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Reviewing the Zero Point Energy

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ABSTRACT: A review of recent developments in the study of the Zero Point Energy (ZPE) is made. The origin and behavior of the electromagnetic fields making up the vacuum ZPE is elucidated. From this it is deduced that the ZPE should increase with time even in a static universe such as Narliker and Arp propose. The small oscillations that a static cosmos undergoes will add a variable component to the overall behavior of the ZPE. This review examines the role played by the ZPE in the origin of atomic masses and gravity, and the dependence of five physical quantities upon the strength of the ZPE. These quantities include Planck's constant, sub-atomic particle masses, run rates of atomic clocks and the speed of light. The suspected quantization of the redshift and its possible relationship to the ZPE is reviewed. The mathematical form of the variation of the ZPE with time is noted, and the variation in those five physical quantities is thereby delineated.

KEYWORDS: Zero Point Energy; Planck's constant; atomic particle masses; atomic clocks; speed of light; redshift; gravity; variable constants.

I. HISTORICAL INTRODUCTION TO THE ZPE

A. 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 of space is more unusual than is commonly understood. It is popularly considered to be a void, an emptiness, or just 'nothingness.' This is the definition of a so-called bare vacuum. However, as science has learned more about the properties of space, a new and contrasting description has arisen, which physicists call the physical vacuum.

To understand the difference between these two definitions, imagine you have a perfectly sealed container. First remove all solids and liquids and gases from it so no atoms or molecules remain. There is now a vacuum in the container. This 17th century concept gave rise to the definition of a vacuum as a totally empty volume of space. It was later discovered that this vacuum would not transmit sound but 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.

Late in the 19th century, it was realized that the vacuum could still contain heat or thermal radiation. If our container with the vacuum is then perfectly insulated so no heat can get in or out, and if it is cooled to absolute zero, or – 273° C, all thermal radiation has been removed. It might be expected that a complete vacuum now exists within the container. However, both theory and experiment show 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 atmospheric pressure of 15 pounds per square inch that is imposed upon our bodies. There is a perfect balance within us and without. Similarly, the radiation pressures of the ZPE are everywhere balanced in our bodies and measuring devices. But the material world of atoms is like a ship supported by a sea of electromagnetic waves of the ZPE.

B. The historical prelude

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The existence of the ZPE began to be perceived 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. Thus, 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. 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. 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 as classical theory seemed unable to account for these data.

However, in 1901 Max Planck derived a mathematical expression that fitted the most recent experimental curves for black body radiation. This formulation overcame the so-called 'ultraviolet catastrophe' at short wavelengths, and 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. Thus radiation is not emitted in continuous amounts but in discrete bundles of energy described by the product of the new constant *'h'*, and the frequency, *'f'*. Kuhn noted Planck was skeptical of the physical significance of his mathematical assumption and his constant *'h'* for over a decade [1]. At best, Planck felt it only applied to particle oscillators and their emitted radiation. This was only a slight modification of Maxwell's classical theory of radiation.

C. Planck and Einstein infer the ZPE

Because of his dissatisfaction, Planck in 1910 formulated his so-called second theory where he derived the blackbody spectral formula with a weaker quantization assumption. His equations, published in 1911, pointed directly to the existence of a zero-point energy [2]. Planck's equation for the radiant energy density, ρ, of a black body had the same temperature-dependent term as derived in his first theory, plus an additional (½) hf term that was totally independent of temperature. It indicated a uniform, isotropic background radiation as shown in Equation (1).

$$\rho\,(f,T)\,df = [8\pi f^2/c^3]\,\{[\,hf/(e^{hf/kT} - 1)] + [hf/2]\}\,df \tag{1}$$

Here, f is radiation frequency, c is light-speed, and k is Boltzmann's constant. If the temperature, T, in (1) drops to zero, we are still left with the Zero Point term, which is temperature independent. In (1), Planck's constant, h, in the Zero Point term simply appears as a scale factor to align theory with experiment and no quantum interpretation is needed. This implies h measures ZPE strength.

Inspired by this development, Albert Einstein and Otto Stern in 1913 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 [3]. Very significantly, they remarked that if, for some reason, dipole oscillators 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 [4]. These calculations show the irreducible energy of each oscillator is (½)*hf*, as Planck and Nernst correctly deduced, rather than Einstein and Stern's *hf*. However, Einstein and Stern's comments are still very pertinent.

D. Observational proof for the ZPE

In 1916, Walther Nernst examined the ZPE's existence from Planck's second theory 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) [5]. Nernst noted both of these developments required an intrinsic cosmological origin for the ZPE. But at that point the ZPE had only appeared in equations and theory without observational proof. If the ZPE was truly universal, there should be observational proof for its existence from experiments that could be performed anywhere.

In 1925 the evidence was obtained and the existence of the ZPE was confirmed. The 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. The ZPF 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. 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. Today, the Lamb shift of spectral lines, as it is now called, is quoted as an observational proof for the existence of the ZPE. Lamb stated the experimental results were *"a proof that the [perfect] vacuum does not exist"* [6].

E. Physics makes a choice

It is at this point, in the mid-1920's, that the direction of physics hung in the balance. Physics could have adopted the approach suggested by Planck's second theory, plus the contributions from Einstein, Stern and Nernst. Classical theory plus an intrinsic cosmological ZPE could then account for all the observed phenomena, 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 major papers were then published in four years using mathematical explorations of Planck's first theory without the intrinsic ZPE. They swung the balance and set physics on a course that led to the present-day Quantum Electro-Dynamics or QED. These four developments are as follows:

(1). 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 was *h/p* where *'p'* is the particle momentum and *'h'* is Planck's constant. (2). In 1925, Max Born, Werner Heisenberg and Pascual Jordan developed quantum mechanics, with Paul Dirac formulating his own version after seeing an advance copy. (3). 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. (4). Finally, in 1927, Heisenberg published his "Uncertainty Principle".

The Heisenberg Uncertainty Principle (HUP) 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. Similarly, 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 the quantum condition from Planck's first theory and the HUP 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 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"* [7]. Thus the ZPE became a part of the QED approach, but only indirectly through the HUP. There was no physical mechanism.

This approach, which is now the standard QED model for the origin of the ZPE, 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"* [8]. Essentially this explanation says the ZPE exists because quantum laws require it as an artifact of atomic particle existence. This was one reason why some physicists used to argue over whether the ZPE was a genuine entity or merely a mathematical construct since it had only come in indirectly via the HUP.

In contrast, Planck's second theory predicted the ZPE as an intrinsic part of the universe and something that potentially would govern atomic behavior. This prediction was experimentally verified by Mulliken and Lamb. But by the time Lamb performed his experiment, the QED approach was well on the way to be 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 these other contributions in that period, some felt the picture was nearly complete. Thus, in 1929, Paul Dirac said: *"The underlying physical laws necessary for the mathematical theory of a large part of physics and the whole of chemistry are thus completely known"* [9].

F. Re-thinking the choice

However, in 1962, Louis de Broglie published a book, '*New Perspectives in Physics*', in which he indicated that serious consideration of Planck's second theory, embracing classical theory with an intrinsic cosmological ZPE, had been widespread [10]. This book initiated a re-examination of that alternative which revealed three of those four key developments have a very viable explanation through classical physics plus the ZPE. As a result of this book, 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"* [11]. This derivation of the Schroedinger equation using statistical mechanics gave a classical alternative to the esoteric Copenhagen view 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 [12]. On this approach, the HUP is not merely the result of theoretical quantum laws. Rather, it is due to the continual battering of sub-atomic particles, and atoms themselves, by the impacting waves of the ZPE. This continual 'jiggling' at relativistic speeds creates an uncertainty in particle position that is perceived as being the result of the HUP. So, on this approach, the ZPE is the ultimate source of the basic limitation in measuring atomic phenomena and, as such, give rise to the indeterminacy or uncertainty which Quantum Electro-Dynamics (QED) can only attribute to quantum laws.

Third, the question of de Broglie's wave-like behavior of matter was addressed. This is not just a theoretical construct as these wave-like characteristics were proven to exist in 1927 by Clinton Davisson and Lester Germer [M R Wehr and J A Richards '*Physics of the Atom*', Addison Wesley, 1960, p.372]. They found electrons were diffracted from single crystals in a way that only waves can be. That same year, George Thomson confirmed the discovery by obtaining similar diffraction patterns when passing electrons through powder and thin foils. The problem was to explain how particles acquire wave-like characteristics; it is not sufficient to say that it is just a law.

The answer to this problem came partly from de Broglie himself. Like Planck, he had made a second, less well-known, proposal. He suggested that both Einstein's equation $E = mc^2$ and Planck's $E = hf$, be equated. Here *'E'* is the energy of the particle of mass *'m'*, and *'c'* is the speed of light. This gives a frequency, $f = mc^2 / h$, called the Compton frequency. De Broglie felt that this frequency was an intrinsic oscillation of the charge of an electron or similar particle. If he had then identified the ZPE as the source of oscillation, he would have been on his way to a solution. Haisch and Rueda note that the electron really does oscillate at the Compton frequency in its own rest frame of reference due to the ZPE. They note *"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"* [13]. Thus the Compton frequency originates from the ZPE imposed intrinsic oscillation of the particle at rest while the de Broglie wavelength results from the motion of the particle and its oscillation.

