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Can Photo Sensors Help Us Understand the Intrinsic Differences Between Quantum and Classical Statistical Behaviors?

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Abstract. We use the following epistemology - understanding and visualizing the invisible *processes* behind all natural phenomena through iterative reconstruction and/or refinement of current working theories towards their limits, constitute our best approach towards discovering actual realities of nature followed by new break-through theories. We use this epistemology to explore the roots of statistical nature of the real world – classical physics, quantum physics and even our mental constructs. Diversity is a natural and healthy outcome of this statistical nature. First, we use a two-beam superposition experiment as an illustrative example of the quantum world to visualize the root of fluctuations (or randomness) in the photo electron counting statistics. We recognize that the fluctuating weak background fields make the quantum world inherently random but the fluctuations are still statistically bounded, indicating that the fundamental laws of nature are still causal. Theoreticians will be challenged for ever to construct a causal and closed form theory free of statistical randomness out of incomplete information. We show by analyzing the essential steps behind any experiment that gaps in the information gathered about any phenomenon is inevitable. This lack of information also influences our personal epistemologies to have “statistical spread” due to its molecular origin, albeit bounded and constrained by the causally driven atomic and molecular interactions across the board. While there are clear differences in the root and manifestation of classical and quantum statistical behavior, on a fundamental level they originate in our theories due to lack of complete information about everything that is involved in every interaction in our experiments. Statistical nature of our theories is a product of incomplete information and we should take it as an inevitable paradigm.

Keywords: Photo electric measurement process**;** Quantum statistical fluctuations; Classical statistical fluctuation; Photo electron statistics; Epistemology for science.
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1. INTRODUCTION

Let us first define our methodology of thinking (epistemology). Purpose of science is to understand and visualize the invisible *processes* behind all natural phenomena that keep the cosmo-sphere and the biosphere incessantly evolving towards some higher plane of information processing capability. We construct all of our theories based on incomplete information. Hence all theories are incomplete. So, we must keep on challenging and iteratively reconstructing old theories until we find their limits. This will create the scientific epistemological “infrastructure” conducive to discovering new higher level theories. We use this epistemology to explore the roots of statistical nature of the real world – classical physics, quantum physics and even our mental constructs. First, in Section 2, we use a two-beam superposition experiment as an illustrative example of the quantum world to visualize the root of fluctuations (or randomness) in the photo electron counting statistics [1]. We recognize that diverse fluctuating weak background particles and fields (vacuum fluctuations, etc.) make the quantum world inherently random but the fluctuations are still statistically bounded, indicating that the fundamental laws of nature are still causal. Theoreticians will be challenged for ever to construct a causal and closed form theory free of statistical randomness out of incomplete information [2,3]. In Section 3, exploration of the measurement processes tells us that the information gap about any phenomenon, classical or quantum, is inevitable. This universal lack of information also influences our personal epistemologies to have “statistical spread” in conjecturing our hypotheses and interpretations, albeit bounded and constrained by the causally driven phenomena of nature. This is explained in Section 4. While there are clear differences in root causes and manifestations of classical and quantum statistical behavior, on a fundamental level they originate in our theories due to lack of complete information. Statistical nature of our theories is a product of incomplete information paradigm enforced on us by the real world.

2. PHOTO ELECTRON EMISSION USING TWO-BEAM SUPERPOSITION EQUATION

2.1. Traditional approach

We are going to consider photo electron emission process that we routinely observe in experiments using two-beam interferometry paying close attention to the underlying physical processes. The interaction process involves three entities – two optical beams generated from the same or two independent light sources (could be lasers) and a photo detector. Depending upon the particular purpose of the experiment, the two optical beams bring two different value of a chosen parameter of light (phase, frequency, polarization and amplitude) and simultaneously impinge upon the photo detecting molecules. In quantum optics, we assume that light beams constitute indivisible elementary particle, photons. And when these photons propagate through an interferometer, by virtue of their intrinsic nonlocal properties (premonitions?), they know where to arrive on the detector plane with exact sinusoidal distribution, even if they are sent out one at a time. In classical physics, we assume that the waves in the light beams interfere (modify their energy distribution) by themselves whenever they are physically superposed. The local strength of the wave amplitude at any point on the detecting plane is dictated by the relative phase difference $2\pi\nu\tau$ due to relative arrival path delay τ between the two beams. We can represent the measured fringe intensity distribution due to superposition as follows for the simple case of two same-frequency beams with parallel polarization:

$$d'(\tau) = \left|A(t)\right|^2 = \left|\vec{a}_1 e^{i2\pi\nu t} + \vec{a}_2 e^{i2\pi\nu(t+\tau)}\right|^2 = a_0[1+\gamma\cos 2\pi\nu\tau] \qquad (1)$$

$$\text{Where, } \gamma \equiv 2a_1a_2/(a_1^2+a_2^2) \text{ and } a_0 \equiv (a_1^2+a_2^2)$$

This standard mathematical approach contains two embedded physical processes [4]. The first one is depicted by the *"+" or summation operator*, the summation (physical superposition effect) of the two beams. The second one is the *square modulus operator* indicating the measured fringes or the energy re-distribution of the two beams.

