**_Chapter 2_**

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# The Quantumness in Detecting Electromagnetic Waves is Determined by the Interaction Properties of the Detector

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## ABSTRACT

Einstein's 1905 paper on the photoelectric effect successfully modeled the published data while explicitly defining light as "indivisible light quanta". One of the key successes of Quantum Mechanics (QM) of 1925-26, is the release of discrete packet of energy hv during any quantum level transitions in atoms and molecules. These two modern successes have overturned the mathematical and experimental knowledge developed over several centuries behind the optical science and engineering, without successfully bridging the knowledge gap epitomized by the still unresolved "wave-particle-duality" (WPD). Note that, optical science and engineering fields are still thriving using Huygens-Fresnel diffraction integral (HF-DI) of 1817 and Maxwell's wave equations of 1876, without any controversy. This chapter resolves this dichotomy by eliminating the need for WPD. We provide a model for the atomic emission as a discrete packet of energy hv, as required by QM, but which evolves and propagates out as a Maxwellian classical exponential wave packet, while diffractively spreading out obeying the HF-DI. The continuing need to accept the magical WPD arises because we have not been systematically and explicitly exploring the two-step *physical processes* which take place during light-detector interaction before the photoelectric data is generated by our apparatus. The two steps are: (i) Linear amplitude-amplitude stimulation induced on the detecting dipoles by the light wave vector; (ii) which is then followed by the quadratic energy absorption step by the detector. If the detector is an LCR oscillator (for radio waves), or an old fashioned Bolometer (for higher frequencies), we would not observe any quantumness in the data. But, when we use a modern quantum photodetector using higher frequency EM waves, we can count highly amplified current pulses of electrons, generated out of each one of the released electron, bound quantum mechanically inside the detector.

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## 1. INTRODUCTION

### 1.1 Healthy Debate to Keep Ourselves Challenged

The modern debate over the quantumness of light has re-emerged [1] as a result of the revival of Newton and Huygens' old "Wave-Particle Duality" (WPD). Although it is actually just our ignorance of the truths behind EM waves and elementary particles, a few of the pioneers of quantum mechanics actively promoted this WPD, and it is currently thought to be the preferred new science. The fundamental problem is that all of our theories are necessarily incomplete because, even though, they have been formulated based upon postulates constructed by far-sighted contemporary geniuses, their knowledge about the working rules of the universe were insufficient. This insufficiency will continue with us, probably, forever, even while our working knowledge of the universe keeps enhancing as we keep iteratively advancing newer theories. Therefore, the driving point of this article is to inspire people to keep challenging the older working theories to explore the possibilities of developing better theories that guides the *visualization of nature's working processes*. Our engineering successes depend upon our capability to *emulate nature allowed physical processes*, in novel ways, even when the theory is not yet perfect.

Newton understood and expressed that his debate with Huygens had remained un-resolved because neither of them were able to figure out the proper and complete model of light, from generation to propagation to detection. Today, several centuries after Newton's time, the founders of the Quantum Mechanics (QM) of early 1900 have revived the old WPD because we have not yet figured out the detailed physical processes behind the generation, propagation and detection processes of Electromagnetic radiation. Maxwell's wave equation has given an excellent formalism to visualize the perpetual propagation of EM waves through the free space and all material media leveraging the electromagnetic tension fields, both in the free space and in material media. Maxwell derived that the *perpetual velocity* of light is empowered by the electromagnetic tension properties, $c^2 = 1/\varepsilon\mu$ , where $\varepsilon$ and $\mu$ are the electromagnetic tension properties of the medium. Optical engineers always use refractive indices to determine the velocity of light in different media, which are derived using, $\varepsilon$ and $\mu$ for the media. For the free space $c_0^2 = 1/\varepsilon_0\mu_0$; consequently $\varepsilon_0$ and $\mu_0$ represent physical parameters of the free space, which we should not neglect [2-5]. We should note that the variable "$c$", from medium to medium, is a derived parameter from the electromagnetic tension properties; "$c$" is not a fundamental constant of nature. Maxwell's waves are amplitude undulation of diverse electromagnetic media. WPD should not encourage us to neglect the critical and routine successes we have been deriving from Maxwell's equations, before we can find an alternate mathematical theory that can explain how an electromagnetic "energy bullet" (photon) can acquire perpetual velocity [5].

## 1.2 Flow of the Paper

Let us briefly underscore that if we pay attention to the *physical processes* behind the emergence of our experimental data, we will find that the quantumness in detecting EM waves lies with the *physical interaction properties* of the detector. During the previous couple of centuries, a lot of fundamental spectrometric and other optical measurements were done by using blackened thermometers, thermopiles and bolometers across the optical spectrum. These early progress was not hampered by the "quantumness of visible light"! If a frequency-resonant classical detectors (dipole oscillator) can keep absorbing energy out of the stimulating EM wave continuously, there is no "quantumness" in the EM waves, as in radio and microwaves. LCR circuits do the job. Today, for higher frequencies of EM waves, we have modern photodetectors. They have frequency-resonant energy absorbing detecting dipoles, which are quantized atoms, molecules, or their assemblies. *They have built-in finite quantum-cups*. They can absorb energy out of the EM wave just to fill up their quantum cups. Once they fill up their quantum-cup with a discrete amount of energy, they cannot accept any more energy until they are completely *recycled*. It does not make logical sense to assign this "quantum cup" discreteness of quantum detectors on to Maxwell's EM waves. Fig. 1 gives a brief summary of the EM wave spectrum and the suitable detectors for each range of frequencies.