G. Two approaches to modern physics

Since then, a steady line of papers has been published using the ZPE approach, which is called Stochastic Electro-Dynamics (SED) in contrast to the more standard QED. SED physics, based on the existence of an all-pervading ZPE, has been able to derive and interpret classically the black-body spectrum, Heisenberg's Principle, 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"* [50]. This requires SED to overhaul a 50-year head-start of QED physics, but good progress is being made.

These developments allow many physical phenomena to have two explanations, one from QED, the other from SED physics. The explanation used is a matter of choice as the mathematics of both give the same answers. But SED physics has the advantage that it is often more easy to conceptualize and avoids the awkward QED mathematics. 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 has yet to be fully formalized.

II. EXAMINING THE TWO APPROACHES TO THE ZPE

A. Basic concepts

Although arising for conceptually different reasons, the ZPE is therefore an integral part of both QED and SED physics. Let us examine some SED concepts. SED 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. At this length, about 10^{-33} centimeters, the vacuum breaks up and its structure becomes granular. 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. This Lorentz invariance is only obtained with an energy density that is proportional to the frequency cubed, precisely what Planck's equation shows in (1) above.

Lorentz invariance makes the ZPF different from the 19th century concepts of an ether. The old ether concept indicated an absolute velocity through the ether could be determined. But the Lorentz invariant condition indicates that the ZPR 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. However, an extremely high acceleration (10^{21} g's) is required to give a radiation bath temperature rise of only 1 degree Kelvin. This relation connecting acceleration through the ZPE and temperature was discovered independently by Paul Davies and William Unruh and is now named the Davies-Unruh effect [14].

B. The energy in the vacuum

The magnitude of the ZPE is truly large and is usually quoted as energy density. Well-known physicist Richard Feynman and others have pointed out that the amount of ZPE in one cubic centimeter of the vacuum "*is greater than the energy density in an atomic nucleus"* [15]. In an atomic nucleus alone, the energy density is of the order of 10^{44} ergs per cubic centimeter. However, because of its mode of origin on the QED approach, it has been stated that: *"Formally, physicists attribute an infinite amount of energy to this background"* [15]. This meant the QED approach could not mathematically integrate the ZPE in their equations. But work by SED physicists indicates there is an upper limit for the ZPE strength at about 10^{114} ergs per cubic centimeter imposed by the Planck length cutoff and other factors. Paul Davies put the estimate slightly higher: *"about 10^{110} joules per cubic centimetre"* [16]. The existence of the Planck length cutoff gave QED physicists a reason to accept the ZPE as a reality rather than just a virtual entity.

The following example illustrates the magnitude of the ZPE. A bright light bulb radiates at 150 watts. By contrast, our sun radiates at 3.8×10^{26} watts. In our galaxy there are 100 billion stars. If 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 10 billion years is roughly the energy locked up in one cubic centimeter of space. The physical vacuum is not just an empty nothingness.

C. Evidence for the ZPE

After Planck's 1911 paper, experimental evidence accumulated hinting at the existence of the ZPE, although its fluctuations do not become significant enough to be observed until the atomic level is attained. Thus, the ZPE explains why cooling alone will never freeze liquid helium. Unless pressure is applied, these ZPE fluctuations prevent helium's atoms from getting close enough to permit solidification. In electronic circuits, like microwave receivers, another problem arises because ZPE fluctuations cause a random 'noise' that places limits on the level to which signals can be amplified. The '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. 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 [17]. 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 have been excluded and 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. A similar effect can be demonstrated on the ocean. Sailors note that if the distance between two boats is less than that between two ocean 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. For plates with an area of one square centimeter separated by 0.5 thousandths of a millimeter, this force is equivalent to a weight of 0.2 milligrams. In January of 1997, Steven Lamoreaux reported experimental verification of theory within 5%. Then in November 1998, Umar Mohideen and Anushree Roy reported verification to within 1% in an experiment that utilized the capabilities of an atomic force microscope [18].

The surface Casimir effect thereby 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. It is these attractive forces that permit real gases to be turned into liquids. (When an 'ideal' gas is compressed, it behaves in a mathematically precise way. When a 'real' gas is compressed, its behavior deviates from the ideal equation). It should be noted that the QED explanation of the surface Casimir effect involves the action of virtual particles whose existence is supported by both QED and SED physics. Virtual particles may now be introduced in the following fashion.

D. Virtual particles and QED physics

As a result of some unusual mathematical explorations by Dirac in 1930, the concept of electron-positron pairs was born. Two years later, Anderson discovered the first positron during cosmic ray research [M R Wehr, J A Richards, '*Physics of the Atom*', Addison Wesley (1960), p.374]. In 1933, Blackett and Occhialini obtained the first cloud chamber photos of the production of electron-positron pairs. Late in 1933 Thibaud and Joliot observed radiation from the annihilation of electron-positron pairs, and proved the mass of the positron was equal to that of the electron [*Ibid*]. In 1955, a team led by Chamberlain and Segre generated the first proton-antiproton pairs, thereby proving that the concept of particle-antiparticle pairs was in fact correct [*Ibid*, p.377].

Experimental evidence had now established the existence of particle-antiparticle pairs that annihilate to give 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"* [19].

To help understand the QED approach, let us suppose for a moment that there is nothing in the vacuum of space at all - no matter, no radiation … nothing. Now according to the Heisenberg

Uncertainty Principle, there could be a certain amount of radiation this totally empty vacuum actually contains, since everything is uncertain. Understand first that, for QED physics, the vacuum between two Casimir plates is considered to be in a negative energy state. So there is positive energy, zero energy, and negative energy in this model. For this reason, QED states that the energy in our 'nothing vacuum' will *average* zero. The HUP allows a 'non zero' energy to exist for short intervals of time, both as above (positive) and below (negative) the zero-datum position. The period of time for this 'non-zero' energy to exist is defined as $h/(2\pi)$ divided by the uncertainty in the energy.

This somewhat confusing situation is avoided in the SED approach because the Zero-Point Energy exists in and of itself, having an energy threshold far above actual zero. In SED physics, therefore, it is easily possible and intuitively understood for the energy density of the ZPE to locally fluctuate above and below the average value.

Back to QED physics: these small vacuum energy fluctuations due to the HUP will produce particle-antiparticle pairs that exist for a short time and then disappear. These particles can be produced because Einstein's famous formula shows that there is equivalence between matter and energy. Thus these particle pairs will form, exist for a brief time, and then disappear. This allows the average properties of the universe to be maintained. Because of their ephemeral existence, these sub-atomic particle pairs are called virtual particles. In other words, the HUP alone requires the vacuum, as seen by QED physics, to be filled with virtual particle pairs flipping in and out of existence like a sort of quantum foam. Indeed, this model also claims virtual photons can pop in and out of existence as they are emitted and then absorbed by various particle processes. Because of this incessant activity on the atomic scale, the vacuum has been described as 'a seething sea of activity', or 'the seething vacuum'. The QED approach then assigns much of the vacuum energy density or ZPE to these virtual particles. On this approach, however, without the HUP vacuum fluctuations, neither virtual particles nor the ZPE would exist. In other words, QED physics attributes these effects to a Principle rather than to a physical cause.

E. Virtual particles and SED physics

It is important to note that the SED approach also requires virtual particles to exist. The whole universe is filled with the electromagnetic waves of the ZPE at a high energy density. The interaction of these waves may be considered to be similar to the waves of the sea. Locally, sea waves collide, peak and crest with foam on their white tops that then disappear. On SED physics, the ZPE is also like a restless sea with peaks and troughs in the energy density of its waves. Einstein's relationship shows that this energy is inter-convertible with mass. However, in order to maintain conservation of electronic charge, any such particulate matter that condenses out of the intense local fluctuations of the vacuum fields must be in the form of particle-antiparticle pairs. The manifestation of virtual particle pairs in the vacuum can be considered to be a result of local peaking and cresting of these electromagnetic waves. The virtual particles then annihilate.

A second process is also at work on the SED approach. As an energetic photon of light comes to a wave peak, its presence may also raise the local energy threshold high enough to allow a virtual electron and positron pair to form and then annihilate, and emit the photon again. In this sense, the SED approach with the electromagnetic ZPE has replaced the old, erroneous concept of the vacuum as a 'Dirac sea' of electrons. Furthermore, SED formalism envisages a veritable zoo of all types of particle pairs that inhabit the vacuum instead of just the electrons and positrons proposed by Dirac. Therefore, on both the QED and SED models, the vacuum is filled with virtual particle pairs flipping in and out of existence. At any instant, it has been calculated that a human body will contain 100 billion virtual particle pairs.

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 presence of the ZPE allowed the formation of virtual particles, then the formation of virtual tachyons was also logical. From this deduction, his subsequent analysis demonstrated that the Cherenkov radiation from these virtual tachyons may have the same spectrum and mass density as the cosmic microwave background radiation (CMB) [20]. This approach is completely consistent with SED physics and the whole topic of vacuum characteristics. However, additional studies are needed to verify that the polarization, lumpiness, and the apparent preferred direction in this background, fits into his model, otherwise the standard CMB explanation may be favored.

This background on virtual particles allows us to examine the Casimir effect on the QED model. For QED, only an explanation in terms of virtual particles is valid. It will be recalled that all particles have a de Broglie wavelength. As a result, QED 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.