The impact of the *"square modulus" operator* will be incorporated in the next section. *Regarding the summation operator*, we need to explicitly recognize as to which interaction process facilitates the summation of two complex amplitudes. Neither classical and nor quantum physics has paid attention to this question. As a result we continue to assume that well formed light beams "interfere" (interact) with each other to generate the new energy distribution even in the absence of detecting (interacting) molecules. We have been carrying on this wrong hypothesis over-riding our daily experience. We see stable and un-perturbed images any way we look even though the light beam forming the particular image on our retina has been crossed by innumerable other image forming beams. We also know that two crossing laser beams do not change each others properties either. If well formed light beams do not interfere with each other, then the mathematically correct time-frequency Fourier theorem should not be used as a de facto principle of physics. It should be used cautiously where it can map real physical interaction processes. The consequence of this innocuous sounding statement, non-interference of light, is enormous both in classical and in quantum physics, an incomplete list of which, in the form of questions, is presented in Fig.1 [1,4-14]. [We will refer to this flow-chart again in the Section 4]. In fact, the mathematically correct classical time-frequency Fourier theorem, epitomizing *linear superposition principle*, deserves to be re-visited for it predicts two physical transformations without providing or identifying the necessary forces of interaction and the concomitant physical processes required for the transformation of any physical entity (EM waves or photons). (i) The theorem implies that a time-finite wave packet with a unique carrier frequency is equivalent to a new frequency distribution given by the Fourier transform of the envelope function. So, far we have not discovered any linear system that can generate new optical frequencies out of the incident ones [11]. (ii) The same theorem also implies that superposed optical beams carrying different frequencies generate a new mean frequency with a temporally undulating amplitude envelope. We have not discovered such a linear system either. A *"mode-locked"* laser produce short pulses not just because of superposition of "modes", but due to *"time-gating"* assistance through the non-linear material devices like intra-cavity saturable absorber or Kerr medium [12]. Well-formed light beams by themselves do not operate on each other.

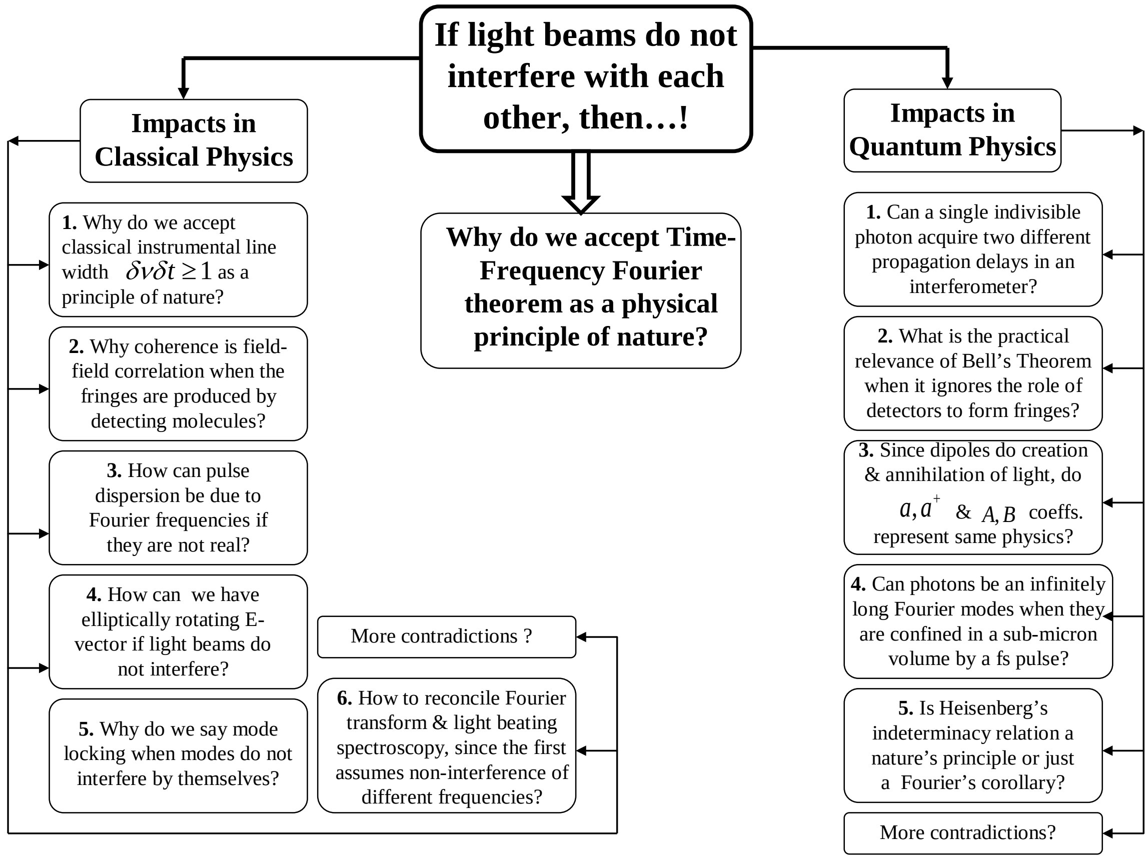

FIGURE 1. This flow chart summarizes the consequences of non-interference of light beams, but in the form of a series of questions to underscore the impact of subjectivity of human minds in doing physics. Framing questions to articulate new observations or to identify paradoxes and contradictions in existing theories, determine the answer we can extract out of nature. But rarely the answer can lead to a final theory of everything because we are always information starved! The above questions highlight the origin of paradoxes and contradictions due to assumption that light beams interfere. Different readers, of course, should find that they would have preferred to frame the questions differently and get somewhat different answers. But the variations will remain bounded by measurements that must reflect realities of nature's causal laws [see Section 4]. Einstein continued asking the same question, "What are light quanta?" during his entire life without being able to resolves the issue conclusively.

