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Hidden Variables: The Elementary Quantum of Light

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ABSTRACT

Re-examination of the work of Max Karl Planck has revealed hidden variables in his famous quantum work, consistent with Einstein's famous sentiment that quantum mechanics is incomplete due to the existence of "hidden variables". The recent discovery of these previously hidden variables, which have been missing from the foundational equations of quantum theory for more than one hundred years, has important implications for all the sciences as well as for understanding the interactions of electromagnetic radiation with matter.

Planck's quantum formula, $E = hv$, is missing the variable for measurement time. Planck had included the missing time variable in his earlier electromagnetic work, but omitted it in his famous work that sparked the quantum revolution. Restoration of measurement time to Planck's quantum formula produces the more complete, $E = \tilde{h} v t$. The numerical value Planck calculated for his action constant "h" takes on new meaning as an *energy* constant " \tilde{h} " for light. Planck's energy constant is the mean energy of a single oscillation of light, namely 6.626×10^{-34} J/oscillation. The mean oscillation energy of light is *constant*, and does not vary with frequency or wavelength. The photon, as historically defined, is a time dependent packet of energy, based on the arbitrary measurement time of one second. An arbitrary, one second increment of energy cannot be a truly indivisible and elementary particle of nature.

Omission of the time variable from Planck's quantum formula contributed to numerous paradoxes in quantum mechanics, such as uncertainty relating to formulations involving time, wave-particle duality, the need for normalization of wave functions, lack of dimensions for the fine structure constant, and irreconcilability of quantum mechanics and general relativity (Einstein's gravitational theory). Many of these paradoxes are simplified or eliminated altogether with a re-interpretation of quantum mechanics with Planck's hidden time variable and *energy* constant.

Keywords: Planck, Hidden variable, Light, Time, Photon

1. INTRODUCTION

There is an elementary quantum of light. It is *not* the photon. Max Karl Planck glimpsed the elementary quantum of light briefly, but did not recognize it. So for more than one hundred years, the elementary quantum of light has remained hidden in the dusty pages of history.

To understand how this could be, one must look back in time to Berlin in the 1890's. Planck was a Professor of theoretical physics at the University of Berlin and focused much of his work on his favorite subject - the irreversibility of entropy (the natural increase of disorder that occurs in the absence of work). While Planck was busy trying to establish a comprehensive mathematical foundation for irreversible processes, many other new and exciting discoveries were being made. Heinrich Hertz had succeeded, for the first time in history, in transmitting and receiving Maxwell's "*mysterious electromagnetic waves*", and had published both his experimental successes as well as his electromagnetic theories. Planck embraced Hertz's "*resonant oscillations*" whole-heartedly, and began developing additional theories on electromagnetic (EM) waves^{1,2}. Planck then used his own electromagnetic theories in an attempt to prove the

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irreversibility of entropy. When Planck presented his first work on this subject at a large scientific meeting in 1897, however, Ludwig Boltzmann loudly and publicly criticized his conclusion. Planck had failed to consider certain effects of time said Boltzmann, and had thus failed to prove the irreversibility of an increase in entropy. Planck was forced to admit that Boltzmann was correct, and that time was a stumbling block to his proof of the irreversibility of entropy. Planck turned next to the black-body radiation experiments as a way to prove entropy's irreversibility.

Black-body radiation is the light emitted by a theoretical "black-body" or perfect light absorber (e.g. a black object). Scientists were trying to find a formula to describe changes to the wavelengths of light emitted by a black-body object, as a function of its temperature. Black-body radiation devices were the super-colliders of their time, and Planck had ready access to the experimental data generated from the device located at the PTR (physics experimental institute) in Berlin. The device had an inner chamber lined with the natural black-body material graphite and a second outer chamber which could be filled with either ice or steam. After the graphite chamber reached equilibrium at either 0° C (273° K) or 100° C (373° K), a window in the chamber was opened, allowing the black-body radiation (that had been spontaneously emitted by the graphite) to leave the chamber and to be measured as a function of time. The intensity of various wavelengths could then be obtained to determine the distribution of energy at various wavelengths and at a given temperature.