F. Choosing between alternatives

Thus both the QED and SED explanations for the ZPE are viable alternatives. However, SED uses the intrinsic electromagnetic waves of the ZPE directly. In contrast, QED uses virtual particles (and/or photons) that have arisen from the vacuum fluctuations that are attributed to the action of the HUP. Thus the QED approach relies on the application of a theoretical Principle which cannot be explored further, while SED formalism acknowledges the independent existence of the ZPE as an intrinsic property of the universe. The SED approach allows for a further examination and analysis of the ZPE and its origin, while this is effectively denied to QED physics since the application of the uncertainty principle is absolute and stifles further investigation. Thus, from this point on, we will adopt the SED approach in this Review.

III. THE ORIGIN OF THE ZPE

A. Two suggested origins

SED physics (or Stochastic Electro-Dynamics) suggests an origin for the Zero-Point Energy (ZPE) and allows us to mathematically determine the behavior of the ZPE through time. The influence of the ZPE on other physical quantities can also be predicted using the SED approach.

We note there are two current explanations for the origin of the ZPE using the SED approach. They have been assessed as follows: "*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"* [15]. 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"* [15].

This second explanation requires the ZPE to be an artefact of atomic particle existence in a manner reminiscent of QED physics. This raises a problem since Puthoff has shown that the ZPE is required to maintain atomic particle motion and stability across the cosmos, and this is examined in detail later. But if the ZPE is required to maintain atomic stability while the motion of these same atomic particles is required for the existence of the ZPE, it then becomes difficult to envisage how either the primordial ZPE or atomic particles originated via this feedback mechanism. It is true several papers have demonstrated that this mechanism can maintain the presence of the ZPE once it had formed. But this avoids the question of its origin. In contrast, Planck's second theory directly required the ZPE to be the cosmological source that influenced atomic particle behavior. This invites us to look more closely at the initial conditions in the cosmos and the origin of the ZPE.

B. The role of Planck particle pairs

The model accepted here is that of an initial expansion of the universe out to a stable position about which it has oscillated. Narliker and Arp have shown that a static cosmos is stable against collapse, but there will be a small oscillation in size [21]. The initial expansion may be attested to by the existence of the cosmic microwave background radiation which is usually considered to be an 'echo' of the original hot super-dense state. That widely accepted interpretation is provisionally accepted here. It is true that there have been other explanations for the microwave background, but the additional data that the background has provided, such as its polarization pattern, the degree of 'lumpiness', and its preferred direction are difficult to reproduce in other models. The evidence for a currently static cosmos has been discussed in detail [22] and includes the quantized redshift, which is difficult to explain if the universe is expanding now. It will be seen later that the brightness of distant Type Ia supernovae has a very natural explanation on the model presented here and obviates the need for accelerating expansion due to 'dark energy'.

We begin, then, with an initial expansion process that fed energy into the vacuum. Gibson has shown that this expansion energy manifested as the smallest particles the cosmos is capable of producing, namely Planck particle pairs (PPP) [23]. PPP have a unique property; their diameters are equal to the Planck length as well as their own Compton wavelengths. Each pair is positively and negatively charged so that the vacuum is electrically neutral. According to SED physics, quantum uncertainty only exists as a result of the ZPE. There was thus no initial quantum time limit for the PPP to remain in existence. Indeed, since the Planck length is the cutoff wavelength for the ZPE, these particles were unaffected by the ZPE as it built up during the expansion process. As the cosmos continued to expand, PPP separation and spin increased. The separation of charges gave rise to electric fields, while their spin created magnetic fields. Some of the initial expansion energy was thereby converted into the primordial electromagnetic fields of the ZPE via this PPP mechanism.

C. ZPE strength should increase with time

Continuing, Gibson has pointed out that expanding the fabric of space will generate separation, spin and intense vorticity among the PPP [23]. He showed that this vorticity feeds energy into the system, which allows the production of more PPP. Therefore, while there is turbulence, PPP numbers will increase. The strength of the ZPE would then be expected to increase with time due to the initial expansion of space and the effect of this on PPP numbers.

However, the formation of vortices is only the first of three phases, the other two being persistence and decay. In these persistence and decay stages, the vorticity continued, so that more PPP would form via this ongoing process. Until all vorticity died away, PPP numbers increased, and so did the strength of the primordial ZPE. Gibson has pointed out that the PPP system is characteristically inelastic [23], while Bizon has established that such inelastic systems have stronger vortices and longer persistence times [24]. Since the cosmos is a very large system with immense energies, the persistence and decay stages for these vortices may be expected to be relatively long. As the strength of the ZPE built up by this process, it would be maintained by the feedback mechanism noted above.

Under the conditions being considered here, it is also important to note that PPP will tend to re-combine due to electrostatic attraction. Once recombination occurs, a pulse of electro-magnetic radiation is emitted yielding the same energy that the Planck particle pair had originally. This energy would further augment the primordial electromagnetic ZPE fields. This recombination process would eventually eliminate the majority of the PPP, although the initial production of PPP from turbulence would partly offset that in the early stages. The ZPE strength would thus increase until all these processes ceased. Throughout this process, the strength of the ZPE would be maintained by the feedback mechanism, as also would be the final strength of the ZPE.

D. Recombining Planck particle pairs

Recent photographs from the Hubble space telescope indicate that the recombination of the PPP has occurred. Greene considered the 'fabric of space' to be made up of Planck particle pairs, so that 'space assumes a granular structure' as stated by Pipkin and Ritter. Photographs of astronomical objects should then be increasingly 'fuzzy' with distance. Such 'fuzziness' is not in evidence despite several searches [25]. These observations suggest that the PPP which had originally formed as a result of the rapid expansion process have now nearly all recombined, leaving the ZPE as the only evidence of their original existence.

Thus the potential energy from the initial expansion of the cosmos was initially manifested as PPP whose numbers built up until turbulence ceased. The recombination of these PPP emitted the electromagnetic radiation of the ZPE as the final manifestation of the energy of the expansion. This intrinsic feature of the vacuum, the ZPE, is now maintained by the feedback mechanism. The precise form of the build-up in strength of the ZPE over time can be derived mathematically using standard mathematical descriptions of turbulence and recombination. One reviewer suggested a change to the derivation in reference [22] to make it more secure. This will appear in subsequent versions, but the final equation remains unchanged by this revision and has the following form:

$$U \sim [\surd(1 - T^2)] / [1 + T] \tag{2}$$

In (2), U is the energy density of the ZPE and orbital time, T, is a ratio with $T = 1$ at the origin of the cosmos and $T = 0$ near the present. The symbol (~) means "*is proportional to*" throughout this review. Thus the cosmological behavior of the ZPE follows physical principles which show that, in the beginning, the ZPE built up rapidly, but its rate of increase slowed with time.

Following the expansion of the universe to its maximum size, the approach adopted by Narliker and Arp indicate that this now static cosmos will oscillate about its final position. These oscillations in a static universe would tend to increase the energy per unit volume of the ZPE when the cosmos was at its minimum position, and decrease the strength of the ZPE at maximum expansion. If the universe has several modes of oscillation, a graph of its behaviour, and hence that of the strength of the ZPE, might be expected to contain flat points in a manner similar to that described in an article by Karlow in the *American Journal of Physics* [26]. Thus, even after the ZPE built up to its maximum value, it is to be expected that there will be cosmological oscillations in its strength. The build-up in the ZPE, plus any oscillations and flat points in its strength, should thereby be echoed in the experimental values of ZPE-dependent quantities. With this background, we are now in a position to explore what happens to those quantities which are dependent upon the ZPE and its energy per unit volume or energy density.

IV. ZPE AND ATOMIC CONSTANTS BEHAVIOR

A. ZPE and Planck's constant

As noted above, in 1911 Planck published his 'second theory' in which the existence of the ZPE was deduced. His equations revealed the ZPE strength, its energy density, is measured by what is now called Planck's constant, h as can be seen above from equation (1). Thus if the ZPE strength increased, h would proportionally increase. So we can write

$$h \sim U \tag{3}$$

where U is uniquely the energy density of the ZPE. This relationship may also be expressed as:

$$h_2 / h_1 = U_2 / U_1 \tag{4}$$

In equation (4), h_1 is the present value of h, while h_2 is its value at some distant galaxy, that is, at an earlier epoch. This nomenclature will be adopted throughout this paper.

There is measured evidence for a variation in h along with synchronous variation in other atomic quantities related through the ZPE. Thus, it has been generally conceded that the officially declared value of h has increased systematically up to about 1970. After this, the data either show a flat point or a small but continuing decline. In 1965, Sanders pointed out that the increasing value of h could only partly be accounted for by the improvements in instrumental resolution [27]. Indeed, such an explanation does not appear to be quantitatively adequate. This is emphasized since other quantities such as (e/h), where e is the electronic charge, ($h/2e$) or the magnetic flux quantum, and ($2e/h$) or the Josephson constant, all show synchronous trends centered around 1970 even though measured by different methods from those used for h. The officially declared values of h and the h/e ratio are listed online here: http://www.setterfield.org/report/report.html (as of 5th September, 2007). Figure 1 graphs the values of h, where the trend becomes apparent.