For photo detection processes, we need to incorporate the role of detecting molecules' first-order susceptibility χ_1 to polarization induced by the superposed E-vectors. It is the simultaneous stimulating response of the molecules to both the beams that effectively carry out the summation implied by the superposition principle. Light beams do not do it by themselves.

Apparently, this conceptual mistake of classical physics has been "resolved" by Dirac's proposal that "photon interferes only with itself" [15], as if $\vec{a}_1 \exp[i2\pi\nu t]$ and $\vec{a}_2 \exp[i2\pi\nu(t+\tau)]$ in Eq.1 represent two distinctly different physical states (information) of the same indivisible photon even though they represent two physically separate beams (some times from separate sources). So the derivation of $d'(\tau)$ implies that each photon has the capacity to execute its premonition as to where to arrive on the detection plane and with what sinusoidal statistical frequency, as given by Eq.1. Raising questions as to how each independent and indivisible photon from the two independent beams can pre-assess the modulo-2π relative phase values of τ and then assures proper statistical distribution, has been successfully postponed by the Complementarity Principle of Copenhagen Interpretation (CI). The delay τ has to be derived from $\tau = (t_1 - t_2)$, two separate pieces of information, which are independent path delays in the two physically separate arms of the interferometer. CI has also ignored the necessity of reconciliation of the reality of non-interference of light: If innumerable photons collectively do not show the effects of superposition in the absence of detecting molecules, then how can the individual members of the same two beams acquire the unique physical property of displaying superposition effects by themselves? We are convinced that Eq.1 does not represent the physical reality of superposition effects due to two light beams because the physical *interaction process* is not explicitly recognized in this equation.

2.2. Correct formulation for optical superposition effects and the origin of statistical fluctuation

Superposition effects due to well-formed light beams emerge as measurable transitions in traditional photo detectors as an electric current due to electrons raised to the conduction band from the valance band. Thus the detector's first-order susceptibility χ_1 to polarization induced by the two superposed E-vectors is an important physical parameter that is not normally taken into account when writing Eq.1 for interferometry when the basic superposition process is linear. We need to explicitly recognize this quantum mechanical (QM) dipolar stimulation and the consequent quantum mechanical level (or band) transition experienced by the photo electrons. And we know that all QM transition rates from one state to another state are necessarily statistical. Thus, there will always be statistical fluctuations in the photo electron emission rate even if we use a CW laser stabilized to ultra precision level both in amplitude and in frequency. We have been erroneously assigning the statistical properties of photo electron transitions to "photons" or electromagnetic fields rather than to the stimulated QM dipoles that transfer the electrons. Of course, fluctuations in the EM fields will also introduce fluctuations in the photo electron transition rates. But we must take great care to separate the two.

$$\text{Field}: E(t) = a(t)e^{i2\pi\nu t};\ \text{Stimulation:} \psi(t) = \chi_1 a(t) e^{i2\pi\nu t};\ \text{Transition rate: } d(t) = \psi^*\psi \qquad (2)$$

The susceptibility to polarization of the dipole χ_1 contains all the classical and quantum response properties of the detecting molecules. Note that while normally we use only the linear (first order susceptibility), in reality, all EM fields induce all possible linear and non-linear susceptibilities all the time. We normally neglect these higher order effects until we encounter molecules with strong nonlinear polarizability, which is becoming more and more common as people are succeeding in creating "designer's molecules". In reality, the total dipole stimulation due to an EM field should be written as:

$$\text{Stimulation: } \Psi(t) = \sum_n \vec{\chi}_n \cdot \vec{E}^n(t);\ \text{Transition rate: } d(t) = \Psi^*(t)\Psi(t) \qquad (3)$$

While Eq.3 already looks complex for general situations, it is even more complex in reality, because both the susceptibility and the EM field should be treated as vectors to accommodate the angle between them in anisotropic media as is done by the specialists in nonlinear optics. It is very important to note that nonlinear susceptibilities χ_n are another source of statistical fluctuation in photo electron emission rate. It is correct that nonlinear effects become measurable only when we use high intensity beams or detecting molecules with high values for χ_n. But, since there is no lower threshold limit in inducing nonlinear stimulations and consequent *energy exchange*, neglecting χ_n implies that we might be neglecting a small fraction of the fluctuation in the photo electron counting rate which is actually due to ever present nonlinear stimulations of the detecting molecules.

