planck particle-antiparticle pairs with individual diameters equal to the Planck length, L*, and whose mass is equal to the fundamental unit known as the Planck mass, M*, which is equal to 2.177 x 10^{-5} grams[77]. Calculation reveals that the Planck particle diameters are equal to their de Broglie wavelength, and as such they are unique entities in the cosmos[78]. Indeed, for particles to have a diameter of L* and mass M*, they also border on a black-hole condition. For this reason the physics describing their behaviour is essentially the same as that for small black-holes. Furthermore, since their diameters are so small, the atoms making up our material universe are essentially unaware of them. To give an easily grasped size comparison, imagine that a Planck particle is represented by the size of a human. On the same representation, then, an electron would be about the size of our galaxy. Therefore, to give another, more approximate comparison, atomic particles would no more be aware of the existence of Planck particle pairs than humans are aware of the atomic particles making up their bodies. Even the de Broglie wavelengths of atomic particles are longer than the de Broglie wavelength of Planck particles by a factor of about 10^{16}.

It should be noted that Planck particles often form the basis for various cosmological theories that are currently under development, such as massive super-strings, 10-dimensional space, and so on. The Planck particles have their equivalent in super-string theory. *"In superstring theory, each 'point' [making up] space can be thought of as a little six-dimensional ball, about [L*] across,"* and the multi-dimensional loops of vibrating strings that go to make up particulate matter are *"scarcely any bigger than these balls of space"* [79]. Therefore, whether the still-developing string theory is invoked or not, it may be considered that Planck particles, or their 6-dimensional equivalent, make up these *"balls of space"*.

On the basis of the Heisenberg uncertainty principle, the QED approach usually assumes that these Planck particle pairs flip in and out of existence in a short time interval known as the Planck time, t* equal to 5.3905 x 10^{-44} seconds[77]. By contrast, SED physics holds the ZPE is itself responsible for the Heisenberg uncertainties. This fact introduces an important element into the discussion since the Planck length marks the cutoff wavelength for the ZPE[40]. The reason for this comes from the concept that the 'fabric of space' breaks down and becomes 'granular' at this length. Consequently, there is nothing to transmit the electromagnetic waves of the ZPE across these discontinuities in the 'fabric'. This implies two things. First, since the ZPE is effectively inactive at the Planck length level, the uncertainty that results from the action of the ZPE on particles will also be absent at that level. Consequently, the uncertainty principle cannot apply to Planck particles. Rather, these Planck particle pairs are the most basic components that make up the very fabric of space. This leads on to the second point; if the Planck particles are the basic constituent making up the structure of the vacuum, the source for the ZPE probably lies with these same Planck particle pairs. If this is the case, the origin and action of these particle pairs needs to be considered in more detail in order to discern how the ZPE is formed.

Planck Particles And Cosmological Inflation

Since the fabric of space seems to be made up of Planck particle-antiparticle pairs, it is logical to assume that these were also the basic components that underwent an inflationary expansion at the inception of the cosmos. This inflationary expansion of the fabric of space would probably impart the initial separation to the Planck particle-antiparticle pairs, which would also prevent their re-combining and annihilating. One mechanism whereby these particle pairs became the basic components of this system is discussed by Gibson[78]. This process of the expansion of the fabric of space fed energy into the system, which became turbulent at the Planck length level and imparted spin to the Planck particle pairs. Two comments are now in order. First, it has been shown by Hawking and others that non-rotating black-holes of Planck mass M* can individually undergo a phase change to become electromagnetic radiation as photons with zero mass, but having the same mass-energy as the original Planck particle[80]. It has been pointed out that the 'evaporation time' for the conversion of Planck particles to photons is equal to the Planck time t*[77]. This may have happened to some of the original Planck particles. Second, two oppositely charged particle pairs that are rotating will also produce electromagnetic radiation. The separation of the particles gives rise to electric fields, while their spin gives rise to magnetic fields. The initial ZPE may therefore have been formed by two distinct processes, namely the separation and spin of the Planck particles plus a possible contribution from Planck particle evaporation. But there is more.

Spinning black-holes are called Kerr black-holes after New Zealand mathematician Roy Kerr who discovered the equations describing their behaviour in 1963[81]. In fact a rotating, charged black-hole is described by the Kerr-Newman solution to the equations[82]. Thus a spinning charged Planck particle, strictly speaking, should be called a Kerr particle. If a non-spinning charged Planck particle approaches a spinning charged Kerr particle in the same direction as its rotation, a Planck-Kerr particle forms and the vorticity in the fabric of space increases further. Since these Planck-Kerr particles are not bouncing off each other, but rather circling round each other, this gives an inelastic characteristic to the system. It has been shown by Bizon et al. that such inelastic collisions will result in stronger vortices[83]. However, Carl Gibson from the University of California at San Diego has gone further. He has shown that this vorticity feeds energy into the system, which allows the production of more Planck particle pairs. In fact he has demonstrated that Planck-Kerr particles can act as powerful sources of large-scale turbulence at the inception of the cosmos, since it can be shown that this turbulence cascades from small scales to large under these circumstances[78].