Among the many equations that had been suggested for black-body radiation, Planck was attracted to Wien's law, which coincidentally eliminated time as a variable. Planck built on his earlier electromagnetic theories and developed an early version of his quantum relationship. He set internal energy ("E") proportional to the product of a generic constant ("a"), the frequency ("v"), and the measurement time ("t_m"):

$$E \approx a v t_m \quad (1)$$

He then used Wien's mathematical methods of converting the experimental time-based energy measurements (ergs/second) to energy density values (ergs/cm³), eliminating the variable for measurement time in the process. Planck wrote four (4) theoretical papers on black-body radiation and the irreversibility of entropy, using Wien's law as the basis.³ By early 1900, Planck used his combined entropy/electromagnetic theory to publish a proof of Wien's law.⁴ Interestingly, Planck's "proof" of Wien's law also contained a derivation and calculation for what later came to be known as Planck's constant "h".

In September 1900, Planck received a new set of black-body measurements from a PTR colleague, Ferdinand Kurlbaum who had visited the Planck's for Sunday dinner. Experimental measurements had been extended down into the infrared region. Wien's law was wrong. Worse yet, Planck had just published a "proof" of Wien's law. After his guest left, Planck played with the numbers until he found a new equation that fit the data much better than Wien's equation. Planck sent the new equation to Kurlbaum the next Monday, and Planck was elated to learn that his new equation fit the new data perfectly. When Planck presented his new black-body equation at a meeting of the German Physical Society the next month, there were no loud critics.⁵ His next challenge was to find a proper derivation for his empirical formula, and as Planck later recalled, "*The explanation of the... radiation law was not so easy.*"⁶

After "*some weeks of the most strenuous work of my life*", Planck completed a formal derivation for his new radiation law. He abandoned the wave theory for light, opting instead for a particle-like treatment of light. He also found it necessary to use the statistical approach championed by his nemesis Boltzmann, as well as Boltzmann's idea that energy can be divided into small amounts.[†] Planck developed Boltzmann's energy suggestion into his Quantum Hypothesis, i.e., the idea that energy is quantized into small *equal* amounts.

Planck's 1901, formal paper⁷ on this topic introduced his famous quantum formula:

$$E = h v \quad (2)$$

where Planck's proportionality constant "h" is equal to 6.626 X 10⁻³⁴ J sec. This fundamental formula is the foundational basis for all of quantum theory. Interestingly, Planck simply *assumed* this formula as a given, and did not

[†] "I see no reason why energy shouldn't also be regarded as divided atomically." L. Boltzmann, 1891, Cited from Flamm, D., "Ludwig Boltzmann - A Pioneer of Modern Physics", arXiv:physics/9710007 v1 7 Oct 1997.

derive or prove it. His arbitrary quantum formula yielded a proportionality constant ("h") equal to the product of energy and time, which Planck referred to as the ultimate "quantum of action".[†]

Historically, Planck's paper was a *tour de force* of nineteenth century physics. He described: 1) the black-body radiation law; 2) the quantum hypothesis; and 3) Planck's constant "h". He also calculated two *more* fundamental constants, "Boltzmann's constant, k_B ", for the energy of a single molecule at different temperatures, and Avogadro's number, the number of molecules per mole. Although some in the physics community were slow to comprehend Planck's monumental achievement, a young Swiss patent clerk named Einstein quickly grasped the implications of Planck's incredible feat.

In 1905 Albert Einstein published his remarkable paper on the production and transformation of light, better known as the photoelectric effect[§]. Einstein first noted that "it is quite conceivable...that the [wave] theory of light...leads to contradictions when applied to the phenomena of emission and transformation of light". He proposed that the interactions of light and matter "appear more readily understood if one assumes that the energy of light is discontinuously distributed in space [in particles]". Thus, Einstein asserted, the paradox of broadly spread out waves somehow interacting with small particles of matter disappeared. When light and matter were both thought of as small particles or quanta, their interactions followed from the rules of mechanics. Einstein began his derivations by deriving the mean energy of a single oscillation of an electron,[§] e.g., a particle of matter. He then proposed a mathematical basis for his light particles, weaving together the mathematics of his light particles with the electron (matter) mathematics. Finally, he used his new light particle hypothesis and quantum mathematics to explain various interactions between light and matter including the photoelectric effect^{**} and the ionization of gases^{††}.