Let us now get back to our simple case of parallel polarized beams superposed by a two-beam interferometer and re-write Eq.1 in terms of dipole stimulations, keeping only the strong linear term χ_1:

$$d(\tau) = \Psi^*\Psi = \left|\chi_1 \vec{a}_1 e^{i2\pi\nu t} + \chi_1 \vec{a}_2 e^{i2\pi\nu(t+\tau)}\right|^2 = \chi_1^2 a_0 [1 + \gamma \cos 2\pi\nu\tau]$$
$$\text{Where, } \gamma \equiv 2a_1 a_2 / (a_1^2 + a_2^2) \text{ and } a_0 \equiv (a_1^2 + a_2^2) \qquad (4)$$

It is worth noting that the quantities within the square brackets of Eq.1 and Eq.4 are identical and the multiplying symbols are constants for a particular experiment. Further, the expression for γ that we normally measure in actual experiments has remained identical. Does this mean that all the preceding arguments are only semantics? On the contrary, the identical expression for the measuring quantity γ, except for the multiplying constant χ_1, has been keeping us mesmerized to accept that 100% of the inherent statistical nature of photo electron emission rate is due to arrival rate and/or "bunching" and "anti-bunching" of indivisible photons. We have been assigning detecting molecules' QM characteristics onto electromagnetic waves and wave packets! [See Jaynes, 16]. When the prediction by a mathematical equation is validated by innumerable independent experiments, it does not necessarily mean that the equation has mapped the real physical processes behind the interaction process that we are studying [as in Eq.1].

In fact, it is the incorporation of correct "constant" parameter χ_1 [as in Eq.4] and explicit recognition of its role in the interaction *process* that is the most important part of doing science.

Even though we have heuristically introduced the QM statistical behavior by referring to detecting molecules and their susceptibilities χ_1, there is nothing QM or statistical mathematically inherent in Eq.1 and 4. They essentially represent classical relation. Real quantum transition concept has not yet been explicitly discussed. The fringes represented by Eq.4 is re-written below with the reminder that all photo detectors are quantized and that each *individual transition* (photo counting "clicks") must be preceded by the absorption of a unique "quantum cup" of energy given by $(\Delta E)_{m-n} = h\nu_{m-n}$, where the suffix "m-n" refers to quantum transition between levels (or bands) m and n.

$$d(\tau) \equiv (\Delta E)_{m-n} = h\nu_{m-n} \overset{?}{=} a_0[1+\gamma\cos 2\pi\nu\tau] \tag{5}$$

If $d(\tau)$ in Eq.5 represents a single quantum transition event in a detector that always requires the absorption of a fixed quantity of energy $(\Delta E)_{m-n}$ to be delivered by a radiation of well defined frequency ν_{m-n}, then can it be equated to a quantity that varies continuously and sinusoidally with the delay τ ? Obviously, the absorbed energy cannot vary sinusoidally for any individual transition even though τ is a continuous variable (assuming ν remains fixed). For a given fixed value of τ the transition *rate* of photo electron will be proportional to $\cos 2\pi\nu\tau$. Thus, it is of paramount importance to recognize that an individual event or the registration of a single photo electron emission for a given value of τ cannot provide very useful information regarding the superposition effect we are studying. The superposition effect embedded in $\cos 2\pi\nu\tau$ can be appreciated and registered only by varying τ. We must register and integrate a large number of single "photo electron events" for each τ while varying τ to cover at least one complete fringe or period of $\cos 2\pi\nu\tau$. Such a cumulative registration has been aptly recognized by the founders of QM as ensemble average, which is represented as $<\Psi^*\Psi>$. A single event $\Psi^*\Psi$ cannot represent QM predictions exactly because of changes inherent in transition probability from event to event. The right hand side of Eq.5 must now be re-interpreted as the rate of discrete transitions in the photo detector; *it is no longer a simple energy balance equation*. We just wanted to underscore the conceptual shift from "discrete photons" to discrete detector transition. The energy equation has become a rate equation determined by the flux of the propagating light energy. Ensemble averaged photo electron count distribution with τ is now given by:

$$D(\tau) = \ <\Psi^*\Psi> \ = \ <a_0[1+\gamma\cos 2\pi\nu\tau]> \tag{6}$$

Alert readers should have noted the emergence of another profoundly different interpretation for ψ or Ψ, defined in Eq.2. The QM wave function is not an abstract "mathematical probability amplitude" as Born defined, but it is a real physical internal undulation of a QM entity stimulated by another entity or a source of energy, like EM waves, in our case. For a detecting molecule under the influence of simultaneous stimulation of two fields Ψ represents the strength of the vectorial *resultant* (or summed) physical amplitude of its dipole undulation [4,7,8]. Of course, $\chi_1(\nu_{m-n})$ of the molecule must conform to the QM allowed transition rule of responding only to radiation of frequency ν_{m-n}. In general, the strength of the transition probability $\chi_1(\nu_{m-n})$ dominates over all other nonlinear stimulations and consequent energy exchange. *Superposition principle naturally allows a quantum detector to collect the necessary quantum of energy* $(\Delta E)_{m-n}$ *for any single transition by gathering energy from multiple fields as long as they are congruent with the QM rules.* We do not need to hypothesize that only an "indivisible single photon" can trigger a detector transition. We should not unnecessarily assign the quantum behavior of detectors to the EM fields [1,4,15].