B. ZPE and the speed of light

Changes in the ZPE energy density also result in changes in lightspeed, c. Studies on the Casimir effect have revealed this relationship. The energy density of a vacuum in a flask is locally lowered between two enclosed metal plates as they are brought closer together compared with the vacuum outside the plates. This occurs because long wavelengths of the ZPE are excluded and exert an excess pressure from outside the plates, as outlined above. In early 1990, both Scharnhorst and Barton published analyses of the effect that the lowered energy density inside the plates had on the speed of light. Their conclusions were confirmed by a 1995 study on c in 'modified vacua', including the Casimir vacuum. This later analysis read in part: *"Whether photons move faster or slower than c depends only on the lower or higher energy density of the modified vacuum respectively"* [28]. The analysis concluded that in all vacua *"It follows automatically that if the vacuum has a lower energy density than the standard vacuum, [lightspeed] v >1, and vice versa,"* ($v = 1$ denotes the current speed of light).

Analysis in [28] noted that c was inversely related to the ZPE energy density. This occurs because the ZPE produces this zoo of sub-atomic particle/antiparticle pairs which form briefly and then annihilate. As a light photon proceeds through the vacuum, it is briefly absorbed by a virtual particle and then re-emitted as the particle pairs annihilate. A moment later the process repeats. Thus the path of a light photon is like a runner going over hurdles. As the strength of the ZPE increases, so, in proportion, the number of virtual particles per unit volume will increase. Therefore, as a photon sweeps through a certain volume of the vacuum, the number of interactions with virtual particles will increase proportionally. The more virtual particles per unit volume, the longer it takes light photons to traverse it. Thus, through time, photons will take longer to reach their destination.

There is an alternative way of looking at the same phenomena. Consider an energetic photon of light, or perhaps a neutrino, traveling through the vacuum, where the energy density of the cresting waves of the ZPE is locally higher. The presence of the photon or neutrino can raise the local energy threshold of the ZPE high enough to allow a virtual particle pair to form, then annihilate, and emit the photon or neutrino again. The virtual particle that is generated depends entirely on the generating photon or neutrino since each has its own intrinsic energy. Furthermore, the virtual particle pair that is generated is required, by the very nature of the process, to be the one with which the photon or neutrino can interact. Thus, the speed of light *c,* or that of the neutrino in the vacuum, is inversely related to the ZPE strength. The precise relationship may be discerned as follows.

C. Vacuum permittivity and permeability

Since the ZPE effectively determines the properties of the vacuum, any changes in the strength of the ZPE will mean that the vacuum's electrical permittivity, ε, and magnetic permeability, μ, are also changing. But with these changes in vacuum properties, the vacuum must remain a non-dispersive medium otherwise photographs of distant astronomical objects would appear blurred. This requires the ratio of electric energy to the magnetic energy in a traveling wave to remain constant. In turn, this means the intrinsic impedance of free space, Ω, must be invariant. It then follows from the definition of intrinsic impedance that:

$$\Omega = \sqrt{(\mu / \varepsilon)} = invariant = \mu c = 1/(\varepsilon c) \tag{5}$$

Thus Ω will always bear the value of 376.7 ohms. From (3) it follows that with all these changes, c must vary inversely to both the vacuum permittivity and permeability, so that

$$\varepsilon \sim \mu \sim 1/c \tag{6}$$

Therefore, at any given instant, c would have the same value in all frames of reference throughout the cosmos. Experimentally, this constraint has been verified by Barnet, Davis, & Sanders [29].

Those who are accustomed to derive Maxwell's equations from Relativity may object that (6) is obtained on the assumption that c is a constant. However, it can be shown that (6) is readily derived without any initial assumptions about the behaviour of c, ε, or μ, which is precisely what Maxwell did originally. Meanwhile, Maxwell's equations have recently been shown to support very large cosmological variations in c with time, in contrast to location, provided both the permittivity and permeability of free space varied as shown in (5) and (6), [30]. Maxwell used the CGS system of units where this variation is permitted, but SI units create a problem because μ is considered to be invariant. This problem arose because c was also assumed to be invariant when those units were formulated, and consequently μ was designated as having a constant value on that basis.

Now, classically, the energy density of an electromagnetic field is given by U, with E and H being the electric and magnetic intensities of the waves, which are proportional to their amplitude. The standard equation then reads:

$$U = (½)(\varepsilon E^2 + \mu H^2) \text{ so that } U = \varepsilon E^2 = \mu H^2 \tag{7}$$

Let us apply (7) exclusively to the intrinsic properties of the vacuum. The energy density, U, then refers to the vacuum Zero-Point Fields while E and H refer specifically to the electric and magnetic intensities of the ZPF. If the intensities of the electromagnetic waves of the ZPE, or their proportional amplitudes, remain unchanged, both E and H will also remain unchanged as the strength of the ZPE varies. Therefore, as U varies so does ε and μ such that

$$U \sim \varepsilon \sim \mu \sim 1/c \tag{8}$$

The last step in (8) follows from (6). This has implications for radiant energy emission since the energy density of that radiation is directly dependent upon the permittivity and permeability of space. This is discussed fully in [31]. Thus (8) indicates c is inversely related to U, so we can write

$$U_2/U_1 = c_1/c_2 \tag{9}$$

D. Cosmological reasons for varying c.

A number of authors demonstrated that serious problems facing cosmologists could be solved by a very high value for c at the inception of the cosmos. Thus in 1987, V.S. Troitskii proposed that c was initially 10^{10} times c now and it then declined to its present value as the universe aged, along with synchronous variations in several atomic constants [32]. In 1993, Moffat published two articles that suggested a high c value during the earliest moments of the universe with an immediate drop to its present value [33]. Albrecht and Magueijo agreed with that concept, and proposed in 1999 that c was 10^{60} times c now at the origin of the cosmos [34]. John Barrow agreed with the initial value proposed, but suggested it dropped over the lifetime of the cosmos rather than immediately after [35]. Unlike Troitskii and this paper, those authors did not consider synchronous changes in related atomic constants. Without this synchronism, based on the ZPE, deep space data demands any c changes be very limited. Relativity may argue against varying c, but these changes in the ZPE affecting c may be considered to be similar to changes in refractive index. In each case, an upper limit velocity still exists, but it is not c in the current medium. Other answers to Relativity also exist [36]. In addition, Einstein's basic assumption, that there is no absolute reference frame anywhere in the universe, is negated by the presence of the Cosmic Microwave Background radiation (CMB). The absolute velocities of our solar system and our galaxy have been individually determined from the CMB. In noting this development, M Harwit in his book *Astrophysical Concepts,* second Edition (Springer-Verlag, New York, 1988), p.178, goes on to comment "Rather, the establishment of an absolute reference frame would emphasize the fact that special relativity is really only meant to deal with small-scale phenomena and that phenomena on larger scales allow us to determine a preferred frame of reference in which cosmic processes look isotropic." In other words, special relativity applies specifically in the atomic frame of reference rather than at the macroscopic level, which may also be deduced from equation (25) below.

E. Measured variation in the speed of light

Because experimental evidence indicated c was declining, an ongoing discussion occurred in scientific journals from the mid 1800's to the mid 1940's,. This decline was in evidence up to about 1970. Physicists, who have a strong preference for the constancy of atomic quantities, were forced to admit with Dorsey: *"As is well known to those acquainted with the several determinations of the velocity of light, the definitive values successively reported … have, in general, decreased monotonously from Cornu's 300.4 megametres per second in 1874 to Anderson's 299.776 in 1940…"* [37]. Re-working the data could not avoid that conclusion.

But the declining values of c were noticed much earlier. In 1886, Newcomb reluctantly concluded that the values of c obtained around 1740 were in agreement with each other, but were about 1% higher than in his own time [38]. In 1941, Birge made a parallel statement while writing about the *c* values obtained by Newcomb, Michelson and others around 1880. Birge had to concede that: *"…these older results are entirely consistent among themselves, but their average is nearly 100 km/s greater than that given by the eight more recent results"* [39]. Yet these scientists held to a constant *c*, which makes their admission even more significant.

Another example is of interest. In 1927, M.E.J. Gheury de Bray was responsible for an initial analysis of the *c* data [40]. Then, after four new determinations by April of 1931, he said *"If the velocity of light is constant, how is it that, INVARIBLY, new determinations give values which are lower than the last one obtained. … There are twenty-two coincidences in favour of a decrease of the velocity of light, while there is not a single one against it"* [40]. Later in 1931 he said, *"I believe that in any other field of inquiry such a discrepancy between observation and theory would be felt intolerable"* [40]. The *c* values recommended by Birge in 1941 are plotted in Figure 2.

F. Analyses of speed of light data

In all, 163 determinations of *c* with thousands of individual experiments using 16 methods over 330 years comprise data for declining *c* values. These data were documented along with the synchronously changing atomic constants in a white paper for Stanford Research Institute (SRI) International and Flinders University in August of 1987 [41]. We suggested the decline in *c* implied a high initial value at the inception of the cosmos, in synchrony with these 'constants'. In 1993, Montgomery and Dolphin performed a thorough statistical analysis of all the data and confirmed the declining trend was significant, but had flattened out in the period 1970 to 1980 [42]. This flattening influenced a decision to make *c* a universal constant in 1983. Since then, it has only been possible to detect changes in *c* indirectly; for example, by comparing orbital phenomena with atomic phenomena. This will be discussed in detail below. Criticisms of this approach based on Relativity, supernovae, Cepheid variables, radioactive decay, Doppler shifts, and pulsars are all examined in reference [31].