In Section 2, we will underscore the unavoidable incompleteness of Classical Mechanics (CM) and Quantum Mechanics (QM) because they have not developed any specific models for the *physical processes* that take place behind the generation and detection of EM waves. We will also underscore the core properties of the three working equations: (i) Huygens-Fresnel Diffraction Integral (HF-DI), Eq.1. (ii) Maxwell's Wave Equation, Eq.2, and (iii) Schrodinger's QM Equation, Eq.3. HF-DI and Maxwell's equations do give us very good working model for the propagation of EM waves. They are the "staples" of optical physics. They are sustaining and empowering the continued advancements of optical science and engineering, without much controversy. In contrast, the interpretations, specifically, the Copenhagen Interpretations, relevant to Eq.3, are still a subject of intense debate. It should be of great interests to us that all these three mathematical equations relies upon Superposition Principle (SP). We will focus on this SP later.

$$U(P_0) = \frac{-i}{\lambda} \iint_{\Sigma} U(P_1) \frac{\exp(ikr_{01})}{r_{01}} \cos\theta \, ds \tag{1}$$

$$\frac{\partial^2 E(x,t)}{\partial t^2} = \frac{1}{\varepsilon\mu} \frac{\partial^2 E(x,t)}{\partial x^2} \equiv c^2 \frac{\partial^2 E(x,t)}{\partial x^2} \tag{2}$$

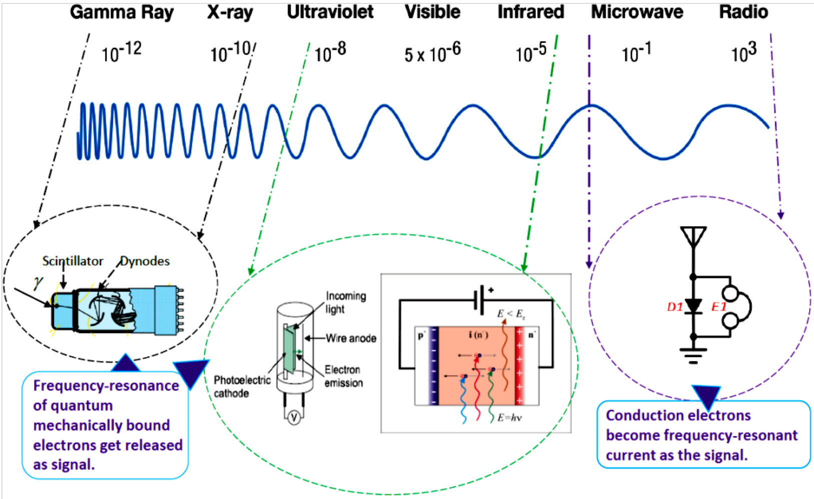



**Fig. 1. EM waves, being harmonic oscillations, can transfer energy to frequency-resonant oscillators (detecting dipoles). When the resonant oscillators can absorb energy continuously from the EM waves, as in the cases of radio to microwaves, the detector designers have no need to learn quantum mechanics. For higher frequency EM waves, the frequency-resonant detectors are usually atoms and molecules with quantum-cups of discrete size for energy absorption. Therefore, these detectors can report only events of discrete energy absorption. The two detectors enclosed within the dashed elliptical enclosures are discrete energy absorbers, while the one within the dashed circle, can keep on absorbing energy continuously. Therefore, we need to pay attention to the physical interaction processes that generate data in our instruments. Mathematical theory alone cannot explain the physics behind interaction processes. [This figure has been synthesized using borrowed cartoons from various freely available websites.]**

$$\frac{\partial\psi(x,t)}{\partial t}=\frac{i\hbar}{2m}\frac{\partial^2\psi(x,t)}{\partial x^2}+\frac{1}{i\hbar}V(x,t)\psi(x,t) \qquad (3)$$

These three phenomenological physics equations have been helping us quantitatively understanding and keep exploring many natural phenomena within each one’s domain of applications for prolong periods. The first equation is directly a superposition equation, superposition of innumerable spherical wavelets. The second and third equations accept the linear combinations of all possible allowed solutions to their respective equations as new solutions, because they are linear differential equations. However, just the simultaneous presence of the allowed solutions within the same physical space does not automatically generate the emergence of the Superposition Effect (SE). There has to be a frequency-resonant detector that can simultaneously respond to all the simultaneously stimulating waves. Then the detector has to execute the square modulus operation, $E^*E$ or $\psi^*\psi$, to absorb the necessary energy and create the measurable data. *Fields, by themselves do not generate data*. Unfortunately, we have developed a sustained cultural belief that the fields by themselves, or even a single component of the superposed field, can generate the Superposition Effect (SE). This defies the logics embedded within our successful mathematical theory (or prescription). This will be clearer from Eq.6 later, where we will discuss the importance of differentiating the mathematical SP (simultaneous presence of multiple amplitude signals in the same space volume) from SE (the energy exchange & data generation by some physical detector that executes the square modulus operation).

In Section 3, we propose a solution to the Wave-Particle Duality while synthesizing Newton's "corpuscular" concept with Huygens' "secondary wavelet" and, at the same time, maintain the conceptual continuity with the predictions of modern QM, both in *discrete-energy-emission* by atoms/molecules and in *discrete-energy-absorption* by quantum detectors. We also propose potential analysis and experiments to derive the photoelectric current pulse (PCP) statistics using the fundamentals of emission, superposition and detection processes. Einstein's photoelectric equation is an energy balancing equation that mapped the previously published data on photoelectric current, which had a frequency threshold. It does not incorporate the amplitude stimulation process by multiple light pulses. Further, Einstein assigned the quantumness to light, rather than to the quantum mechanically bound electrons in materials. An atom can collide with a kinetic particle and acquire out of it the necessary 'quantum' amount of energy and achieve a higher quantum level energy state. That is why Boltzmann's classical statistics is a critical tool in QM formalism.

## 2. INCOMPLETENESS OF CLASSICAL AND QUANTUM PHYSICS

Incompleteness in our overall knowledge is natural and pervasive. Incompleteness in our theories are deeply fundamental.

Gödel's "Incompleteness Theorem" [6] has demonstrated that no mathematical theory can ever be complete, because all mathematical theories have to start with an axiom or a postulate, which are unproven but intelligent guesses only, and not some confirmed knowledge, due to our initial ignorance about the rules of nature. Therefore, we should subject all theories to continuous critical evaluation to advance our deeper knowledge on visualizing the physical interaction processes that nature executes. Evolution is a sustained story of continuous engineering successes by all species [7].