We identified two mathematical operators in Eq.1, *summation* and *square modulus*. Search behind the physical *summation* operation helped recognized the role of detecting molecules. Let us now appreciate the role of *square modulus* operation. Note the difference between classical prescription for intensity, as the square of the real signal, $a^2\cos^2 2\pi\nu t$, in contrast to QM prescription of square modulus of the complex representation, $\left|a\exp i2\pi\nu t\right|^2$. Only by taking time integration over a few cycles of the classical *real* expression can we obtain the QM prescribed expression for intensity or photo current [4,9,10]. We interpret this time-integration (akin to taking square modulus) as a physical reality for the detecting molecules. So Ψ represents a joint "*quantum compatibility sensing dance*" ("qcsd") of the detecting dipole with the field to assess ν_{m-n} before it can undergo a QM allowed transition $\Psi^*\Psi$. There is no arbitrary "*collapse of wave function*". We can and we should try to visualize invisible QM interaction *processes* as it provides deeper insights into the interaction processes [1,4,9].

Let us now use this "qcsd" to further "explain" the root of unique quantum fluctuations. We know that quantum field theory has hypothesized the existence of "background fluctuations" and "quantum foam". Cosmology has hypothesized existence of enormous quantity of "dark energy" and "dark matter". We also know the omnipresence of EM radiations from Planck's law and incessantly shooting cosmic rays from our cosmic-ray detecting experiments. Thus no interactants can remain uninfluenced from all these diverse background *energy donors*. We hypothesize that during this short "qcsd" period, all these other omnipresent "unwanted" entities also try to participate in the "dance" and share their stimulating capabilities through various linear and nonlinear processes and succeed in creating the "quantum chaos" or randomness! But, fortunately, the fluctuation is bounded due to the overwhelming strength of the linear QM transition probability $\chi_1(\nu_{m-n})$ between the levels m-n. However weak it may be, $D(\tau)$ is influenced by all possible linear and nonlinear stimulations by the background fluctuations besides the desired EM fields:

$$D(\tau) = \left\langle \left| \{\sum_p (\vec{\chi}_1 \vec{E}_p + \sum_n \vec{\chi}_n \vec{E}_p^n)\} + \{\sum_q (\vec{\xi}_1 \vec{U}_q + \sum_n \vec{\xi}_n \vec{U}_q^n)\} + \sum_r (\vec{\zeta}_1 \vec{V}_r + \sum_r \vec{\zeta}_n \vec{V}_r^n)\} + ... \right|^2 \right\rangle \quad (7)$$

Where $\vec{E}_p$ is the p-th EM wave; and $\vec{U}_q, \vec{V}_r$, etc. are various background perturbation fields with ξ_n, ζ_n, etc. as corresponding susceptibilities of the same detecting molecule [4]. Generalized analytical impact of such a perturbation hypothesis during "qcsd" periods on quantum transition probabilities will be discussed elsewhere.

3. UNIVERSAL INDETERMINACY IN ALL MEASUREMENTS

We have gathered staggering amount of knowledge about the workings behind the evolving cosmic universe by grouping related observations using pure logical hypotheses (cause-and-effect) and then creating theories based on pure mathematical logics. Implication of all these successes is that interaction processes in nature must strictly follow causality. So, when some natural phenomenon exhibit statistical randomness in its repeatedly measured outcomes, but always within some bounds, we should accept the premise that there must be some *cause* that gives rise to this *effect* of *bounded* randomness. We have applied this same logic in the last section to "explain" the origin of quantum fluctuation in the photo electron counting statistics. Successes of classical statistics (gas laws and thermodynamics) directs us to assume that orderly (or well bounded) statistical randomness arise due to our incapability in gathering all the necessary information about the initial state of a complex system for the prediction of its exact final state. It is not just that handling 10^{23} equations to follow the states of one gram-mole of gas is a formidable task. The task may not be impossible for modern super computers. Unfortunately, it is impossible for us to measure the initial states of 10^{23} molecules at the same instant. Further, even if we invent 10^{23} suitable nano-machines, none of our measurements can ever be exact. There will always be some finite error in every possible measurement that we may attempt to carry out. With the advent of staggeringly successful QM, we should have re-visited classical measurement processes to appreciate the inherent falsity of deterministic epistemology in classical physics well recognized in [2]. Let us re-visit the limits in the classical measurement capabilities in light of confirmed knowledge about the existence of "fuzzy" atoms and molecules provided by quantum theories. Let us analyze as to how precisely we can measure the fundamental units, the mass, length and time – MLT.

Measurement of Mass, M: We can never measure the mass of the "standard kilogram" with accuracy better than a constituent single molecule. In reality, it is always far worse. This can actually be appreciated from the knowledge of classical physics including statistical mechanics of late 1800's. Knowledge of quantum mechanics was really not necessary. All materials have a finite and non-zero vapor pressure and hence it is exchanging a good number of molecules with its surroundings all the time. So, the number of molecules N contained in the standard kilogram is never fixed. It is always fluctuating randomly. The weight of our standard mass, besides being quantized to Nm (m being mass of a single molecule), N is never precisely determinable as it is always fluctuating due to uncertain chance random evaporations and condensations. But, for most practical purposes, the accuracy that we can achieve is more than enough for most practical purposes. So we never pay attention to this minute error in our measurement of mass. But, on a fundamental level, it is insurmountable error nonetheless.