Although Einstein's light-quanta proposal was slow to gain acceptance, his successful use of Planck's quantum hypothesis to explain the photoelectric effect encouraged others to adopt Planck's work. Neils Bohr, for example, while rejecting Einstein's light-quanta hypothesis, embraced Planck's quantum formula and used Planck's proportionality constant "h" in his famous theory of the hydrogen atom. Arthur Compton's 1923 paper declaring that "the scattering of X-rays is a quantum phenomenon", settled the debate in Einstein's favor. A few years later the term "photon" was coined for Einstein's particles of light, and the photon came to be regarded as an elementary particle of nature defined by Planck's quantum formula, $E = h\nu$. Unlike other elementary particles defined by a constant value (such as the electron and its uniform charge) the photon was paradoxically defined by an energy value that is infinitely variable (Fig. 1).

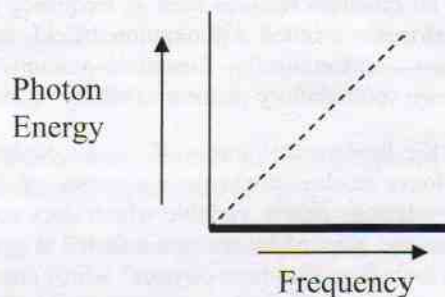


Figure 1. Direct relationship between photon energy and frequency, according to Planck's quantum formula, $E = h\nu$.

[†] The Principle of Least Action - Nature opposes any needless expenditure of energy, and natural motions proceed along the path of shortest distance, briefest time, and minimal energy. $S = \int T - V dt$, where S is the action (energy • time), T is kinetic energy, V is potential energy, and t is time. Or simply, $S = \Delta E \Delta t$ (e.g., Joule seconds).

[§] $\bar{E} = RT/N$, where \bar{E} = mean energy of electron oscillatory motion, R = universal gas constant, T = absolute temperature, and N = Avogadro's number. Ibid 7.

^{**} "The simplest conception is that a light quantum transfers its entire energy to a single electron..." Ibid 7.

^{††} "We have to assume that, in ionization of a gas by ultraviolet light, one energy quantum of light serves to ionize one gas molecule." Ibid 7.

As frequency increases, so too does photon energy. The idea “that light has a very large number of elementary constituents, one for each frequency” – is an oddity that has caused countless hours of consternation for scientists the world over.⁹

After Planck and Einstein introduced their quantum concepts many questions and paradoxes arose. For example, experimental observations indicated that light behaved as both a wave and a particle. In 1922, Louis-Victor de Broglie proposed that light waves possess momentum (just like particles), and that particles are “waves” with measurable wavelengths (just like light). A few years later, in 1925, Werner Heisenberg developed matrix mechanics for particles, which was the first formal mathematical description for quantum mechanics. The next year, Erwin Schrödinger published his famous equation on wave mechanics, and after another year showed mathematically that his wave approach and Heisenberg’s photon matrices were equivalent. Both struggled with the need for integral numbers in quantum mechanics.

A revolution in quantum mechanics had begun. Meeting in Copenhagen in 1927, Bohr and Heisenberg developed the Copenhagen Interpretation, which became the “standard” interpretation of quantum mechanics. Bohr proposed his Complementarity Principle, postulating that light had a wave-particle duality, and that either a wave aspect of light could be measured, or a particle (photon) aspect could be measured, but not both at the same time. Heisenberg proposed his Uncertainty Principle suggesting that there is always uncertainty in the measurement and determination of any two paired and complementary quantities, such as momentum and position, or energy and time, e.g., $\Delta E \cdot \Delta t \geq h$. A mysterious dimensionless constant - the fine structure constant - was discovered, and it defied all explanation.^{‡‡} Paradoxes multiplied like rabbits and as Einstein later wrote:¹⁰

“But what is light really? Is it a wave or a shower of photons? There seems no likelihood for forming a consistent description of the phenomena of light by a choice of only one of the two languages. It seems as though we must use sometimes the one theory and sometimes the other, while at times we may use either. We are faced with a new kind of difficulty. We have two contradictory pictures of reality; separately neither of them fully explains the phenomena of light, but together they do.”