Our Evidence Based Science (EBS) has been thriving upon experimentally reproducible data to validate our theories. However, no apparatus can extract *complete information* about any unknown entity under study. We construct our apparatus to generate data through interaction between the unknown entity under study and a known referent entity. First, no apparatus we construct has 100% fidelity in transferring the 'recorded' data [8, See Ch.12]. Second, we never know the complete properties of any referent entity. We deliberately assume wide ranges of approximations and also assume all the forces are negligible except the one force of interaction under consideration. Further, we also neglect the influence of all the diverse "background fluctuations". Thus, all of our data are approximate and hence our knowledge about the unknown entity can only be approximate, and not complete. That is why we do not have the choice but to accept that all of our theories will always be incomplete. We must accept this barrier of insurmountable incompleteness of all theories and develop a strategy to keep iteratively improving them. One of the proposed strategy is to incorporate the interaction process visualization, while taking guidance from the mathematical logics built into the working theory and iteratively keep pushing to develop better and better theories.

We intend to apply this "interaction process visualization" strategy to enhance the theory of photoelectric emission [9,9a].

## 2.1 Foundational Background in Framing an Equation Determines its Future Strengths

Let us briefly explore the foundational background of the three equations, Eq.1 to 3, presented above. Eq. 1 is a literal mathematical translation, made by Fresnel in 1817, of the postulate of "Secondary Wavelets" by Huygens in 1690: Once a wave is triggered on a tension field by a suitable external force, every point on the wavefront keeps generating secondary wavelets moving in the same direction. The conceptual physical picture behind this postulate is as follows. A parent tension field cannot assimilate (absorb) the original external perturbing energy that has triggered the wave. Therefore, the tension field spontaneously tries to get rid of the perturbing energy by simply pushing it forward out of every point. Thus, the wave is perpetually regenerated as a superposition of innumerable secondary wavelets in the same forward direction. Therefore, the original wave packet keeps moving indefinitely. That is what happens for EM waves in the medium of the free space, or in the media of different materials. Thus, Huygens postulate, based upon his initial logical mental visualization, received a mathematical formulation by Fresnel. It became a great success story in physics. This wave theory guided the advancement of physics from many directions. Then, in 1876, Maxwell mathematically restructured the experimentally observed laws of Electrostatics and Magnetostatics, and unified them [10,11]. Maxwell derived the EM wave equation, Eq.2. Note that Eq.1 is functionally a solution of Maxwell's wave equation since it is a linear superposition of innumerable spherical wavelets.

Thus, the evolutionary history of the Eq.1 and Eq.2 are grounded on centuries of experiments and understanding of the *physical pictures* of the natural processes involved in electromagnetism. This is why we see the continued successes in optical science and engineering including the successful emergence of the new applied fields of Plasmonic Photonics, Nanophotonics, and Metamaterials.

However, Maxwell's equation cannot model the physical processes behind the generation, and the absorption of light by atoms and molecules. Planck's law of 1901 on the Blackbody Radiation underscored that the atomic and molecular radiation exchanges must take place with the emission and absorption of EM wave energy in discrete amounts. In 1913, Bohr proposed his "old quantum theory" and gave the "planetary" model of atoms having discrete energy levels. However, it was not extendable much beyond the Hydrogen atom. In 1914, Frank and Hertz experimentally demonstrated that the heavier atoms like Mercury also possess discrete quantized energy levels. Then, in 1925, Heisenberg presented his Matrix mechanics as one of the foundational approach to modern Quantum Mechanics. It can precisely predict the quantum energies that we can measure. However, it was not helpful in visualizing the physical picture of atomic emission and absorption processes. In 1926, Schrodinger produced his "wave equation", which appeared to be a better approach to QM from the standpoint of visualizing the physical pictures of "particles" as "plane waves". Unfortunately, the concept of "plane wave" is a mathematical fiction, not a reality. All waves are always spatially finite and yet propagate by spreading diffractively. Unfortunately, even the Schrodinger's equation (Eq. 3) has not succeeded in helping us visualize the physical processes behind the absorption or the release of energy taking place in atoms and molecules. It can predict only the final measurable discrete energy exchanges. The *process* remains hidden behind the postulate, "collapse of the wave function"! Therefore, the early founders of QM, while establishing the currently dominant Copenhagen Philosophy, promoted the philosophy that the purpose of physics theories is just to validate the experimental data, not to visualize the *interaction processes* that nature carries out everywhere. Schrodinger's equation does not give the precise position of an orbiting electron in an atom! Should we take this limitation as "forever"; or, should we take it as an entry point for further enquiry and further enhancement of the theory?

Let us briefly compare Maxwell's Eq.2 with the Schrodinger's Eq.3. Eq.2 is a *proper wave equation* since it balances the temporal "acceleration" with the spatial "acceleration" through the second derivative of time and space, respectively. This leads to the *perpetual wave velocity* of light, $c^2 = 1/\varepsilon\mu$, where $\varepsilon$ and $\mu$ are the nature's action parameters, the electric and magnetic tension properties of the medium in which EM waves are traveling [5]. We should note that $c$ is a medium-dependent variable and a derived parameter, and not a "fundamental constant" of nature. Schrodinger's equation does not have the built in "temporal acceleration" (second derivative of time). That is why quantum particles cannot be "perpetual waves" like the EM waves are. In fact, this is why there is a "potential gradient" term $V(x,t)$ in Eq.3, which provides the "distance limited " physical push/pull potential gradient for the particle to move; but it cannot move perpetually like the EM waves. However, the quantum mechanical beauty of this equation is that the allowed solutions are *amplitude-harmonics* and accommodates the *Superposition Principle*, just as Maxwell's equation does.

Thus, even though both the EM waves and the quantum particles "transport energies" and exchange them during physical interactions to generate observable effects; form the standpoint of interactions, they are amplitude signals obeying the SP (Superposition Principle). Neither of these two equations of propagation represent energy-bullets from the standpoint of triggering any energy exchange process directly. *They trigger the interaction process as amplitude-amplitude stimulations.* When the interactions are compatible, i.e. frequency-resonant, they will trigger linear amplitude stimulation, followed by the square-law energy transfer process ($\psi^*\psi$) and exchange energy $h\nu$. This is a two-step process, built into the mathematical recipe. EM waves neither propagate as energy bullets, nor can generate superposition effect (energy transfer) by itself without being facilitated by a detector to execute the square modulus operation. Huygens Principle categorically underscores that wavelets keep propagating without interacting with each other, or physically transforming each other's characteristic wave properties. We call this important characteristic of EM waves as Non-Interaction of Waves (NIW) in the absence of interacting materials [8].