G. The fine structure constant and electronic charge

In order to get to the key reason why experiments failed to detect *c* variation post 1970, several matters need to be settled first. To begin, we note that (3) and (8) indicate that

$$hc = invariant \quad \text{so that} \quad h \sim 1/c \tag{10}$$

This conclusion is supported to an accuracy of parts per million by observations out to the frontiers of the cosmos, including studies of the fine structure constant, α [43]. This constant is a combination of four physical quantities such that $\alpha = [e^2/\varepsilon][1/(2hc)]$, where *e* is the electronic charge. From (10), *hc* is cosmologically invariant, but observational evidence for α also requires that throughout the cosmos

$$e^2/\varepsilon = constant \tag{11}$$

An exception occurs in strong gravitational fields as shown in [44]. This is due to a change in the self-energy of the system that is analogous to the change in the stored energy of a charged air capacitor taken to a region of differing dielectric constant. On this basis, the "missing mass" problem may admit a resolution as in reference [31]. Now (8) has ε proportional to *U*, so that

$$e^2 \sim U \tag{12}$$

But many experiments measure e in the context of the permittivity of its environment. Thus changes in e alone often have to be deduced from other quantities such as the ratio h/e. This ratio should be proportional to the square root of U, while h is directly proportional to U. When the h/e data for Figure 3 are examined in detail, as in reference [31], this variation proposed by (12) is supported.

H. Varying frequencies and the ZPE

To achieve accord with Maxwell's equations and a time varying c, frequencies are required to vary as c and wavelengths must remain fixed [30]. One reason is that, since photon energies are conserved in transit through space with time-varying c and h, then we have

$$E = hf = hc/\lambda = constant \qquad (13)$$

Now h is inversely proportional to c as in (10), so it follows from (13) that a photon's frequency, f, must be inversely related to h and directly related to c. Thus, as the photon travels through space and its speed declines, the wavelength, λ, remains unchanged, but its frequency drops in proportion to the speed. So for a cosmologically time-varying ZPE, and hence c, we have

$$f \sim c \sim 1/h \sim 1/U \qquad (14)$$

Note that this is a different situation to that normally encountered in which light goes from, say, air into glass. In this case, the wavelength varies as light goes from one medium into another. The wave fronts bunch-up in the glass as the waves behind approach the glass with higher speed, and so crowd together in the denser medium. However, an entirely different situation pertains to light traveling through the universe with a cosmologically increasing ZPE. In this case, the whole wave train is slowing simultaneously so there is no bunching up effect. It is rather like a freight train that is slowing down while hauling a large number of box cars. The length of the cars remains fixed, but the number of cars passing an observer per unit time will drop. So for light, wavelengths remain fixed but frequencies vary in proportion to velocity which is itself ZPE dependent.

Equations (13) and (14) lead to an observational fact pointed out by Birge [45]. Light-speed had been measured as varying without an observed change in wavelengths compared with the standard metre. Birge admitted that this evidence allowed only one conclusion. He stated *"if the value of c … is actually changing with time, but the value of λ in terms of the standard metre shows no corresponding change, then it necessarily follows that the value of every atomic frequency ... must be changing"* [45]. This follows from the basic equation

$$c = f\lambda \qquad (15)$$

Since λ is unchanged here, then, as Birge noted, frequency f must obey the equation

$$f \sim c \qquad (16)$$

These equations, and Birge's conclusion that atomic and photon frequencies obey (16), point to one reason for the declared constancy of c in 1983. From 1972 to 1983, the experimental value of c was obtained using lasers. This method measured the frequency of the light at known wavelengths using atomic time and frequency standards to determine c from equation (15). But if atomic frequencies are changing synchronously with c, no variation in c could be detected, and none was. Now a basic reason exists why atomic frequencies (as distinct from photon frequencies) obey (16), and it comes from atomic mass behavior – which is also ZPE dependent. Let us review this development.

V. MASS AND THE ZERO-POINT ENERGY

A. The ZPE origin of mass

There are a number of problems associated with standard models for mass. Most theories envisage matter as being composed of massless charged particles. In order for these particles to have mass, the Higgs boson was introduced. The energy from a cloud of Higgs bosons around each particle is meant to impart mass to the particle, depending on how well the Higgs bosons "stick" to the particle. No-one knows what governs this "sticking". These and other problems are overcome in the SED alternative proposed by Haisch et al. They agree, along with quantum pioneers de Broglie and Schroedinger, that subatomic particles such as electrons are indeed actually massless, point-like charges, which are often called partons. This is generally accepted.

Haisch then notes that the electromagnetic waves of the ZPE impinge upon a charged, point-like particle, causing it to randomly jitter in a manner similar to what we see in Brownian motion. Schroedinger referred to this "jitter motion" by its German equivalent, *Zitterbewegung*. In the usual model, first proposed by Dirac, the fluctuations of this *Zitterbewegung* happen at the speed of light. Hal Puthoff then explains what happens [46]: *"In this view the particle mass* m *is of dynamical origin, originating in parton-motion response to the electromagnetic zero-point fluctuations of the vacuum. It is therefore simply a special case of the general proposition that the internal kinetic energy of a system contributes to the effective mass of that system."* The mathematical calculations support this view. In that case [47], *"the Higgs might not be needed to explain rest mass at all. The inherent energy in a particle may be a result of its jittering motion. A massless particle may pick up energy from it, hence acquiring what we think of as rest mass."*

In a similar way, inertial mass can be accounted for since an electron accelerated through the electromagnetic fields of the vacuum experiences a pressure, a retarding force proportional to the acceleration, from these ambient fields in a way formalised in 1994 by Haisch, Rueda and Puthoff [48]. Furthermore, different resonant frequencies of different particles result in different masses. This occurs because *"Photons in the quantum vacuum with the same frequency as the jitter are much more likely to bounce off a particle…Higher resonance frequencies … probably mean a greater mass, as there are more high frequency vacuum photons to bounce off"* [48].

B. Behavior of atomic masses

The formulations of Haisch's team show the parton's oscillation in response to the ZPE gives it a rest mass which may be represented by the quantity m such that [47, 48]

$$m = \Gamma h\omega^2/(4\pi^2c^2) \tag{17}$$

Here, ω is the *Zitterbewegung* oscillation frequency of the particle, while Γ is the Abraham-Lorentz damping constant of the parton. This damping constant is given by $e^2/(6\pi\varepsilon mc^3)$, where e is the electronic charge. Substituting for Γ in (17) and collecting mass terms, m, then gives us

$$m^2 = (e^2\, h\, \omega^2) / (24\, \pi^3\, \varepsilon\, c^5) \tag{18}$$

From (11) we recall that e^2/ε is constant throughout the cosmos, except in strong gravitational fields [44]. This exception happens as a result of a change in the stored energy of the system in a manner similar to a charged air capacitor taken into a region of differing dielectric constant. Now Dirac stated that the *Zitterbewegung* occurs near c. Puthoff shows the oscillator resonance frequency is $\omega = kc,$ where k is inversely dependent upon parton size, as ZPE waves significantly smaller than this produce little translational movement of the parton [48]. Hence k is independent of c. So we can write

$$\omega \sim c \tag{19}$$

This is in accord with equation (16). When (19) is linked with equations (10), (11), (12) the result is that

$$m \sim 1/c^2 \sim h^2 \sim U^2 \tag{20}$$

If (20) is to be expressed without the proportionality, it can be written that

$$m_2/m_1 = (U_2/U_1)^2 = (c_1/c_2)^2 \tag{21}$$

This is an important conclusion. Since atomic masses m are proportional to $1/c^2$, then in Einstein's equation, $E = mc^2$, the energy, E, will be conserved in atomic processes as c varies.

C. Atomic frequencies and the speed of light

Let us apply (21) to electrons in orbits and nucleons in orbitals. The kinetic energy of these particles is given by $\frac{1}{2} mv^2$ where v is the tangential velocity. If m varies as $1/c^2$ it follows that v must vary as c. Birge's statement about atomic frequencies follows, since orbit velocities

$$v \sim c \sim f \tag{22}$$

The formulation for electron velocity in the first Bohr orbit verifies this since A.N. Cox in *Allen's Astrophysical Quantities*, page 9 (Springer Verlag, 2000) quotes this as being given by

$$v = 2\pi e^2 / (\varepsilon h) \sim 1/U \sim c \tag{23}$$

In (23), the proportionalities affirm French's comment that the frequency of light emitted by an electron transition to the ground state orbit *"is identical with the frequency of revolution in the [ground state] orbit"* [49]. Therefore (22), shows that atomic frequencies generally obey (16) in the same way that photon frequencies do. Thus, when c is higher, atomic frequencies are higher and atomic time intervals, t, are shorter, so t is proportional to $1/c$. This is supported by the fact that some forms of atomic time are defined in terms of the electron revolution time in the first Bohr orbit. Thus Cox, op. cit., page 9, gives the time, t, an electron takes for $1/(2\pi)$ revolutions in the first Bohr orbit as

$$t = h^3 \varepsilon^2 / (8\pi^3 me^4) \sim U \sim 1/c \tag{24}$$

The proportionalities follow from (3), (8), (10), (11) and (20). From this it is clear that

$$ct = constant \tag{25}$$

Seen from an atomic point of view, the speed of light is a constant, so Special Relativity applies there.