The concepts embodied by the Copenhagen Interpretation evolved into the Standard Model of Particle Physics, and the paradoxes evolved as well. For example, the Standard Model can explain most forces associated with light and matter, however it cannot explain gravity. This is a significant issue since gravity is a fundamental aspect of our reality. By 1916, Einstein had developed his general theory of relativity and gravity, relying primarily on mechanical features of matter such as mass and velocity, without relying on quantum features such as frequency or Planck’s action constant. Einstein assumed that only the mass and energy of matter excited a gravitational field, and that together gravity and matter satisfied the law of conservation of energy. Unfortunately, Einstein’s attempts to unify his quantum and gravitational theories were unsuccessful, and *two more* contradictory pictures of reality resulted.

Many attempts have been made to unify the fundamental forces of nature, explaining both gravitational and quantum features of matter. Invariably more paradoxes resulted. Heisenberg’s matrix mechanics can unify gravity and quantum mechanics only with the addition of a mysterious matrix variable which does not correspond to any known aspect of reality. Similarly, quantum gravity theories are plagued by an issue referred to as the “Problem of Time”, i.e., there seems to be a missing time factor. Solutions include a “two-time-physics” which attempts to resolve the Problem of Time by adding another time dimension to the quantum equations.¹¹

Both Planck and Einstein were deeply troubled by the paradoxes and uncertainties that their quantum work had spawned. Einstein voiced his concerns formally in 1935, in his famous “EPR” paper, proposing that quantum mechanics is incomplete because it does not provide a theoretical element corresponding to each element of reality.¹² He suggested that “hidden variables” are responsible for this incomplete state of affairs. In the 1950’s David Bohm further

^{‡‡} The fine-structure constant “has been a mystery every since it was discovered more than fifty years ago, and all good theoretical physicists put this number up on their wall and worry about it. Immediately you would like to know where this number for a coupling comes from: is it related to pi or perhaps to the base of natural logarithms? Nobody knows. It’s one of the greatest damn mysteries of physics: a magic number that comes to us with no understanding by man” Feynman, R. [QED. The Strange Theory of Light and Matter], Princeton Univ. Press, 129, (1988).

championed the idea that quantum mechanics is incomplete due to hidden variables, and numerous physicists since then have expressed their similar dissatisfaction with quantum physics.

Recent research has revealed the identities of some of the hidden variables hypothesized by Einstein.¹³⁻¹⁵ In the course of performing some experimental work related to light, Einstein's concept for considering the mean energy of a single oscillation (of an electron) was used. Rather than calculating the energy for a single *electron* oscillation, however, the mean energy of a single oscillation of *light* was calculated instead. Calculations of mean light oscillation energy at various photon energies were performed, anticipating that high energy photons would possess higher oscillation energies than low energy photons. The startling result, however, was the finding that the mean oscillation energy for light is constant. Equally startling was the finding that the numerical value, of light's constant mean oscillation energy, is equal to the numerical value of Planck's action constant "h". The question immediately arose - had Planck's action constant been misinterpreted so long ago? Was it really an *energy* constant? If true, then a time variable was missing from Planck's quantum formula.

An extensive foray into the historical records provided answers in the affirmative. Planck's constant is an energy constant, and not an action constant. As for the missing time variable, it had been present in earlier versions of Planck's quantum relationship but he omitted it from his black-body derivation. Planck probably did this for what he thought were sound reasons at the time, but which in hindsight, led to needless paradoxes and misinterpretations.

Upon restoration to Planck's quantum formula, the hidden time variable suggests a far richer interpretation of quantum mechanics. Modeling an elementary quantum of light represented by an invariant and universal energy constant - the mean oscillation energy - banishes many of the uncertainties and paradoxes of earlier quantum mechanics.