It is apparent that Nature is a marvelously creative system engineer. It is the diverse physical transformations through diverse physical interactions, from dust-to-dust, that nature has been maintaining a cyclically evolving universe, both in the Cosmosphere and in our Biosphere. All species, from viruses to humans are a product of three to four billion years' of evolution where all the species have been constantly carrying out diverse routine and innovative engineering activities, by simply emulating nature-allowed *processes,* without knowing or deciphering the laws of nature. Humans have started succeeding in inventing approximate but serious mathematical theories starting less than one thousand years back. Our, key point is that successful biological evolution requires sustained and successful engineering innovations allowed by the rules of nature, irrespective of whether we can theorize the rules perfectly well or not. Therefore, it *is more important* for us to use the powerful logics of math to guide us to visualize the nature allowed *interaction processes* so that we can emulate them more efficiently, rather than seeking only esthetic beauty and harmony inside the elegant mathematical universe we can create.

### 2.2 Mathematical Superposition Principle (SP) is Incomplete without Recognizing the Physical Processes Behind the Recordable Superposition Effect (SE)

We have already mentioned that the three equations (Eq.1, 2, 3) have the common property of abiding by the Superposition Principle (SP). Eq.1 is a direct statement of the SP, as it represents linear summation of harmonic waves. The Eq.2 of Maxwell and Eq.3 of Schrodinger, both are linear differential equations. Therefore, mathematically, any linear combination of individual solutions of these equations will also satisfy their respective equations. We know this as the Superposition Principle (SP). Thus, we see that SP plays a very significant role both in the classical and in the quantum physics. *This is a very important* *conceptual continuity in nature*, which we should not neglect. Therefore, it is of critical importance for us to visualize the invisible operational processes, which generate the final measurable data in our instruments, after being "superposed" to interact with a detector, whether it is classical or quantum mechanical.

### 2.3 Differentiating between Superposition Principle (SP) and Superposition Effect (SE)

We need to recognize nature's fundamental *Interaction Principle* behind her perpetual evolution processes. No observable and/or measurable physical transformation can happen in nature without some interaction between more than one physical entities, guided by some mutually compatible force of interaction. Even our mathematical theory defines superposition principle as summation of more than one physical entity containing amplitudes and phases carried by *multiple entities*. Therefore, a single particle, or a well-defined single pulse of EM wave, cannot generate by itself the measurable superposition effect. Eq.4 represents the mathematical expression for the generic amplitude Superposition Principle (SP) where $a_n(t)e^{-i2\pi\nu t+\phi_n}$ can be considered as solutions of either the Maxwell or the Schrodinger equation. The two sets of n-parametric values cannot be carried by any single elementary entity:

$$E_{total}(t) \text{ or } \psi_{total}(t) = \sum_n a_n(t)e^{-i2\pi\nu t+\phi_n} \tag{4}$$

We trust our mathematical equations when validated by diverse experiments. Then, we must respect and leverage the built-in logics behind working mathematical equations to explore and visualize the *interaction processes* it represents. However, Eq.4 does not generate data. We know that EM waves do not interact by themselves to generate data due to the NIW property of waves. Light beams from billions of galaxies and/or stars cross through each other during their long journey in space towards our earth. However, our telescopes, when record well resolved images, the incoming waves preserve all the spectral and other characteristics of each one of the cosmic entity under study. Without frequency sensitive light detector array, we cannot register the images of stars. The same is true for interferometers. We cannot register superposition fringes without the active participation of all the beams simultaneously stimulating the detector array [Ch.2 & 3 in 8]. However, it is a slightly different story for particles. Particles do interact with each other. However, one still needs a "particle" detector to register simultaneous presence of multiple particles bringing multiple amplitude and phase information, as is implied by the generic superposition Eq.4. Our mathematical recipe tells us that only the square modulus of the Eq.4 can generate measureable data. However, the "square modulus" has to be a physical operation executed by some material detector that is frequency resonant to be stimulated. Then it *absorbs energy out of all the stimulating beams* and undergoes physical transformation to report that the detector array has executed the square modulus operation. Therefore, for the registration of optical interference phenomenon, we must first recognize the generic electromagnetic polarizability of a suitable material dipole, as in Eq.5, consisting of both a linear term and a set of nonlinear terms, where $\chi_n(\nu)$ is the n-th *polarizability interaction parameter* of the detecting dipoles. If the detector is a quantum dipole, then $\chi_n(\nu)$ represents its quantum dipole property. For a radio receiver, it is the polarizability of the frequency tuned LCR circuit.

$$P(t) = \varepsilon_0[\chi_1(\nu)E(t) + \chi_2(\nu)E^2(t) + \chi_3(\nu)E^3(t) + .....] \tag{5}$$

Fortunately, for most EM wave detection under normal intensity levels, the approximation of keeping only the linear term is sufficiently accurate. Then, we can express the instantaneous energy *available for absorption* by a detecting dipole can be expressed as Eq.6, where $a_n(t)\exp[-i2\pi\nu t + \phi_n]$ now represents n-different EM signals, *simultaneously stimulating* the material detecting dipoles:

$$|P(t)|^2 = \varepsilon_0^2\chi_1^2(\nu)\left|\sum\nolimits_n E_n(t)\right|^2 = \varepsilon_0^2\chi_1^2(\nu)\left|\sum\nolimits_n a_n(t)e^{-i2\pi\nu t + \phi_n}\right|^2 \tag{6}$$

Eq.6 represents the time-varying propagating EM wave energy available to fill up the quantum cup of the stimulated dipoles. This energy absorption/transfer process is a time finite integration of Eq.6, *executed by the detector while being simultaneously stimulated by all the n-signals* [12]. We should not ignore the built-in mathematical logics into our working equations and insert diverse incongruent interpretations, as if a single physical "wave" entity can generate the superposition effect, violating the causal relations built into our successful mathematical Eq.6.

