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It is the 'Quantum, hν' – The 'Right Answer'

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Philosophy: **A 'Philosophy' appropriate to the title of the paper is a 'Quote' from none other than the main character of the Paper, Max Planck himself and is given below:**

Max Planck (1858 - 1947) the 1918 Nobel Laureate quotes:

"A new scientific truth does not triumph by convincing its opponents and making them see the light, but rather because its opponents eventually die and a new generation grows up that is familiar with it."

PICTURE DEPICTING A GRAND WELCOME TO THE RESEARCH PAPER

………..Author

Max Planck (Left) - The *Propounder* and Albert Einstein (Right) the *validator,* the two stalwarts of the Quantum Theory. (Picture from 'Science Photo Library up-loaded on 2nd August 2016 in which Max Planck presenting the Planck Medal to Einstein.)

Fig.1

Key Words: Black body radiation, Continuity of action, Copenhagen Interpretation, Matter Waves, Photon, Quantum (Some 60 words of 'Quantum' as prefix, for example, 'Quantum Mechanics (QM), Quantum Electrodynamics (QED). etc.), Radiation of energy, Schrodinger

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Wave Equation, Theory of Quanta, Ultraviolet Catastrophe, Uncertainty Principle, Zero Point Energy.

Abstract: Some of the matter in the paper are excerpts from the author's previous internationally published research paper [24]. Beginning with Newton's classical theory of light and Continuity of action, The entire paper is developed into really a mega treatment. The researchers earlier to Max Planck and their failure to explain the nature of thermal radiation arriving at the well known 'Ultraviolet Catastrophe' has been extensively dealt with and finally arriving at the concept of 'Quantum' by Max Planck. After the discovery of the 'Quantum' by Max Planck in 1901, physicists began the research to such great extent that as on today nearly after 120 years, the word, 'Quantum' started appearing in almost all fields of research in Physics. Hence, the author has presented in this paper a large number of terms both frequently appearing such as 'Quantum Electrodynamics (QED)' and rarely appearing such as 'Quantum Key Distribution (QKD)' in the fields of Physics. The rarely appearing terms come only in specific cases and their descriptions are limited to just saying what it is. In spite of keeping the brevity of the paper, indeed it has become exhaustive and lengthy running into some 50 pages. The author has co-related the events of the Bhagavad Gita as a Quantum Universe wherein the author has compared Lord Krishna as an ever known Quantum Physicist thereby giving it a philosophical touch. There are in all over 40 figures. As a picture speaks thousand words, pictures of scientists are given at appropriate places. In addition to usual references, the author has mentioned few of his personal copies of books on the subject.

I INTRODUCTION

We begin with the 'Failure of the *Classical Theory* and introduction of the *Quantum Theory* by Max Planck'. Before the arrival of the Quantum by Max Planck one has to deal with the research of many past workers in the field of black body radiation with the help of some Mathematics. The moment we arrive at the Planck's theory of Quanta, we go to the second derivation of Planck and arrive at the Zero Point Energy. Later on, a major part of the paper is devoted to dealing with terms with the word, 'Quantum' as a prefix.

II REVIEW OF LITERATURE

2.1 FAILURE OF THE *CLASSICAL THEORY* AND INTRODUCTION OF THE *QUANTUM THEORY* BY MAX PLANCK

Most of the introductory parts of the paper are excerpts from a Research Paper published by author, V.C.A. Nair [24] "The Dual Nature of Matter and the Uncertainty Principle led the Quantum Theory to Wave Mechanics" – International Applied Research Journal in Science, Engineering and Technology, Vol.4, Issue-12, Dec. 2017, p. 44-56.

2.1.1 The Origin: The Corpuscular theory of light as suggested by the English mathematician, astronomer, theologian and physicist, Sir Isaac Newton (Fig.4) could not explain certain phenomena like *Refraction* and *Diffraction.* It was later challenged by Huygens and Fresnel by their famous wave theory of light. By this theory they could explain almost all phenomena associated with light and radiation. Even the wave theory of light broke down because according to that the velocity of propagation of light through a medium is given by $v = \sqrt{\left(\frac{E}{\rho}\right)}$ where v is the velocity of light, E the elastic modulus of the medium and ρ

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its density. As v is very high of value 3 x 10^8 ms^{-1}, the elasticity of the medium comes out to be very high and hence becomes contradictory. Further, this led to the conclusion that the medium is a most rigid elastic solid. At this juncture, the Scottish mathematical physicist, James Clerk Maxwell (Fig.5) came forward with his classical *Electromagnetic Wave Theory of Light.* He started with an original and novel idea of A '*Displacement Current'*. According to this new concept, light or radiation is considered as the result of rapidly alternating displacement currents in the medium which give rise to magnetic fields, similar to those with conduction currents. The two fields, the electric and magnetic inseparably associated, the one varying proportionately with the other and the variation of one giving rise to the other, urge each other with a finite velocity, viz. that of light and given by $\frac{1}{\sqrt{(\varepsilon_0 \mu_0)}}$, where ε_0 and μ_0 are specific inductive capacity and permeability respectively of the medium. It did not much involve the elasticity of the medium and Maxwell's electromagnetic theory of light was fully accepted.