D. Data describing atomic mass behavior

The behavior of atomic masses in (20) is supported by the officially declared values of electron or proton masses which show a consistent upward trend until about 1970. After that date, a flat point or slight decline occurred. These values for the electron rest mass, m, are graphed in Figure 4. The rest mass of the proton follows a precisely similar curve. All data are in reference [41]. In this respect, the Rydberg constant for an infinite nucleus, R_∞, gives a good cross-check on data trends as it contains five time-varying quantities h, c, e^2, ε, and m, but combines them in such a way that R_∞ should remain unchanged since $R_\infty = [e^2/\varepsilon]^2 [2\pi^2 m/(ch^3)]$. The declared values of R_∞ in Figure 5 confirm this. No trend is apparent. Rather there is just a scatter about a fixed value, in contrast to the other Figures.

If the origin of mass is resolved by this ZPE approach, it is expected that the ZPE mechanism would give some insights into the origin of gravity. This is needed as problems exist with General Relativity and its geometric interpretation of gravity. For example, a collection of scientific papers in 2002 entitled *Pushing Gravity,* edited by Matthew R. Edwards [Apeiron] reiterated on page 94 that "*it is not widely appreciated that this is a purely mathematical model, lacking a physical mechanism to initiate motion.*" These problems are overcome by the ZPE approach which has reproduced all the major predictions of General Relativity [44]. Here is a brief review of the ZPE origin of gravity.

E. The origin of gravity

In 1968 Andrei Sakharov linked gravitation and inertia with the ZPE. In 1989 Puthoff made it into a quantifiable theory of gravitation. Haisch and Rueda developed it further. They noted all charges in the cosmos undergo *Zitterbewegung* jostling by interaction with the ZPE. This jitter is relativistic so that the charges move at velocities close to c. Haisch, Rueda and Puthoff state [50]:

"Now a basic result from classical electrodynamics is that a fluctuating charge emits an electromagnetic radiation field. The result is that all charges in the universe will emit secondary electromagnetic fields in response to their interactions with the primary field, the ZPF. The secondary electromagnetic fields turn out to have a remarkable property. Between any two [charged] particles they give rise to an attractive force. The force is much weaker than the ordinary attractive or repulsive forces between two stationary electric charges, and is always attractive, whether the charges are positive or negative. The result is that the secondary fields give rise to an attractive force we propose may be identified with gravity. … Since the gravitational force is caused by the trembling motion, there is no need to speak any longer of a gravitational mass as the source of gravitation. The source of gravitation is the driven motion of a charge, not the attractive power of the thing physicists are used to thinking of as mass." So, on SED physics, the presence of the ZPE will not in and of itself result in the forces that QED and General Relativity (GR) associate with gravity or a cosmological constant [51]. The problem QED and GR have with a ZPE exerting a massive force because of its mere presence is thereby easily avoided.

On this basis, the all-pervasive ZPE will have its density increased towards massive bodies by the (attractive) secondary fields emitted by the oscillating point-like charges that comprise matter. The more oscillating charges there are, the more secondary fields there are and hence the greater the total energy density of the ZPE in the vicinity of those charges. Analysis has shown the strength of these electromagnetic fields is proportional to the inverse square of the distance from their origin. Furthermore, their potential falls off inversely as the distance from the massive body. Thus, the behavior of the strength of the ZPE around oscillating charges mimics a gravitational field and may be uniquely identified with it as Haisch and his colleagues have established. These characteristics also fulfil all the requirements that Eddington laid down for an alternative model for gravity to General Relativity [52]. Thus, gravitation and mass are simply manifestations of electromagnetic energy linked directly with the ZPE. Therefore, this approach has already unified gravity with electromagnetism and quantum behavior - a very desirable result.

VI. ORBITAL AND ATOMIC CLOCKS.

A. Comparing the two clocks

This discussion on gravitation and (24) suggest that both orbital and atomic clock rates need a closer scrutiny as both clocks are used as timekeepers. The orbital clock is gravitationally governed, and followed by planets and spacecraft, while the atomic clock is defined in terms of atomic processes. Science prefers the atomic clock because its precision is at least 5 parts in 10^{15} using caesium. The important quantity determining orbit times gravitationally is *Gm*, where *G* is the Newtonian gravitational constant and *m* is the main mass. Since gravity and mass are ZPE effects, *G* and *m* are related. With a cosmologically varying ZPE, *Gm* can be shown to remain constant for a given system [44]. This is apparent since *G* bears the units of [meters^3/(kilogram-seconds^2)] and since mass is in the denominator of *G* it will cancel out any changes in the product *Gm*. So for varying ZPE

$$\mathrm{Gm} = constant \tag{26}$$

Now Kepler's third law for circular orbits, states that the orbit time, *T*, is given by:

$$T^2 = 4\pi^2 r^3/(Gm) = constant \tag{27}$$

Since *Gm* is invariant and orbit radius, *r*, is fixed, then, as the ZPE varies cosmologically, the orbital or gravitational clock marks time at a constant rate as in (27). Equation (27) also requires that gravitational acceleration remains unchanged. By contrast, (24) and (25) indicate atomic clocks tick at a rate proportional to *c* and proportional to 1/*U*. Both [31] and [41] show this applies to radiometric clocks also. So, with increasing ZPE, atomic clocks tick more slowly. If an atomic interval is "*t* ", then

$$t \sim 1/c \sim h \sim U \tag{28}$$

If (28) is to be expressed without the proportionality, it can be stated that

$$t_2/t_1 = c_1/c_2 = h_2/h_1 = U_2/U_1 \tag{29}$$

In 1965, Kovalevsky noted that if gravitational and atomic clock rates were different, *"then Planck's constant as well as atomic frequencies would drift"* [53]. The data indicate this is so.

B. Trends in clock data

These data trends are noticed with comparisons between orbital and atomic clocks. Lunar laser ranging using atomic clocks were compared with orbital data for the interval 1955 to 1981 by Van Flandern. He concluded that: *"the number of atomic seconds in a[n orbital] interval is becoming fewer. Presumably, if the result has any generality to it, this means that atomic phenomena are slowing down with respect to [orbital] phenomena"* [54]. This work has continued in several observatories. One analysis stated:

"Recently, several independent investigators have reported discrepancies between the optical observations and the planetary ephemerides. The discussions by Yao and Smith (1988, 1991, 1993), Krasinsky et al. (1993), Standish & Williams (1990), Seidelman et al. (1985, 1986), Seidelman (1992), Kolesnik (1995, 1996), and Poppe et al. (1999) indicate that [atomic clocks had] a negative linear drift [slowing] before 1960, and an equivalent positive drift [speeding up] after that date. A paper by Yuri

Kolesnik (1996) reports on positive drift of the planets relative to their ephemerides based on optical observations covering thirty years with atomic time. This study uses data from many observatories around the world, and all observations independently detect the planetary drifts. … [T]he planetary drifts Kolesnik and several other investigators have detected are based on accurate modern optical observations and they use atomic time. Therefore, these drifts are unquestionably real" [55]. The data turnaround occurred near 1970. Van Flandern considered data from 1951 to 1983. He recently indicated that atomic clocks truly appeared to be slowing during the 1950's and early 1960's, but more recent data show the trend really had reversed. For this reason he assumed he had been mistaken.

The data plots by Kolesnik for Mercury, Venus and the Sun all indicate the slowing of atomic clocks reversed between 1960 and 1970 [55]. Masreliez states atomic clocks may be gaining about 7 seconds every 50 years over the orbital clock. The Pioneer anomaly is of like magnitude, and may originate in the same discrepancy. A data plot for Mercury similar to Kolesnik is in Figure 6. Other planetary and solar data give results supporting atomic clock trends in (28) and (29). In [31, 41] it is shown radiometric clocks follow atomic clocks. Comparing radiometric dates with orbital dates for historical artefacts shows the effects of cosmos oscillation recorded from 1650 BC up to the present [31]. The data graphed in Figure 8 show the main ZPE curve must have started before 2600 BC.

VII. ZPE AND ATOMIC BEHAVIOR.

A. ZPE and atomic orbits

Any discussion about the ZPE and atomic phenomena should note that the all pervasive ZPE 'sea' seems to maintain the stability of atomic orbits across the cosmos. Classical physics required an electron orbiting a proton to be radiating energy, and so spiral into the nucleus. As this does not happen, QED physics invokes quantum laws, but an actual physical explanation is still needed. If classical physics is valid, the energy electrons radiate as they orbit their protons can be calculated, along with the energy that these electrons receive from the all-pervasive ZPE. It was stated that in a quantitative analysis "*Boyer and Claverie and Diner have shown that if one considers circular orbits only, then one obtains an equilibrium [orbit] 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"* [56].

In 1987 Puthoff examined this in detail [57]. His Abstract stated: *"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…"* . He noted that, in the same way that a child on a swing receives resonantly timed pushes from an adult to keep the swing going, so also the electron received resonantly timed "pushes" from the ZPE. He elaborated as follows: *"The circular motion [of an electron in its orbit] can be thought of as two harmonic oscillator motions at right angles and 90 degrees out of phase, superimposed. These two oscillators are driven by the resonant components of the ZPE just as you would keep a kid swinging on a swing by resonantly-timed pushes. The oscillator motion acts as a filter to select out the energy at the right frequency (around 450 angstroms wavelength for the hydrogen atom Bohr orbit ground state)"* [58]. This resonance mechanism transfers energy from the Zero Point Fields (ZPF) and maintains electrons in their atomic orbits. Since over 87% of atoms in the cosmos are hydrogen, this analysis is relevant.