Let us also note that we always design our *superposition* experimental apparatus such that more than one signal of similar class (mutually phase-steady) is generated and then superposed *simultaneously* on an interaction-compatible detector, or a detector array. That is why Michelson developed the technique of alignment of interferometers using white-light to ascertain zero relative path delays between the two arms of any two-beam interferometer [13]. With the advent of lasers, we now can generate wave trains that have phase-steady relation over a long time duration and the alignment restrictions are relaxed. This is long coherence time (or length). The theory of optical coherence is a major subject developed by classical physics over a couple of centuries [14]. Glauber gave it a quantum mechanical formalism [15], which turns out to be mathematically equivalent to classical formalism [16].

We conclude this section by underscoring that the Superposition Principle (SP) is the correct mathematical starting point to start analyzing both the classical and the quantum mechanical superposition effects. However, the mathematical expression for SP does not represent any observables data. The mathematical square modulus does represent the energy transfer process, but only when the detectors' polarizability parameter is incorporated to *model the physical* *interaction process.* Accordingly, the continued progress of Evidence Based Science along the right path critically depends upon the incorporation of visualizing the invisible *interaction processes* within our apparatus that generate the “evidence” (data) for us.

## 3. PROPOSED MODEL FOR THE HYBRID PHOTON WAVE PACKET TO RESOLVE THE WAVE-PARTICLE DUALITY CONUNDRUM

Conceptual models presented here can collectively eliminate the need for continuing with the postulate of Wave-Particle Duality (WPD). The WPD does not represent any new knowledge about “photons” and “particles” that can facilitate the continuous advance of our evidence based science. We need to keep exploring possible physical *process models* behind the absorption and emission of EM wave energy by atoms and molecules. Currently neither the Maxwell’s equation nor the Schrodinger equation provides explicit guidance in this direction. Yet, these are excellent working theories; and hence they have definitely captured some of the nature’s actual working processes behind Maxwellian ether and Schrodinger’s “waving” particles. Therefore, deeper exploration will be worthwhile.

Our approach relies upon preserving conceptual continuity and logical congruence between the working theories and diverse observations while introducing newer concepts. This paper does not suggest any new theories or any fundamental changes. Our key approach is to suggest newer views that can eventually be validated through new experiments within the bounds of the current theories, while opening up the gates for the directions of future improvements.

### 3.1 The Hybrid Photon Wave Packet

We are proposing that all EM energies, emitted by atoms and molecules, propagate out as time-finite Maxwellian wave packets [17] leveraging the all-pervading electromagnetic tension field, whether cosmic vacuum or material media. The model tacitly accepts the Newtonian “corpuscles” and the Einsteinian “light quanta”, $h\nu$, in the sense that the total energy available out of the wave packet is $h\nu$. We chose the shape of the wave packet, emergent out of atoms or molecules, as dominantly an exponential to conform to the observation that spontaneous emissions show the spectral line width as Lorentzian [17], which is the mathematical Fourier transform of an exponential function. We have demonstrated elsewhere [8, See Ch.5] that the time-integrated fringe width function of classical spectrometers to any time finite wave pulse is the square modulus of the Fourier transform of the incident temporal wave envelope. We show this model of photon wave packet, consisting of quasi-exponential time envelope, in Fig. 2.

According Eq.1, Huygens-Fresnel Diffraction Integral, light always propagates through the process of diffractive spreading. Therefore, individual light pulses are no longer capable of delivering all its energy to any remote atoms whose physical cross-section is approximately 1A. This is why a completely new separate field of micro-cavity QED has evolved for some time [18]. However, even for ordinary photodetectors, the detecting atoms and molecules have only Angstrom size physical cross-section. At very low light level, the so-called single-photon flux levels, the energy flux propagating through $(1A)^2$– cross section in a 1mm diameter collimated 1mW laser beam could provide only ~ $10^{-18}$ photon-equivalent energy $h\nu$ per second. Obviously, the effective energy absorption cross section of the detecting element has to be many orders of magnitude larger than $(1A)^2$. From the classical dipole models, from radio to cell phone to atom, we already know that, at frequency resonance, the dipole projects itself as a much larger energy-harvesting cup. We would call this behavior of frequency-resonant atoms as projecting an enlarged quantum cup (Fig. 3). The computed energy converging field lines are shown in Fig. 3b [19,20]. We would call this as a *push-pull phenomenon*, jointly generated by the electromagnetic tension field and the frequency resonant dipole. The tension field, with imposed wave generated on it by some earlier dipole, is perpetually seeking out some *energy sink* to get rid of the perturbation energy so it can come back to its original unperturbed quiescent state. A ground-state dipole, after stimulation in the presence of a frequency-resonant signal, collaborates with the tension field to pull in (suck in) the amount energy it *can*. A cell phone or a radio oscillator can keep pulling in energy as long as their circuit is in “on” state. In contrast, quantum atoms or molecules can pull in only the allowed quantum cupful of energy until it is recycled to its original ground state again.

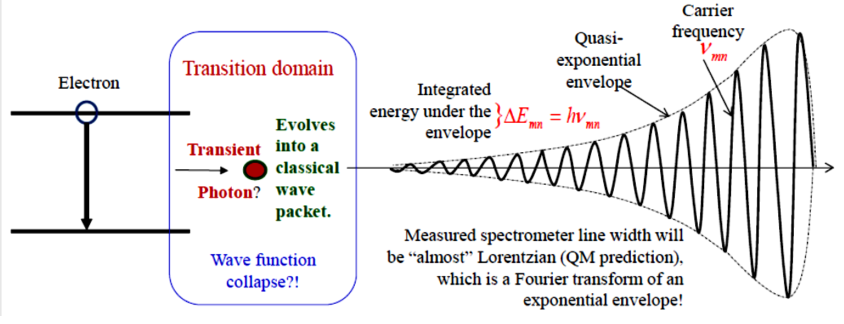



**Fig. 2. A hybrid photon mode that harmoniously accommodates the concepts of Newton, Huygens, Maxwell, Planck, Einstein, Lorentz and Schrödinger. All lights emitted by atoms and molecules are Newtonian pulses, but propagate as Huygens “secondary wavelets”, following Maxwell’s wave equation, and remaining as independent pulses following Huygens’ postulate of Non-Interaction of Waves (NIW). So far, neither Maxwell’s equations, nor that of Schrodinger, provide explicit model for “the transition domain”, as to how the discrete packet of energy $h\nu$ evolves into a classical wave packet. For radio and microwaves, the radiating dipoles physically oscillate to generate the radiation. Does nature have a very different model for the atomic world; or are we missing something?**