2.1.2 The Failure: Two of the basic results of the electromagnetic theory are:

2.1.2.1 Radiation of energy is associated with a moving charge whether it is accelerated or decelerated. The radiation of energy takes place in the form of electromagnetic pulse or wave train as sound waves originate from a sounding body such as a tuning fork. The rate of loss of energy E due to radiation from a charge 'q' moving with an acceleration 'a' is given by

$$\frac{dE}{dt} = \left(\frac{2q^2a^2}{3c^3}\right) \text{ where 'c' is the velocity of light}$$

2.1.2.2 Continuity of action: Since the electric and magnetic fields vary continuously with time, the flow of energy in an electromagnetic wave should be continuous over the entire wave front. In short, the radiation of energy must take place in a continuous fashion.

These results of the electromagnetic theory of Maxwell given above made the nuclear atom model given by Rutherford unstable. The nuclear atom model put forward by Rutherford consists of a central nucleus around which are certain number of electrons assumed stationary and arranged around the nucleus in proper order, Consider for simplicity a two electron atom as in Fig.3 situated diametrically opposite to the nucleus and distance 'r' from it, and 'e' the electronic charge. The force of attraction between the positively charged nucleus and the negatively charged electron and the force of repulsion between the two electrons can be worked and given by avoiding the constants that might arise in any system of units.

$$\text{Force of attraction} = \frac{2\,e\,e}{r^2} = \frac{2e^2}{r^2}$$

$$\text{Force of repulsion} = \frac{e\,e}{(2r)^2} = \frac{e^2}{4r^2}$$

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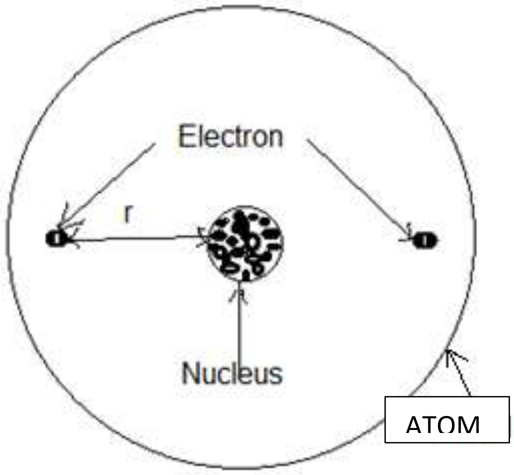
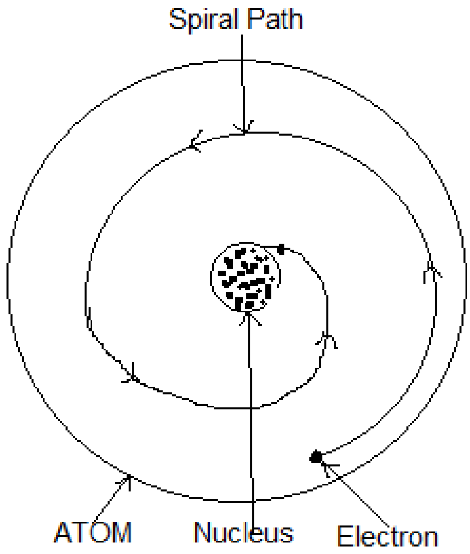


Fig,2 Rutherford's Atom Model



Fig,3 Imagination of the electron spiraling towards the nucleus

It is seen that the force of attraction is 8 times the force of repulsion and hence the electrons which are assumed to be stationary, will fall inside the nucleus due to the force of attraction thereby losing the stability of the atom.

In order to overcome this difficulty, Rutherford assumed that the electrons are not stationary but move around the nucleus in certain orbits similar to planets that move around the Sun. This suggestion was well received by scientists. But, according to the classical electromagnetic theory of Maxwell, a moving electron must radiate energy in a continuous fashion in which case, as no energy is derived from outside sources, the electron in the atom must be continuously losing energy and must become weak and fall inside the nucleus by traversing a spiral path. (Fig.3) The stability of the atom is again lost. This was one of the major failures of the classical electromagnetic theory.