Several implications follow on from these facts. The first is that a Planck-Kerr particle is effectively a spinning dipole, which from the components separation and spin give rise to electric and magnetic fields. In this way, the energy of expansion and consequent turbulence is transferred to the spin energy of the particles, which gives rise to the electromagnetic fields making up the ZPE.

The second implication relates to the size of vortices that develop and the formation of galaxies and planets. Recent work has shown that the masses of galactic nuclei are of the order of 1000 times the mass of the supermassive black-hole (SMBH) at their cores[84]. This correlation indicates that the SMBH may actually govern the size of the galactic nucleus that develops. This conclusion is strengthened by the work of Rachel Bean and Joao Magueijo[85] who propose that these SMBH formed in the first split second of the universe's existence[86]. Furthermore, Doug Richstone of the University of Michigan presented his research to the January 2000 meeting of the American Astronomical Society indicating that *"giant black holes might create galaxies in the first place"* [87]. This agrees with the analysis by Gordon Garmire of Pennsylvania State University which suggested that *"giant black holes might have formed at the dawn of time, and been the seeds around which galaxies grew"* [87]. This would strongly suggest that a consistent approach may be possible on the role played by very small and very large primordial black holes at the inception of the cosmos. The vorticity involved in both the small and large processes may explain why the appearance of galactic spiral arms mimics that of a large-scale turbulent eddy or whirlpool. Gibson points out further that the observed minute temperature fluctuations in the Cosmic Microwave Background agree closely with theoretical predictions if the origin of these fluctuations was this initial turbulence. This follows since cosmological inflation by a factor of about 10^{50} enlarges the signature of the turbulence by the same factor[78].

Some Relevant Possibilities

Several relevant possibilities emerge from all the above information. First, according to a paper submitted to Physical Review A, Victor Flambaum and Julian Berengut have pointed out that when a Planck mass black hole has a negative charge, the situation exists whereby *"Two protons in orbit around [it] would react to form a deuterium nucleus. …The arrival of a third proton would trigger the reaction to make helium 3, and the process carry on to build ever heavier nuclei around the black hole"* [88]. In view of the fact that Flambaum and Berengut suggest that alpha particles and neutrons can also be involved[88], these types of black holes could act as a catalyst for building the range of elements we see in the cosmos today in the earliest moments of the universe. Importantly in this case, some local variations in elemental abundances might be expected, and this is observed in our own galaxy. It may also explain why an iron abundance three times that of our solar system has been observed in a quasar at the frontier of the cosmos[90], and why the abundance of helium 3 in our galaxy is anomalous if it had been formed by stars, but not if it had been formed at the inception of the cosmos[91]. It may also account for the earthly abundance of gold and platinum, which is too great for supernovae to satisfactorily explain[92]. In similar vein, a series of strong metal lines in the spectra of three quasars[93] around a redshift value of z = 6 may also be explicable by this mechanism.

Second, vorticity may play a part as far as planet formation is concerned. The commonly accepted process whereby a proto-star lights up and becomes a T-Tauri star has set severe limits on the time available for dust to aggregate into larger solid objects. The problem is that intense stellar winds, typical of T-Tauri stars, blow any dust in their stellar neighborhood into outer space, thus preventing the aggregation of larger bodies. In order to overcome this problem, Provenzale demonstrated in two dimensions that dust particles migrate to the centre of anticyclonic vortices[94]. Bracco et al. continued the analysis for the proto-stellar disks. Their *"simulations suggest anticyclonic vortices form as long-lived coherent structures."* Their analysis agreed that *"such vortices trap particles effectively ... even if the turbulence is decaying"* [95]. With the turbulence at the Planck length level cascading from small scales to large, a hierarchy of such vortices is likely to have played an important role in the aggregation of particles to form planetary and other objects.