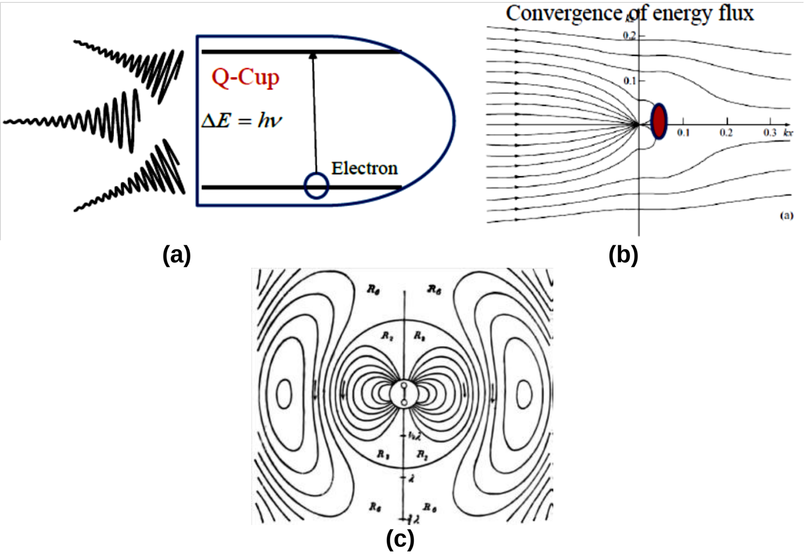



**Fig. 3. There is a field-dipole "Push-Pull" interaction process. (a) The quantum cup concept: multiple photon wave packets simultaneously stimulate a detecting dipole. (b) Computed model for converging Poynting vector lines justifying the quantum cup concept [19]. (c) Hertz's symmetric dipole radiation model [20]**

## 3.2 Limits of Einstein's Photoelectric Equation

Einstein's photoelectric equation (Eq.7) represents an energy-balancing equation based on the measurement of the kinetic energy of electrons *already free out of its quantum mechanical bound state*. The Eq.7 is correct within its limited domain of energy balancing bookkeeping.

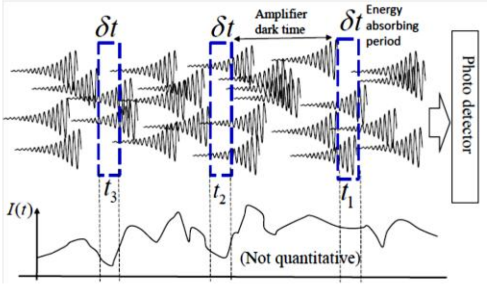
$$h\nu = \phi_{work\ fn.} + (1/2)m\mathrm{v}_{el.}^2 \tag{7}$$

It is not a phenomenological equation that can help us explore *the physical processes* behind light-matter interactions, which triggers the release of quantum mechanically bound electrons inside materials and its ejection process. It does not model the initial *light-dipole amplitude-amplitude quantum mechanical stimulation process*. Unfortunately, Einstein modeled his equation in 1905, eight years before Bohr's "old quantum theory" and twenty years before the "modern" quantum theory became known. We should not try to extract phenomenological interpretations about electromagnetic radiation out of Eq.7, overriding unusually successful phenomenological equations of Huygens-Fresnel, Maxwell and Schrodinger. Eq.1 and Eq.2 clearly imply light propagates as wave *amplitudes*, and not as energy bullets. Even Schrodinger equation is successful because it treats the excited states of quantum entities as harmonically oscillating *amplitude entities.* Measured energy exchange always happens after a quadratic square modulus operation $\psi^*\psi$ is executed by a frequency-resonant amplitude oscillation that has been successfully triggered.

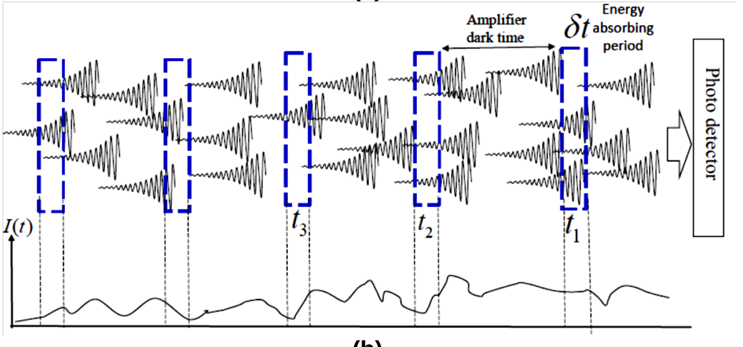
### 3.3 Semiclassical Model of Photon Wave-Packet

We are now combining the Hybrid Photon Model (Fig. 2) with the push-pull postulate of absorption of a quantum cupful of energy (Fig. 3), to build the semiclassical model for photoelectron emission. Given the overwhelming successes of Eq.1 ad Eq.2, it is now obvious that only way a sufficient amount of quantum cup-full of energy can be gathered, would be from a large number of propagating wave packets simultaneously stimulating the detecting dipole. We show this in the two cartoons of Fig. 4. A proper theory need to use the Superposition Principle of simultaneous stimulation by many, many time-finite classical photon wave packets, $E(\nu_q, t)$ , stimulating a quantum detector, whose *interaction parameter* is embedded in its polarizability factor $\chi(\nu_q)$ for the photo detecting atoms/molecules. Eq.8 shows the multi-step interaction processes -- first the frequency-resonant amplitude-amplitude stimulation $a(t)$ due to multiple wave packets, $E(\nu_q, t)$ , followed by the quadratic step of *perceived* available energy flow per unit time, or the intensity, $I(t)$. Then the individual quantum entity, or quantum cup, takes the time interval $\delta t$ (see the last integral of Eq.8) to fill up their quantum cups. If the flowing light beam carries $(nh\nu + x)$ amount of energy over the integration interval of $\delta t$ , then $n$ bound electrons will be released and the leftover $x$ amount of energy will continue to flow through the photodetector array, unused. This is why the assumption that the quantum efficiency of the detector is ideally 100%, which can never be realistically realized in practice. The physical process steps are: (i) Joint amplitude stimulation or the application of the Superposition Principle; (ii) Nonlinear square modulus operation; (iii) Time integrated energy collection over a finite time interval. These three steps are literally built into our mathematical prescriptions. The last two steps constitute the Superposition Effect, which the detector registers. Defying these logically self-consistent steps in favor of accepting “single photon interferes”, deprives us from advancing mathematically self-consistent theories relying upon *visualizing the invisible interaction processes that are built into working mathematical theories.*

$$a(t) = \sum_q \chi(\nu_q) E(\nu_q, t) \Rightarrow I(t) = \left| \sum_q \chi(\nu_q) E(\nu_q, t) \right|^2 \Rightarrow (nh\nu + x) = \int_{\delta t} I(t) dt \tag{8}$$