The second major failure was in the explanation of the *'black body radiation'* put forward by many and some ten stalwarts among whom are shown in Figs. 4 o 13 following chronology, Albert Einstein (Fig.13) happens to occupy the last place. The first among the pictures is of Sir Isaac Newton (Fig.4). Newton was, perhaps, the only scientist among the few in his times to assign the word 'radiation' for both 'light' and 'heat' His main failure was in the explanation regarding the nature of these two especially the first one and the second one taken up as 'thermal radiation' two centuries later by other scientists. At this juncture I would like to quote what Bergmann [2, preface, p.v] has said in in the preface of his classical book, Basic Theories of Physics-Heat and Quanta, *"Of all the classical theories of physics, the theory of heat is undoubtedly the most difficult and perhaps because of its*

***intellectual challenge to many of us the most fascinating"* It is the investigations done by physicists on thermal radiation that have revolutionalized the entire Physics which gave birth to the Quantum and started a new era in Modern Physics.**

As early as 1859 the Prussian-German physicist, Kirchhoff Gustav (Fig.6) was the first scientist to study quantitatively the behavior of a black body. A black body is a surface which

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will receive all the heat given to it and when allowed to cool, will radiate all the heat received by it. One may even call such a body as a perfectly black body. Kirchhoff asserted that the radiation from a black body depends only on the temperature and not on the nature or on the material of the body.

I shall arrive at the law from Roberts [38. p.381-3]. Consider an isotropic body at temperature T emits radiation of energy Q into vacuum in unit time per unit area and if the wavelength lies between λ and λ + dλ. If a_λ is the absorptive power of the surface, then the fraction of the energy absorbed is: a_λ dQ. The remaining

Fig.4 Sir Isaac Newton(1642-1727)

Fig.5James Clerk Maxwell (1831-1879)

Fig.6 Kirchhoff Gustav (1824-1887)

Fig.7 Stefan Josef (1835-1893)

Fig.8 Ludwig Boltzmann (1844-1906)

Fig.9 Lord Rayleigh (1842-1919)

Fig.10 Wien Wilhem (1864-1928)

(1 - a_λ) dQ is either reflected or transmitted. If e_λ is the emissive power of the body, the quantity of energy of the given wavelength emitted by the body per unit area per second is e_λ dλ. In order to maintain equilibrium in the enclosure, the amount of energy absorbed must equal the amount of energy emitted and hence:

$$a_\lambda \, dQ = e_\lambda \, d\lambda.$$

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Fig.11 James Jeans (1877-1946)

Fig.12 Max Planck (1858-1947)

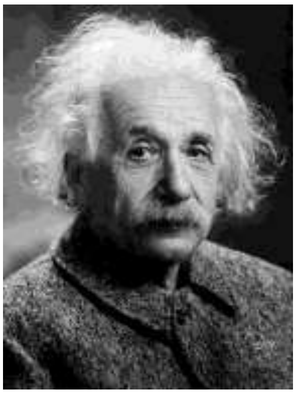

Fig.13 Albert Einstein (1879-1955)

Figs. 4 to 13 Some stalwarts of Thermal Radiation

$\therefore \frac{dQ}{d\lambda} = \frac{e_\lambda}{a\lambda}$ **which depends only on the temperature and hence**

$\frac{e_\lambda}{a\lambda}$ **= constant for a given temperature**

That is, the *"Ratio of emissive power to the absorptive power for radiation of a given wavelength is the same for all bodies at the same temperature"* which is Kirchhoff's law

In the year 1884 the physicist, mathematician and poet, Stefan Josef (Fig.7) and the Austrian physicist and philosopher, Boltzmann (Fig. 8) came forward and applying the idea of pressure exerted by electromagnetic radiation and also based on thermodynamic principles, arrived at a conclusion that the energy E radiated by a black body is directly proportional to the fourth power of the Absolute temperature and the same is expressed by

$$E = \sigma T^4 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

Where σ is the famous Stefan-Boltzmann constant the value of which is 5.67 x 10^{-8} W^{-2} K^{-4}.

In the year 1893, the German physicist Wilhem Wien (Fig.10) considering the adiabatic expansion in a container arrived at an expression for the energy distribution of black body radiation as

$$dE = K\,\lambda^{-5}\, e^{-(\frac{a}{\lambda T})}\, d\lambda \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

where K and a are constants. He further showed that the product λ T for a particular radiation is constant the value of which is 2.898 x 10^{-3} m^0K.

In the year 1900, the English physicist, Lord Rayleigh (Fig .9) and another English physicist, astronomer and mathematician, James Jeans (Fig.11) struck strictly on the electromagnetic theory of Maxwell and asserted that the black body emits radiations of

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'*Continuously variable*' wavelengths from zero to infinity and with this as the basis obtained the following expression for the energy distribution of black body radiation:

$$dE = B\,\lambda^{-4}\,T\,e^{-\left(\frac{a}{\lambda T}\right)}\,d\lambda \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

where a and B are constants.