2. DERIVATIONS AND CALCULATIONS

§ 1. Derivation of the Mean Energy of a Single Oscillation of Electromagnetic Energy

Start with the mathematical relationships from Planck's quantum formula for photon energy, "E = hv", where "v = N t⁻¹", and "N" is the total number of oscillations measured per unit time. To obtain the mean energy per oscillation ("Ē"), divide mean photon energy ("E_N") by the number of waves "N" comprising the photon:

$$\bar{E} = \frac{E_N}{N \text{ osc}} = \frac{hv}{N \text{ osc}} = \frac{(6.626 \times 10^{-34} \text{ J sec})(N \text{ sec}^{-1})}{N \text{ osc}} = 6.626 \times 10^{-34} \text{ J/osc} \quad (3)$$

The mean energy for a single oscillation or wave of light is *numerically equal* to the value of Planck's proportionality constant "h" (and can be alternatively represented as "ħ").

§ 2. Mean Oscillation Energy is Constant and Independent of Frequency

Consider three different frequencies v_{1,3}, such that:

$$v_1 \ll v_2 \ll v_3$$

$$v_1 = 1 \times 10^3 \text{ sec}^{-1} \text{ (Radio)}; \quad v_2 = 2 \times 10^9 \text{ sec}^{-1} \text{ (MW)}; \quad v_3 = 3 \times 10^{15} \text{ sec}^{-1} \text{ (UV)}. \quad (4)$$

Next, obtain the mean photon energy at each frequency v_{1,3} according to Eq. 2 above:

$$E_1 = 6.626 \times 10^{-31} \text{ J} \quad E_2 = 1.325 \times 10^{-24} \text{ J} \quad E_3 = 1.988 \times 10^{-18} \text{ J} \quad (5)$$

The photon energies are all different and are directly proportional to the frequency for each photon (i.e. proportional to the number "N" oscillations of electromagnetic energy in 1 second, comprising each photon). Next, to determine the

mean energy of a *single* oscillation in each photon, one must divide the mean photon energy by the number of oscillations in that photon:

$$\begin{aligned} E_{\text{osc1}} &= 6.626 \times 10^{-31} \text{ J} / 1 \times 10^3 \text{ osc} = 6.626 \times 10^{-34} \text{ J / osc} \\ E_{\text{osc2}} &= 1.325 \times 10^{-24} \text{ J} / 2 \times 10^9 \text{ osc} = 6.626 \times 10^{-34} \text{ J / osc} \\ E_{\text{osc3}} &= 1.988 \times 10^{-18} \text{ J} / 3 \times 10^{15} \text{ osc} = 6.626 \times 10^{-34} \text{ J / osc} \end{aligned} \quad (6)$$

The mean energy of a single wave of light is the same for all three frequencies ν_{1-3} , namely $6.626 \times 10^{-34} \text{ J/osc}$. Performing the same calculations for wavelength, it becomes clear that the mean energy of a single wavelength of light is also $6.626 \times 10^{-34} \text{ J}$ for all three different wavelengths λ_{1-3} . The mean oscillation energy of light is *constant*, and does not vary with frequency or wavelength.

§ 3. The Photon

Substituting mean oscillation energy, " $\hbar\nu$ ", for the action constant in Planck's quantum formula:

$$\hbar\nu = E_N / t \quad (7)$$

produces an energy rate. To obtain total energy one must multiply the energy rate by the period of time during which the energy is measured (measurement time, " t_m "):

$$E_N = \hbar\nu t_m \quad (8)$$

This expanded quantum formula can be compared with the traditional condensed quantum formula. Set measurement time equal to a value of "one second":

$$E_N = \hbar\nu \cdot 1 \text{ sec} = (6.626 \times 10^{-34} \text{ J}) N = h\nu \quad (9)$$

A one second measurement time yields the familiar photon energy value of classical quantum mechanics. Referring to Equation 9, above, it can be seen that:

$$h = \hbar t_m \quad \text{when} \quad t_m = 1 \text{ sec} \quad (10)$$

One second time intervals are arbitrary, however, so consider measurement times of differing durations such as three (3.0) seconds or one-half (0.5) second, for light with the frequency, " ν ", of " N oscillations per second:

$$E_{N3.0} = \hbar\nu \cdot 3.0 \text{ sec} = (1.988 \times 10^{-33} \text{ J}) N \quad (11)$$

$$E_{N0.5} = \hbar\nu \cdot 0.5 \text{ sec} = (3.313 \times 10^{-34} \text{ J}) N \quad (12)$$