Measurement of Length: The length of our standard meter can never be more accurate than the width of a single molecule constituting the material of the "standard meter". First, due to vapor pressure, as mentioned earlier, the reference end-surfaces are randomly loosing and accepting some molecules with its ambient atmosphere. So, the precise locations of the end surfaces become uncertain and indeterminate at least to a fraction of the average width of a molecule. Further, even in the solid-state, the molecules are randomly vibrating about its mean position. Thus the distance between the two average end-face locations is changing from instant to instant. Further, atoms and molecules themselves are "fuzzy" in the domain of an Angstrom ($10^{-8} cm$, the diameter of a Hydrogen atom). So the physical length or the distance between two points is never determinable to accuracy better than an Angstrom.

Measurement of Time: To our current state of knowledge, we do not have any natural device that shows the running time continuously. Running time is a human invented concept that we needed to conduct our lives. It is the *rate of change* in some measurable physical parameter of objects that is at the root of concept of time. We accurately quantify time only in terms of the period of oscillation of a harmonic undulator by observing its state of motion (or phase). The undulator can be Earth's axial spin period or its orbital rotation period around the Sun, the period of a clock pendulum, the period of an electronic oscillator, or the periods of oscillation of the waves of water, sound or light. We count the number of oscillations N and then multiply the oscillation period τ_0 and create our measurable "running" time $\Delta t = N\tau_0$, which, in reality is only a longer period or interval of time. Thus, running time is not a directly measurable physical parameter of anything in this universe. Any attempt to manipulate time will only modify the period of oscillation of the physical device we are trying to control. The universe is made out of wide varieties of natural harmonic undulators, but there is no entity that has universal running time as its physical parameter. So, the successful mathematical constructs containing "running time" on equal footing with space coordinates deviates us into constructing logically congruent but un-physical models of the universe. Accordingly, all such successful theories, whether classical, relativistic or quantum field, should be re-visited [1], re-constructed and re-interpreted in terms of a reference frequency that is a true physical parameter.

So measuring time exactly requires figuring out how to measure the period of undulation τ_0 exactly. Unfortunately, in the experimental world, there is no deterministic means to identify exactly one complete cycle of any wave or an oscillator. So, we end up counting many cycles N and taking statistical average to find an average period, modulo 2π, to reduce the random chance errors in our measurement. We cannot measure one single period exactly.

Thus, in the classical world, we cannot determine (measure) any of the fundamental units, MLT, exactly. We have always been forced to accept some statistical average of random fluctuations in the physical system or in data gathering or in both. All classical measurements have always been intrinsically indeterminate from the stand point of *exactness*. Classical physics was never precisely deterministic [2] because one cannot *predict the final outcome* of a system without knowing the *exact initial state parameters*. We just never paid attention to this point as we were very happy with the accuracy we obtained until QM started predicting and demanding values of physical parameters with much higher precision than the classical theories have been caring about. This is the inherent strength of QM. However, it is unfortunate that this realization came only after Heisenberg proposed his QM indeterminacy relation. First, in the final analysis, all QM measurements are extracted from values of M, L and/or T in some form or other through some classical "measuring meters". Second, his indeterminacy relation is really a corollary of the Fourier theorem, strengthened by Schwartz's inequality [9]. It states that the product of the half-widths of any Fourier transform function-pair is always greater than or equal to unity. We have never declared the Fourier theorem as a principle of nature. So, we should not rush to declare an ad hoc corollary of a parent mathematical theorem as a principle of nature. Using today's nano technologies we can now hold, manipulate and move or "map' well identified individual atoms without any *uncertainty*, although there will be some *indeterminacy* in the measurement precision. The strengths and successes of the Schrodinger's equation is not compromised at all if we recognized Heisenberg's indeterminacy relation only a useful mathematical (corollary) guiding tool rather than as a principle of nature.

It is very unfortunate that we have been using the Fourier theorem as a de-facto principle of nature in all branches of physics, starting with classical physics, because it has been providing us with many successes in modeling natural processes, some times correctly and sometimes due to pure coincidences out of mathematical jugglery and partially correct hypotheses. [See flow chart of Fig.1 and for details see references [4-14]]. In fact, the mathematically correct classical time-frequency Fourier theorem, epitomizing *linear superposition principle*, deserves to be re-visited for it predicts two physical transformations without providing or identifying the necessary forces of interaction and the concomitant physical processes required for the transformation of any physical entity (EM waves or photons). (i) The theorem implies that a time-finite wave packet with a unique carrier frequency is equivalent to a new frequency distribution given by the Fourier transform of the envelope function. So, far we have not discovered any linear system that can generate new optical frequencies out of the incident ones [13]. (ii) The same theorem also implies that superposed optical beams carrying different frequencies generate a new mean frequency with a temporally undulating amplitude envelope. We have not discovered such a linear system either. A "*mode-locked*" laser produce short pulses not just because of superposition of "modes", but due to "*time-gating*" assistance through the non-linear material devices like intra-cavity saturable absorber or Kerr medium [14]. Well-formed light beams do not create new energy distribution by operating on each other by themselves.