**(a)**




**(b)**

**Fig. 4. Two samples of random photon wave packets traveling towards a photodetector array. In both representations, the total number of photon wave packets are the same; but for (b), the wave packets are distributed over a longer time stretch than for (a). Therefore, for case (b), the effective number of pulses available for detectors to absorb energy over the same period $\delta t$ is lower, hence, the rate of photon counts will also be lower with more statistical fluctuations. Further, if the relative phases of the pulses are same (laser source), or random (thermal source), the resultant effective intensity fluctuation will be different, generating different photon counting statistics during the same time interval**

Eq.8 provides us with the multi-step visualizable picture behind the light and material dipole stimulation, which remains missing in Einstein's direct data modeling postulate behind Eq.7. The period $\delta t$ for collecting the energy $h\nu$ before a quantum mechanically bound electron can be released is still an unsettled number, but continuing measurements imply that it is most likely around 1ps, or may be slightly less [21].

We know that the temporal and spatial coherence characteristics play critical roles in determining the visibility of interference (superposition) fringes in all interferometry [22]. The same is also true for the statistical distribution in generating the photoelectric current pulses (PCP). We have presented this modelling guideline in Eq.8. We also know through existing measurements that the statistical distribution of PCP's (i) is super-Poissonian for thermal sources, (ii) is Poissonian for lasers, and (iii) is sub-Poissonian for special sources like nonlinear down conversion [23]. QM has also established that the de-excitation of atoms and molecular quantum levels are statistically random with characteristic life times. Then the statistical distribution of "bullet" photons as they propagate towards a detector cannot be the only explanation behind the emergence of PCP statistics. Of course, laser sources, due to very fast-stimulated emission process should produce more "in-phase and aggregated" wave packets compared to thermal sources. However, we believe that the superposition model of photon wave packet, presented here, is a more realistic approach to derive PCP statistics from the fundamental interaction process dictated by the coherence and amplitudes of the light pulses. The detecting dipole's quantum cup must need a finite time interval to harvest the quantum cupful of energy it requires, however short time it may be. The statistical fluctuation arises due fluctuation in the available intensity variation, hence in the energy, dictated by the *coherence properties* of the flowing photon wave packets (amplitude and phase). The model time-fluctuating intensity curves for $I(t)$ in the bottom of Fig. 4 underscore this point. Fig. 4a and 4b show the same number of photon wave packets. However, their temporal density is different and correspondingly, the potential intensity variation with time is different. Hence, the availability of $nh\nu$ amount of energy over any $\delta t$ period, or the fluctuations in the number $n$ of photoelectrons, will be different for the two cases shown in Fig. 4a and b. By incorporating the fractional energy term $x$ in $(nh\nu + x)$ in Eq.8, we are underscoring that the classical light flux can be continuously reduced to any value, even below $h\nu$ . Therefore, the time intervals during non-emission of photoelectrons for extremely low levels of light flux would not necessarily mean complete absence EM wave energy.

### 3.4 The "Push-Pull" Dipole Model Clears Up the Misleading Belief that "Granularity Proves the Discreteness of Photon"

Fig, 5(i) is a sample photograph of systematic buildup of spatial granularity with prolonged exposure to a very weak beam-flux passing through a double slit [borrowed from the web]. Such photographs have been consistently used to justify the quantumness of Maxwell's EM waves. Photographic plates have small randomly distributed Ag-Halide crystallites and CCD arrays have regular array of small detecting pixels. Therefore, irrespective of the incident beam intensity and the exposure time, under sufficient enlargement of the "pictures", they will always show the spatial granularity. It is the buildup of the temporal granularity under low light exposures, which we need to explain using our photon wave packet and quantum cup models.

Both the photographic film and the CCD detector are built out of assemblies of quantum mechanical detecting dipoles. Under the influence of frequency resonant EM waves, the push-pull *interaction process* starts, unfurling the dipolar “quantum cups” [see Fig. 3(b) and Fig. 5(ii)].

When the detecting dipoles are densely packed, the arrays of opened up quantum cup fields overlap with each other (Fig. 5(ii)) and the detecting entities compete with each other to fill up their individual quantum cup with the necessary $h\nu$ quantity of energy out of all the photon wave packets flowing through them and stimulating them simultaneously [24]. The number of photoelectron generation has been defined by the last integral in Eq. 8, reproduced here as Eq.9:

$$(nh\nu + x) = \int_{\delta t} I(t)dt \tag{9}$$

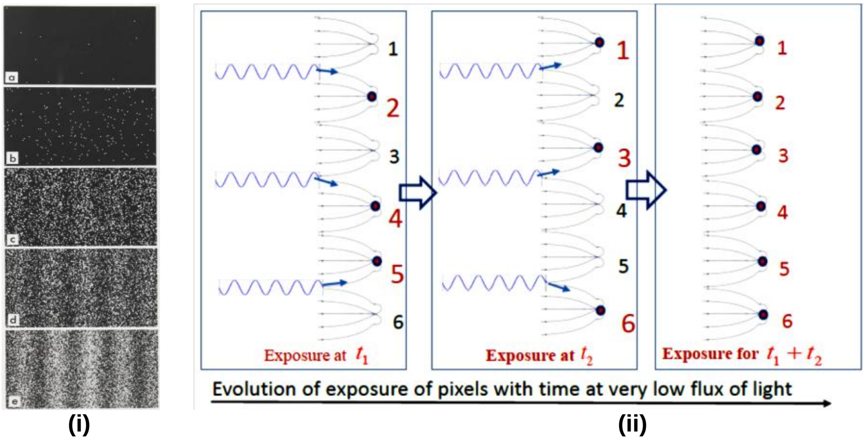



**Fig. 5. (i) Sequential buildup of higher contrast fringes with prolonged exposure for very weak diffracting signals. Detecting surfaces consist of discrete and spatially separated detecting pixels that are quantum cups. (ii) Application of quantum-cup concept along with the joint “push-pull” property of electromagnetic tension field, which pushes energy to the frequency–resonant dipole. The dipole pulls in one quantum cupful of energy out of the propagating EM waves. Under extremely low flux density, densely packed quantum cups compete with each other and there are statistical winners and losers. However, over prolonged exposure all of them can fill up their quantum cup dring successive exposure periods. The first box, “Exposure at $t_1$”: the dipoles 2, 4 & 5 are the winners and 1, 3 and 6 are the losers in the competition. The second box, Exposure at $t_2$”: Dipoles 1, 3 and 6 are free now to absorb the available energy, since dipoles 2, 4 and 5 can no longer absorb any more energy. The last box shows that all quantum-cup detectors are now “exposed”**

At high levels of propagating energy-flux, when $n$ in Eq.9 is larger than the number of detector elements intercepted by the light beam, all quantum cups succeed in filling up their energy requirement and get exposed (or, release photoelectron). At low levels of flowing energy density, when $n$ in Eq.9 is less than the number of detecting elements, statistically some quantum cups will win over their neighbors during the first propagation interval $\delta t$ . Since the exposed detecting element can no longer compete for further energy, during the follow-on intervals of $\delta t$ , the unexposed detecting elements will have the opportunity to pull in the available energy to fill up their quantum cups. This is the physical explanation behind the “slow” buildup of temporal granularity, pictorially explained in Fig.5(ii), where only two $\delta t$ exposure intervals has been presented. The third box shows that all the detecting elements have been exposed. The temporal granularity does not require “bullet photon” model. The concept of “bullet photon” actually defies the physical logics built into the three historically successful phenomenological equations, the Huygens-Fresnel diffraction integral, Maxwell’s wave equation and Schrodinger’s harmonic equation for quantum particles, shown in Eq.1, Eq.2 and Eq.3, respectively. They all propagate *amplitudes*, not energy bullets.

## 4. SUMMARY AND CONCLUSION

We started with the objective of eliminating the need for continuing with the concept of wave-particle duality (WPD), which actually represents our ignorance about the realistic physical models for waves and particles. Interested readers may consult the literature [25-29], where a large number of authors have been trying to develop the semiclassical treatment of the quantum world for decades. We took the photoelectric effect as a case example to show that it is possible to eliminate the WPD with the semiclassical approach when we assume that all atomic and molecular emissions consists of *semi-exponential classical light pulses*. We have provided the rationales behind this model that are self-consistent.

It is the field of elementary particles that are still in some controversy [30-32], besides the Copenhagen Interpretation of the Schrodinger’s equation. We understand that Huygens-Fresnel Diffraction Integral and Maxwell’s Wave Equation do not represent the ultimate and complete knowledge about electromagnetism. In spite of that, these phenomenological equations of electromagnetism have been guiding us for over several centuries through uninterrupted evolution of optical science and engineering without any serious controversies. Newer applied fields are successfully emerging and maturing – Nanophotonics, Plasmonic Photonics, Metamaterials and a wide variety of Biophotonics. In all these fields, the electromagnetic tension properties, $\varepsilon \,\&\, \mu$ , in regular materials have been playing the key roles through the parameter of *refractive index* [5]. In none of these successfully evolving fields, the leading scientists are propagating EM waves as energy bullets; they are using Maxwell’s equation set. QM has not developed any systematic theory that can explicitly provide the perpetual velocity to “indivisible bullet photons”. We have purposefully underscored that all the three equations of significance in fundamental physics (Eq.1, 2, and 3) deal with *amplitudes-amplitude* superposition, or interaction. Next comes the square modulus operation, $E^*(t)E(t)$ or $\psi^*(t)\psi(t)$ , to derive the "intensity" and then the energy exchange happens only after an integration of the "intensity" over a finite period, however short it could be. The postulate of "Wave function collapse" only suppresses this necessary enquiry to keep advancing physics. The concepts we are promoting are built-into the mathematical logics of our working equations. As good engineers, we must leverage these mathematical logics to maximize the visualization of the *interaction processes* that nature has been carrying out. These are successful phenomenological equations. None of them indicate the existence and propagation of EM waves as discrete "energy bullets". That is why our efforts to improve upon these successful phenomenological equations would be productive and useful [5,25-29]. One of our suggestions is to re-develop the equations of electromagnetism to find an electromagnetic model for the elementary particles as *localized harmonic oscillators* [5], because Schrodinger's equation represent localized harmonic oscillators, not perpetually propagating "plane waves" like Maxwellian EM waves; Schrodinger's particles require a separate potential gradient around it to move in space, obeying Newtonian inertia.

## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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He has expertise in lasers, nonlinear optics, remote sensing systems, nanotechnology, spectroscopy, and optical instrumentation. He has been a Principal Investigator and/or Technical Lead on numerous NASA sponsored projects. Dr. Prasad was instrumental in sending laser and lidar components for space qualification studies under NASA's MISSE 6 and MISSE 7 and MISSE 11 missions. Currently, Dr. Prasad is leading several research efforts including the development of long range coherent ladar for space surveillance of resident space objects, wind lidar architecture, and development of novel nanotechnology-based material composites/alloys for thermos-electrics, electronics processors, radiation shielding and ultra-high temperature environments.

Dr. Prasad is member of several review committees and panels at NASA. Dr. Prasad is actively involved in various conference committees and workshop activities including SPIE and ISS R&D Utilization committees. Dr. Prasad has published more than 175 papers, has 11 patents, and author of more than 25 technical reports. Dr. Prasad is a Senior Member of OSA and SPIE. He has won several performance awards including NASA Innovator award (2023) and several distinguished performance awards and group achievement awards.

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