When measurement time equals some value other than "one second", the photon energies are different, even though the frequency is the same. A longer measurement time measures more oscillations, resulting in greater total energy. When the measurement time equals a numerical value of "one", the photon energies of traditional quantum mechanics are obtained. The photon, as historically defined, is a time dependent packet of energy, based on the arbitrary measurement time of one second.

An arbitrary, *one second* increment of energy cannot be a truly indivisible and elementary particle of nature.

3. THE HISTORICAL RECORD

The true brilliance of Planck was in suggesting that energy is quantized in small *equal* amounts, and in calculating the numerical value - $6.626 \times 10^{-34} \text{ J}$ - for that quantum of energy. As Planck commented to Paul Ehrenfest, "*Now it seems to me not completely impossible that there is a bridge from this assumption (of the existence of an*

elementary quantum of electric charge e) to the existence of an elementary quantum of energy".¹⁶ Interestingly, it seems that although Planck conceptualized his constant as an *energy* constant, he formulated it as an *action* constant. Planck's publications leading up to his famous black-body and quantum formula paper, reveal important clues as to why he formulated the numerical value of "h" as an action constant rather than an actual *energy* constant.

In the years just prior to his black-body derivation, Planck published a series of papers on his electromagnetic theory, in relation to the irreversibility of an increase in entropy. In those papers, one finds an earlier version of his quantum relationship:³

$$\frac{dS}{dt} \cdot dt = \frac{I}{a \nu} \frac{dU}{dt} \cdot \log \frac{U}{b \nu} \quad (13)$$

where "U" is internal energy, and which simplifies to the equivalence:

$$dU \approx a \nu dt \quad (14)$$

Clearly Planck was familiar with the mathematical relationship described in Eq. 8 above, $E_N = \tilde{h} \nu t_m$.

This was the same work, however, which caused Boltzmann to publicly criticize Planck for his inappropriate assumptions related to time and electromagnetic radiation. Planck turned to the methods of Wien and the black-body radiation puzzle to achieve his goal of establishing the mathematical foundations for entropy. He combined his previous electromagnetic work with Wien's method for converting the experimental, time-dependent energy measurements into energy densities. This resulted in data that was thus independent of time. This approach may have been especially appealing to Planck, as it eliminated the source of Boltzmann's earlier criticisms. It also allowed Planck to derive a "proof" of Wien's black-body radiation law, relying heavily on formulations related to entropy and its irreversibility.

Unfortunately, Wien's equation and Planck's derivation were incorrect. Planck later admitted in his famous black-body paper:⁷

"... the law of energy distribution in the normal spectrum, first derived by W. Wien from molecular-kinetic considerations and later by me from the theory of electromagnetic radiation, is not valid generally."

Although his derivation of Wien's equation from his theory of electromagnetic radiation was not generally valid, Planck used his theory once again to derive his new black-body equation:⁷

"In any case the theory requires a correction, and I shall attempt in the following to accomplish this on the basis of the theory of electromagnetic radiation which I developed."

Not surprisingly, Planck found that his black-body derivation required a somewhat arbitrary approach, as well as a certain willingness to overlook simple, practical details:⁵

"You will find many points in the treatment to be presented arbitrary and complicated, but as I said a moment ago I do not want to pay attention to a proof of the necessity and the simple, practical details."

Turning now to Planck's mathematical assumptions, one finds in the preamble to his derivation:⁷

"§1. ... we shall refer to the average energy U of a single resonator. Then to the total energy

$$U_N = NU \quad \text{[Planck's] Equation 1.}"$$

Planck began his black-body derivation assuming that the energy of a vibrating molecule (i.e., a resonator) was independent of time, consistent with the mathematical methods of the failed Wien equation. To determine whether this was an appropriate assumption, one could examine the actual laboratory measurements Planck used to calculate his