4. UNIVERSAL INFORMATION GAP IN ALL EXPERIMENTS

In this section we will discuss two more contexts that fundamentally limit our information gather capability. First, (i) we can never gather complete information related to any particular interaction process going on between interactants that we try to study. Second, (ii) the human conjectures to fill this information gap (hypotheses) enforced by experimental limitations, are always colored by our personal thinking models and we are bound to introduce our personal prejudices, however logical they may appear.

4.1. Statistical fluctuations due to inevitable instrumental information gap

If we try to analyze an environment that does not undergo any change or transformation, very little scientific information can be extracted out of that environment.

(i) We can scientifically measure only those re-producible quantitative *transformations* (changes in states) that are experienced by our interactants (or detector-detectee, or sensor-sensee interaction).

(ii) Any transformation in a measurable physical parameter requires *energy exchange* between the interactants.

(iii) The energy exchange must be guided by at least one of the known four *forces of interaction* between the interactants and it must be strong enough to facilitate the exchange of energy, which are usually constrained by unique characteristics of each interactant.

(iv) All force rules being range (distance) dependent, energy exchange between the interactants requires that they must experience each other as *local* or *physically superposed* entities (experience each other within their sphere of influence).

(v) Energy exchange is inherently a *statistically fluctuating* process, classical or QM, because all interacting entities are always perturbed by other weaker and/or random interaction forces as they are bathed in a see of incessantly present fluctuations. While it is necessary for us to drop the effects of these weak background fluctuations to create manageable theories, we must not ignore the real physical impacts on all possible transformations we measure.

(vi) All measured transformations give us *incomplete information* regarding the true details of the influence of the weaker forces on the measured transformation. We happily accept the result as only due to the strongest force of interaction and interpret the fluctuations in the outcome as statistical randomness.

(vii) We suffer from another level of *information degradation* during the process of gathering the results of targeted transformation as the relevant signals are transported through some sensing instrument, which is, in reality, another set of complex interaction processes. For example, a slow photo detecting device, due to its high LCR value, averages the oscillatory heterodyne beat signal into a steady current and we loose the information that the original optical signal contained multiple carrier frequencies.

We summarize these observations common to all measurements with the acronym *SEMT* to describe the above universal steps behind all experiments. It stands for ***S****uperposition* ***E****ffects as* ***M****easured* ***T****ransformations* [1]. The *SEMT* analysis forces us to accept the universal principle of *locality* and *causality* behind all interactions that result in real measurable transformation. The interactants in an experiment must be physically *superposed* (present) within the range of the *interacting force* that will allow for some *energy exchange* followed by some *transformations* that is measurable for us through some classical meter. Superposition effect is thus an *active causal and local process*, and is not a passive mathematical principle only! These understandings also provide us with a path to reduce the epistemological gap between the classical randomness and quantum randomness – paradigm of information gap.

We can now appreciate that all of our working theories are necessarily incomplete as they are based on incomplete knowledge of the universe. Even diverse kinds of experimental validations of a theory cannot assure us of its "completeness" or "finality". All matured theories need to be iteratively refined towards higher levels by constantly mapping and re-mapping the actual interaction *processes* that are invisible to us, but exists nonetheless as nature's ultimate reality. Such an approach is the bedrock for advancing fundamental science.

4.2. Origin of statistical spread in human interpretations

We observe measure imagine visualize understand and then develop some over-arching hypothesis and then mathematize to capture the operating rules behind the observed set of phenomena [1]. Unfortunately, however pure logic they may represent, mathematical theories cannot "speak" for themselves. We do and we are *"prejudiced"*. Our interpretations cannot be identical because of diversity built into our thinking patterns driven by statistical nature of cerebral molecular interactions, variations in DNA and variations in our cultures. Fortunately, this diversity is the key assurance for our sustainable evolution because our scientific minds remain open to corrections. We understand that in spite of *correct* predictive capability of our *working* theories none is capable of capturing complete reality and perfect interpretation of the universe.

Consciously or unconsciously, we define (i) the *purpose* of doing science based on (ii) our personal *epistemology* (or methodology of thinking) to model nature, so we can remain self-consistent with our "working" theories to map nature even though we know that the theories have been constructed based on incomplete information. We are also biased. We have strong tendency to give higher weight to those observations and data that better fit our already organized epistemic platform. These tendencies clearly show statistical variations, but bounded by nature's reality that we must consistently conform to advance our scientific modeling. How do we reduce this statistical spread in modeling nature? Our personal view is to stay focused on continuously refining visualizing models for the invisible interaction processes that represent the ultimate reality of nature.