The concluding comment in Puthoff's paper also carries 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"* [57]. The very existence of atomic structures depends on this ZPE sea. Without it, all matter in the cosmos collapses. New Scientist featured this in July 1987 and again in July 1990 under the heading *"Why atoms don't collapse."*

B. ZPE variations and the atom

Atomic orbit energies therefore seem to be sustained by the ZPE. But we can go further. The Bohr atom scales all orbit energies according to the ground state orbit. So, if the ground state orbit has an energy change, all other orbits will scale their energies proportionally. This means that wavelengths of emitted light will also be scaled in proportion to the energy of the ground state orbit of the atom. Thus, if the ZPE strength varied cosmologically, then all atomic structures throughout the cosmos might be expected to adjust their orbit energies simultaneously. Now atomic orbit radii have remained constant during the time that such measurements have been possible. But, throughout that time, the strength of the ZPE has increased. Therefore, any increase in the energy density of the ZPE seems to require that a quantum threshold must be crossed before atomic orbits take up their new energy state.

For example, if the strength of the ZPE was lower in the past, then, as the ZPE increased, a series of quantum thresholds was reached, the magnitude of atomic orbit energies would increase in a set of jumps. However, atomic orbit energies are negative because they are in the field of the nucleus, so this increase in the magnitude of the orbit energy means it will become more negative at the quantum jump as time increases. Between these jumps, atomic orbit energies will remain constant since atomic orbits cannot access additional energy available from the vacuum until that energy had built up to the quantum threshold. The light emitted by atoms would be unchanged between jumps, when energy is conserved, but would become bluer (more energetic) with each jump as we approach the present. So, as we look back in time, we should see the light from atomic transitions getting less energetic or redder in a series of jumps. But we do look back in time with progressively more distant astronomical objects, and these objects indeed show an increasing redshift with distance. So, if the redshift went in a series of jumps, instead of a smooth progression, it would indicate the redshift is related to the ZPE and atomic orbit energy, rather than being related to galaxy velocities or universal expansion.

C. ZPE and the redshift

Since 1976, William Tifft [59] and others [60] have called attention to the fact that galaxy redshifts go in a series of jumps or are quantized. It is generally agreed that cosmological expansion would not occur in jumps. Furthermore, since the redshift quantum jump goes right through some galaxies, and because some galaxies have undergone a reduction in redshift by one basic quantum jump of 2.667 km/s, the redshift cannot be due to galaxy motion. This conclusion is reinforced with analysis of the redshift/distance function. If the redshift is z, then the function is given as:

$$(1 + z) = [1 + x] / [\sqrt{(1 - x^2)}] \tag{30}$$

Here in (30), x is distance such that $(x = 0)$ near our galaxy while $(x = 1)$ at the origin of the cosmos. This formulation overcomes difficulties with determining an absolute distance scale. In actual practice, astronomers often substitute the quantity v/c for x where v is the inferred velocity of expansion. In this form, it becomes the relativistic Doppler formula for the redshift. However, [22] has demonstrated the build-up of ZPE strength due to turbulence and recombination actually follows equation (2) above. But (2) is the inverse form of (30) except in (2) we have orbital time T while in (30) we have distance x.

Since looking back in time astronomically is the same as looking further out into the distant cosmos, this is to be expected. Thus, the redshift as a measure of distance is not negated by these proposals. Rather, the redshift and ZPE strength are inversely related from (30) and (2) so we can now write

$$(1 + z) \sim 1/U \tag{31}$$

Redshift data thereby confirm the predicted behavior of the ZPE right back to the origin of the cosmos.

We should note that the standard Doppler formula for the redshift behavior breaks down at high redshifts as evidenced by the intensity of light from Type Ia supernovas. This discrepancy has resulted in the necessity to invoke accelerating expansion of the cosmos. In contrast, the derivation of (2) and hence the form of (31) has a degree of flexibility which easily accommodates these supernova results. Further, the motion of galaxies in clusters is determined by the redshift. This motion is the root of the missing mass problem for galaxy clusters in the standard model. Yet if the redshift is not due to galaxy motion but is the response of atoms to an increasing ZPE, this problem is completely avoided.

D. The cause of the quantum change

In order to discern the reason for the quantum change in atomic orbit energies with increasing ZPE, it is only necessary to examine the effects of increasing ZPE on atomic particles. Recent work has been done on this by Hal Puthoff [61]. He shows that the Coulomb and vacuum fluctuation pressure tending to expand the sphere of the electron or parton from its interior is more than offset by a Casimir pressure from the ZPE acting from the outside tending to collapse it. Thus all charges experience a net external force from the ZPE which tends to collapse them. Once the ZPE strength increases to a quantum threshold, the electron or parton radius will undergo a quantum decrease.

With this reduction in parton volume is a quantum change in parton mass. At the quantum jump with time moving forward, the parton volume is decreased. This means that the mass of the atomic particle has increased. This results from the fact that partons are ‘jiggled’ by the waves of the ZPE. Wave sizes that are significantly different from parton sizes produce little translational movement of the parton [48]. A smaller parton has a higher resonant frequency and so is ‘jiggled’ by waves of shorter wavelength. Since there are many more short wavelengths than long in the ZPE, the smaller parton will have a greater kinetic energy, and so a greater mass, imparted to it by the ZPE waves.

It is important to note here that there are two different mechanisms whereby the parton’s mass increases. Both mechanisms increase the parton’s ‘jitter’ and hence its ‘jitter volume’. First, there is the quantum decrease in the parton’s actual volume from Casimir pressure which gives a quantum increase in mass. Second, there is the steady increase in parton mass due to a steady increase in the number of impacting waves of given wavelength as ZPE strength increases. The graph of parton mass, m, is thus a smooth curve, rising with time, with a small discrete increase at the quantum jump.

At the moment of this quantum jump, there is an infinitesimally small change in the strength of the ZPE, and hence no effective change in any of the synchronously changing physical quantities. The outcome of this is that atomic orbit radii decrease marginally with a resultant marginal increase in the magnitude of orbit energy. Velocities of electrons in their orbits remain unchanged in this process as does their orbital angular momentum. Calculations performed in reference [31] based on the physical parameters involved have shown that the resultant basic quantum change, if expressed as a velocity, is 2.633 km/s. This is very close to the basic quantum change found by Tifft of 2.667 km/s.

VIII. MATHEMATICAL DESCRIPTION OF ATOMIC BEHAVIOR

The behaviour over time of atomic quantities dependent on the ZPE has been elucidated and the form of behavior delineated. From (31) and this discussion, the results can be summarized as follows:

$$1/U \sim 1/h \sim c \sim 1/(\sqrt{m}) \sim 1/t \sim (1 + z) = [(1 + T)/\sqrt{(1 - T^2)}] \qquad (32)$$

This is graphed in Figure 7. Observational data and physics behind (32) provide a logical framework for the theoretical proposals of a high initial value for lightspeed at the inception of the cosmos [33, 34]. It also supports the approach of those who suggested a decline in *c* over the lifetime of the cosmos [22, 32, 35, 41]. It may be helpful to remember that when the curve is examined on a smaller scale for *z* and *m*, a ripple will be apparent, as well as the effects of universal oscillation on the ZPE strength. Thus, even after $T = 0$ earlier in history, the data show an oscillation which changed direction in 1970. Finally, the years elapsed, t_e, on the atomic clock, or its equivalent, namely the distance in light years that light has travelled, is then given by substituting for T in the integral of (32) which is formulated as follows:

$$t_e = K[(\arcsin T) - \sqrt{(1 - T^2)} + 1] \qquad (33)$$

The final term of unity in (33) is included since this gives $t_e = 0$ when $T = 0$. At the origin of the cosmos, when $T = 1$, the terms within the square brackets in (33) total 2.5708. Since the universe is about 14 billion atomic years old, and light has traveled up to 14 billion light years, then the numerical value of K must accord with that. This, then, concludes our review of the ZPE, which still has much to teach us.

IX. SUMMARY

This review reveals how the ZPE is a key factor in understanding many physical processes. Five physical quantities are linked to it, namely Planck's constant, *h*; light-speed, *c*; atomic masses, *m*; the rate of ticking of atomic clocks, *t*, (including radiometric clocks); and the redshift, $(1 + z)$. Any ZPE variation over time will result in a variation in these quantities. Physics and mathematics show the ZPE will increase with time. Once the ZPE maximum was attained, the small oscillations inherent in a static cosmos, first predicted by Narliker and Arp, would add a variable component to the ZPE. This occurs because the ZPE energy per unit volume is slightly greater when the cosmos was at its minimum size, and slightly less at the maximum. Data from these five quantities support this and indicate the ZPE strength was a maximum near 1970, followed by a slow decline. This explains trends in the five data sets which many paradigms struggle to account for, or treat dismissively. It provides a physical reason behind Dirac's idea of variations in the constants, and opens up a potentially fruitful line of enquiry.