Third, it strongly appears that atomic orbit energies are sustained by the ZPE. It is therefore possible that, if the energy density of the ZPE were to vary significantly, then all atomic structures throughout the cosmos might be expected to adjust their orbit energies to be in accord with the sustaining power available from the vacuum. In view of the fact that orbit energies go in quantum jumps, it might also be anticipated that any such change in the energy density of the ZPE might have to cross a quantum threshold before the atoms actually took up their new energy state. For example, if the ZPE was systematically lower the further back in time we went, then, as a series of quantum thresholds was reached, atomic orbit energies might also be expected to become lower in a set of jumps. The light emitted by atomic processes would therefore be redder in a series of steps and stairs as we look back in time, since the red end of the spectrum is the low energy end. The quantised redshift of light from distant galaxies[96-102] may in fact be evidence for this very phenomenon. At the same time, a lower energy density for the ZPE would also mean a higher value for the speed of light from equation (8). In practice, a lower energy density for the ZPE also means fewer virtual particles per unit distance in the path of a photon. Consequently, fewer absorptions and re-emissions of the photon would occur over that distance, so light would reach its destination more quickly. The behaviour of lightspeed over the lifetime of the cosmos is becoming a matter for increasing discussion as a very high initial speed solves a number of astronomical problems[103-104]. Proposals that lightspeed has dropped over the entire lifetime of the cosmos have recently been made[105-106]. The ultimate reason for this behaviour appears to lay in the properties of the vacuum as discussed here.

As a result of these considerations, it becomes apparent that atomic behaviour, the redshift and c should be linked via the ZPE. Since 'h' can be considered a measure of the strength of the ZPE with 'c' inversely related to it, this scenario suggesting that the ZPE has increased with time finds observational support from the measured values of 'c' and 'h' as in the 1987 Report by Norman and Setterfield[107]. The observational evidence presented there indicated that 'h' was measured as increasing during the 20th century with 'c' decreasing in such a way that 'hc' was invariant. This suggests that the ZPE is increasing with time for reasons which are briefly explored in a moment. Furthermore, since looking out into astronomical distance is equivalent to looking back in time, and since redshift and lightspeed can be shown to be directly related through the ZPE, the graph of redshift against distance should be the same as the graph of lightspeed against time. All that is required to change from one to the other is to re-scale the axes. These important matters are currently under investigation.

Fourth, the reason for the suggested increase in the ZPE that was mentioned above also needs examination. The explanation for this increase could hinge on the behaviour of the universe. Observational evidence, including the quantised redshift, seems to indicate that the universe may now be static[103, 108-109] following a period of rapid expansion to its maximum size. As the inflationary process stretched the fabric of space out to this limit causing intense vorticity, the Planck particle pairs making up the fabric of space were given their initial separation and spin. Since each particle pair has a positive and negative charge, the separation and spin of these charges would give rise to the initial ZPE as noted above. The process of 'evaporation' of Planck particles directly to photons of the same mass-energy would also augment the strength of the ZPE throughout the lifetime of the cosmos.

However, once the maximum size for the cosmos was attained, that only marked the end of the first of three phases commonly associated with the lifetime of vortices, namely the formation phase. The other two phases associated with vortices are the persistence and decay stages, which follow after vortex formation has occurred[110]. In these persistence and decay stages, the vorticity in the fabric of space continued. With continuing vorticity, the formation of Planck-Kerr particles, and hence more Planck particle pairs, would also be an ongoing processes by the mechanisms outlined above. This would result in an increase in the strength of the ZPE until this vorticity died away completely. Since we are dealing with a very large system and immense energies, the time involved with the persistence and decay stages in the life of these vortices may be expected to be relatively large. Once the vorticity died out, the ZPE might be expected to maintain a constant energy density by the feedback mechanism[111]. It is also possible that the universe undergoes an oscillation about its final mean position, since Arp and Narliker pointed out that such oscillations would occur in a static cosmos[108]. These matters may repay further investigation.

Summary and Conclusions

It thus appears that the existence of the Zero-Point Energy of the vacuum influences a number of other factors. Any variation in the energy density of the ZPE leads to an inverse variation in lightspeed. Furthermore, since the ZPE supports atomic orbits across the cosmos, any significant variation in its energy would also be expected to affect the energy level of each atomic orbit. Since the strength of the ZPE is measured by Planck's constant 'h', and h has been measured as increasing throughout the 20th century, this probably indicates that the energy density of the ZPE has been increasing with time. This conclusion has been strongly supported by a measured and statistically significant decrease in the velocity of light over the last 300 years. This leads to an examination of the origin of the ZPE which may be traced to the separation and spin of Planck particle pairs. The initial expansion of the cosmos involved intense turbulence at the Planck particle level, which imparted this separation and spin. This vorticity has also been demonstrated to lead to an increase in numbers of these particles. These numbers would therefore have continued to rise during the persistence and decay phases of the vorticity.

This, in turn, resulted in an increase in the ZPE over time. This suggests that some current thinking about a high value for lightspeed at the inception of the cosmos may be valid. It also suggests an explanation for the measured redshift quantisation and the origin of some anomalous elemental abundances. The key role initially played by vortices and black holes also has implications for galaxy and planet formation.

Barry Setterfield, 26th December 2002

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