Our *purpose* of doing science and our *epistemology* are normally inseparable since our *desire* to interpret nature is dominated by our biological drives, first, survival and second, sustainable evolution into the future. Our interpretation of nature is always "colored" by these biological drives. This point can be appreciated by carefully analyzing our cerebral interpretations of the five different sensorial (sight, smell, hearing, taste and touch) signals. Let us consider sight. The image formed on our retinal molecular detector array is inverted, but the brain interprets it as erect for our evolutionary purpose. If one wears an image-inverting eye glass, the brain can be fooled for a short while; but soon it will start "seeing" erect "reality" out of the erect images on the retina. We "see" vivid colors, but electromagnetic radiation does not possess any physical color. Signals from the "red", "green" and "blue" frequency sensitive retinal molecules are synthesized and interpreted by the brain as vivid colors suitable for our ease of distinguishing and recognizing different objects necessary for our survival and evolution. A deeper look at the molecular processes behind the other four sensorial functions will also reveal the same point. We do not "see" or "sense" the reality or the objective truth experienced by the sensorial molecules. We have evolved considering our subjective interpretation by our brains as the objective truth only because, within a statistical averaging boundary, we all agree to our cerebral interpretations. These molecule based signals are perfectly reproducible that is set by the inviolable objective laws of nature, which we want to discover. But the cerebral interpretations of the same molecular signals are variable from specie to specie and even variable from member to member within the same specie. Our physical living and thinking are results of complex molecular interactions. Careful analysis of our interpretations show that the statistical breadth of our perceptions of the identical situation is sufficiently broad such that our love-lives and socio-political lives are fraught with frustrating experiences, surprisingly, which also provides us with the diverse (some times, divergent) impetuses towards our social evolution. Even when the "readings" are taken from external "inanimate" instrumental sensors, the explanations are generated by human neural net systems, which are biologically sufficiently different. It will be wise for us to humbly accept Buddha's admonition to think like blind people who are trying to succeed in visualizing the invisible elephant using their touch sensor [1]. Visualizing the cosmic elephant is more daunting task because we do not even know whether we have invented all possible sensors to explore all the invisible complex interaction processes that make the cosmic elephant as manifest as it is to us. The visualized pictures are bound to have sufficient statistical variations. But they should definitely appear to be convergent if the epistemic foundations are logically congruent and we demand conceptual continuity between diverse observations; for the cosmic elephant is a one integral system that has been systematically revealing itself through diverse questions framed by our cause-effect hypotheses and their refined representations, our mathematical theories. Framing the question determines the answer we create. To illustrate this inherent bias, we have constructed a set of questions in Fig.1 to highlight some contradictions and paradoxes based on the hypotheses that light beams do not interfere with each other, which is not articulated in standard texts.

5. SUMMARY & DISCUSSIONS

All entities are always subject to uncontrollable innumerable "collisions" with other classical and quantum entities with rapidly changing parameters. This is the root cause of statistical randomness in all spheres of the evolving universe. While this limits our capability in constructing closed form theories, it assures creative and evolving diversity around us! The theories suffer from the paradigm of incomplete information and we try to validate them with inexact data that can be extracted from any experiments. However, the observed statistical fluctuations are always well bounded implying that the fundamental laws of nature are causal. In the classical world, the collision energy exchange is essentially kinetic as in the case for air molecules confined in a pressure cylinder. The energy transfer can be of any amount. The occurrence of many-body collisions is rare. In the quantum world, all transformational energy exchange is preceded by "quantum compatibility sensing dance" ("qcsd") through amplitude-amplitude stimulations followed by energy exchange, which always happens by a discrete amount. The cosmic tension field, in which these quantum interactants are manifest, is more like a "stormy ocean" ("quantum foam", "background fluctuations", "dark energy", dark matter", etc.) rather than like a "quiet starry night". Very weak many-body interactions are quite prevalent. All possible undulating fields are traveling in every possible direction, and are seeking to participate in the "qcsd" at all possible *chance encounters*. While measurable transformations are predominantly guided by linear "qcsd", the moment and the precise quantity of energy exchanged is now invariably randomized. Thus the quantum statistical behavior is functionally profoundly different from classical interactions. However, conceptual root of statistical randomness is essentially similar for both the classical and quantum worlds – inherently unavoidable interactions with entities that cannot be identified, and even if identified, their physical parameters cannot be measured exactly. Nature appears to be deterministic and causal in her own laws behind all interaction processes. But she has put us on an eternally challenged environment of never being able to determine the exact initial or final states of anything!

Some recent publications indicate that the progress in physics has been slowed down [17-20] as it has failed to discover any new fundamental understanding of the nature of matter and light waves beyond old quantum field theories. Laughlin [18] has indicated the importance of *"emergence"* over *"reductionism"*. However, we believe the problem is more complex and deeper. We have provided concrete examples for a better approach to re-invigorate the progress in physics. We believe it is because we have abrogated the real purpose of doing physics – *understanding and visualizing the invisible interaction processes* in nature and then emulate them to create technologies for our sustainable evolution in harmony with nature. Since the beginning of twentieth century we have become overconfident on the powers of mathematical theories as they have produced an enormous series of successes in predicting the outcomes in nature even though we really have not understood the underlying physical processes. We have started telling nature as to how she ought to behave by using our mathematical inventions rather than humbly staying the course of discovering the real physical process using mathematics, but as a tool. This paper demonstrates that all successful theories, albeit being inherently incomplete, necessarily have captured some realities behind nature's interaction processes. Since equations and experimental devices cannot speak for themselves, we must take proactive approach to imagine, visualize and articulate the descriptions of the possible processes that are being modeled by the equation. Epistemology of the Copenhagen school has actually tried to undermine our natural instinct and capability of imagination and visualization [1,4]. We have been able to discover many deeper understandings behind classical and quantum optics [1,4,7-16] by insisting on creating visualizable models for working equations. An important example is that well formed light beams do not interact with each other *(non-interference of light) and consequently, the time-frequency Fourier theorem cannot be a principle of nature*.

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