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FIGURE 1: Recommended values of Planck's constant, hx10^{-34} J-s

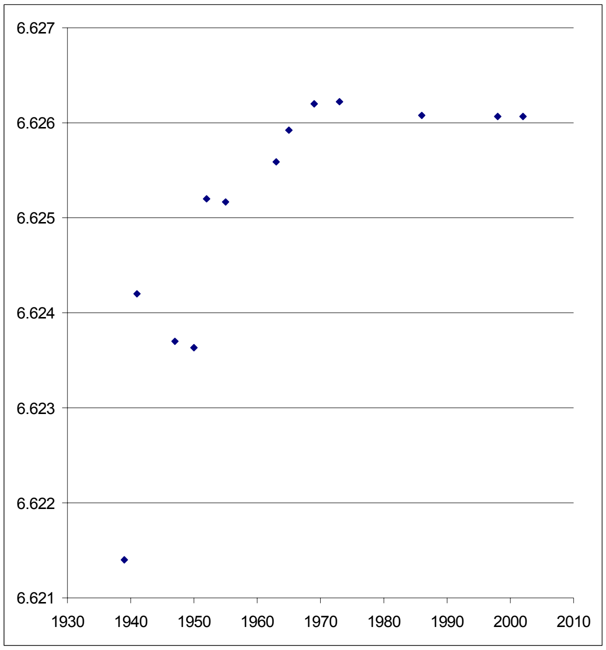


FIGURE 2: Birge's recommended values of light velocity, c x 10^5 km/s

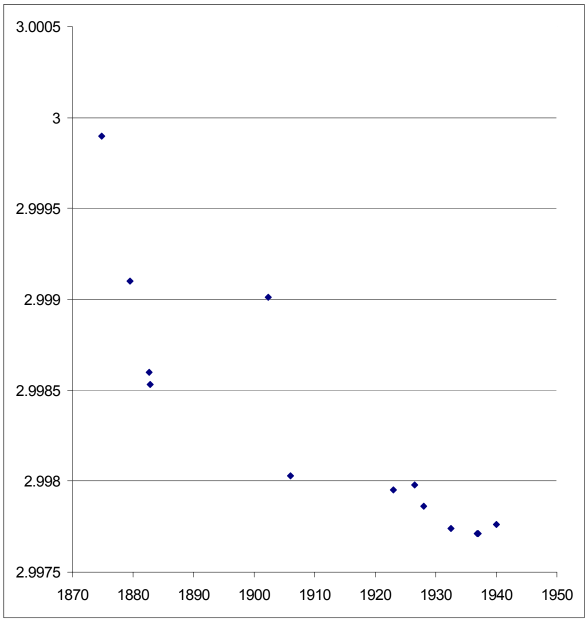


FIGURE 3: Recommended values of h/e x 10-15 J-s/C

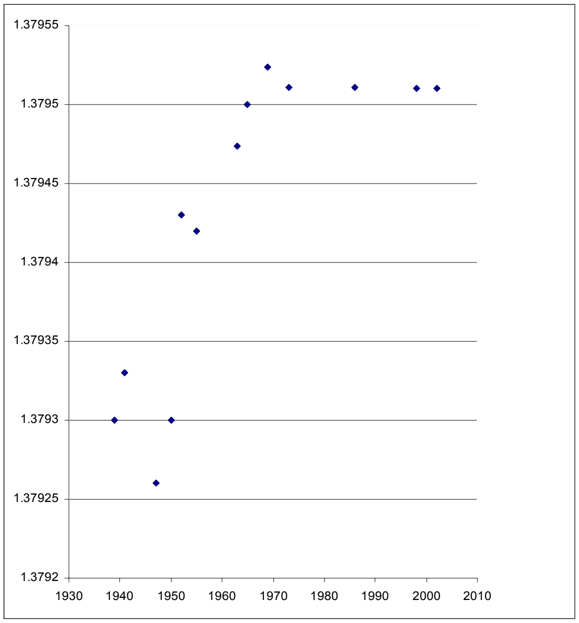


FIGURE 4: Recommended values of electron rest-mass, m x 10^{-31} kg

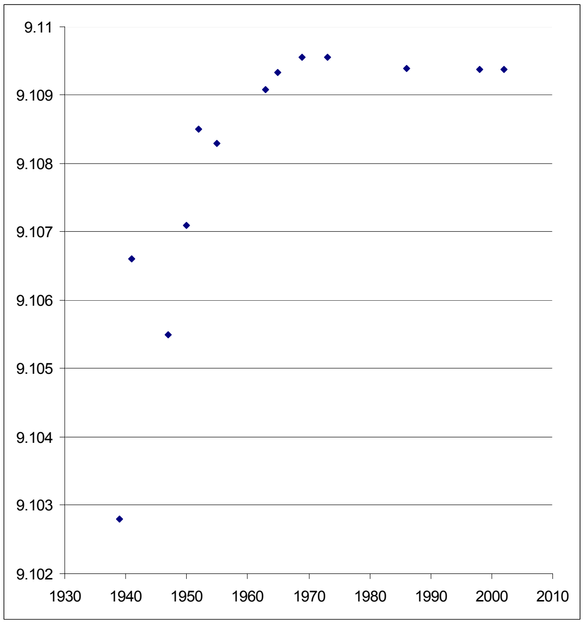


FIGURE 5: Recommended values of the Rydberg constant R_∞ cm^{-1}

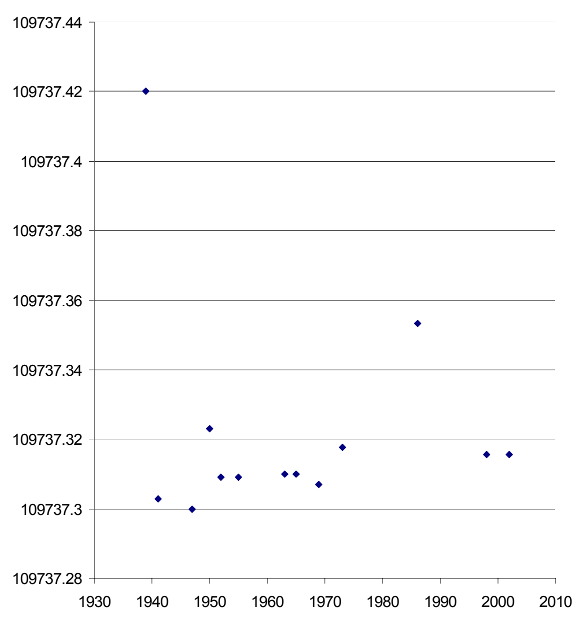


FIGURE 6: Secular variation of corrections to the mean longitude of the planet Mercury in arc-seconds (after Kolesnik)

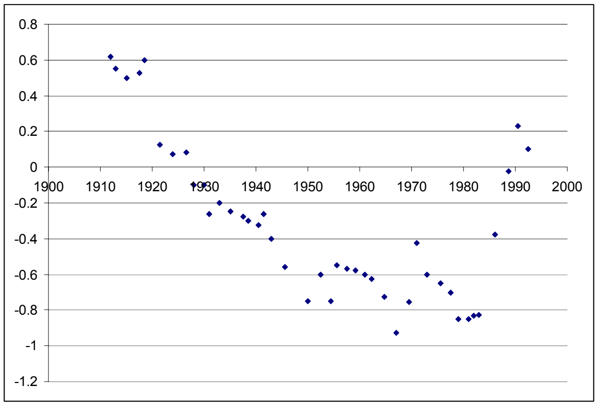
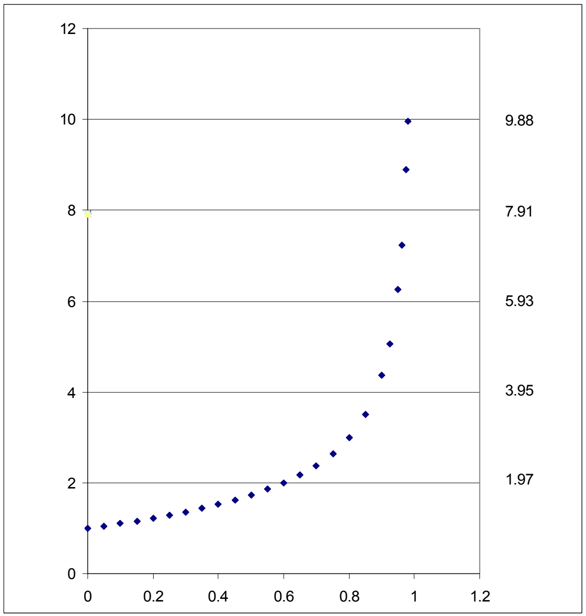
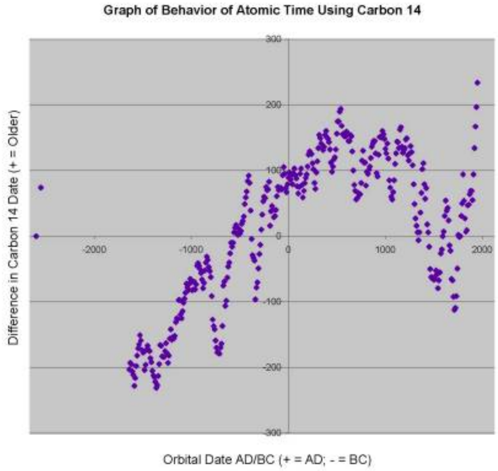


FIGURE 7: Graph of (57) the inverse of ZPE behavior and *h*. Behavior of (1+z) on left axis and *c* x 10^7 on right.



Horizontal axis: *Time T = 0 now, and T = 1 at origin of cosmos.*

Figure 8: C-14 Atomic Dates compared with Orbital Dates



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