2.2 The Ultraviolet Catastrophe:

These different formulae for the energy distribution of black body radiation obtained on the basis of classical theory led to wrong and absurd conclusions as they did not fit into experimental curves obtained earlier by scientists such as Paschen, Lummer, Pringsheim and others. For example, the energy distribution formula of Wien agreed with region of short wavelengths whereas the formula of Rayleigh and Jeans agreed with the region of long wavelengths. Thus, not a single formula could explain the nature of the experimental curves throughout their wavelength range. This led to the failure of the classical theory because the theoretical derivations were mathematically correct and free from errors, an anomalous situation had to be accepted in the disagreement of theory with experiment unless one assumed the fundamental assumptions of the classical theory were at fault This is known in classical physics as the *"Ultraviolet Catastrophe"*. In fact it is the catastrophe of classical physics.

2.3 Planck's Theory of Quanta:

The ultraviolet catastrophe led the great German theoretical physicist, Max Planck (Fig.12), Dean of the Academy of Sciences at the University of Berlin proposed at the end of the year 1900 and to be exact on 14 December that year a new revolutionary hypothesis known as the *"Theory of Quanta"* by means of which he was able to derive a correct law of thermal radiation. With the arrival of this theory, the entire classical theory broke down.

In the early evening of Sunday, October 7, 1900—120 years ago—Max Planck found the functional form of the curve that we now know as the Planck distribution of black-body radiation. By my account, it was the birthdate of quantum mechanics. On the fateful day of Dec 14, 1900, Max Planck presented one of the most revolutionary papers in the history of humankind, the paper that gave birth to the theory of quantum mechanics and changed our perception of the observed universe at the microscale in the most unexpected manner. Max Planck presented his paper titled *Zur Theorie des Gesetzes der Energieverteilung im Normalspektrum,* explaining the theory of the Law of Energy Distribution in Normal Spectrum at a meeting of the German Physical Society in Berlin.

The recent advancements in technology, industry, agriculture, medicine and rocketry are due to a small seed sown on 14 December 1900 into the fertile soil of scientific knowledge by Max Planck and, since, carefully cultivated by a whole galaxy of brilliant scientists prominent among whom are Albert Einstein (Fig.13), Louis de Broglie (Fig.14), Werner

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Fig.14 Louis de Broglie (1892-1987)

Fig.15 Werner Heisenberg (1901-1976)

Fig.16 Erwin Schrodinger (1887-1961)

Fig.17 Max Born (1882-1970)

Figs. 14 to 17.The stalwarts of Quantum Mechanics

Heisenberg (Fig.15), Erwin Schrodinger (Fig.16) and Max Born (Fig.17) who are considered as the founding fathers of Quantum Physics. Planck argued that the classical ideas of continuity of action might be wrong and proposed instead, that the energy changes could take place only discontinuously and discretely always as integral multiples of a small unit of energy which he called *"Quantum"*. The light quanta of different types of radiation carry different amounts of energy and that the amount of energy of a light quantum is directly proportional to its frequency. Writing ν for the frequency of radiation and E the energy of the light quantum, we can express Planck's assumption in the form

$$E = h\nu$$

where h is the constant of proportionality known as the Planck's constant the value of which is 6.62 x 10^{-34} Joule second. The value of this constant is as great to Physics as its magnitude is small. From the unit, 'Joule second (Js)', whether the energy is small or time is small, their product is small leading to something like 'action' and it is the Planck's constant of action and is the smallest action ever known in the universe.

With this as the basis, Planck derived the following expression for the energy distribution of black body radiation.

$$dE = \frac{8\pi h c \lambda^{-5}}{[e^{\frac{hc}{(k\lambda T)}} - 1]} d\lambda \; \ldots\ldots\ldots\ldots\ldots\ldots\ldots \; (4)$$

where h is the Plank's constant, c the velocity of light, λ the wavelength, k the Boltzmann constant and T the absolute temperature. The formula can also be written in terms of the frequency ν of the radiation following c = ν λ. The formula is in full agreement with the experimental curves (Fig.18) [47]. Planck's law given by equation (4) is in perfect agreement with the experimental curves. Further, the earlier radiation laws of Wien and Rayleigh-Jeans can be obtained from this law as particular cases. Thus, for the short wavelength region, $e^{\frac{hc}{(k\lambda T)}}$ becomes large compared to unity so that Planck's formula reduces to

$$dE = 8\pi h c \lambda^{-5} \left(e^{-[\frac{hc}{(k\lambda T)}]}\right) d\lambda = K \lambda^{-5} \left(e^{-[\frac{a}{(\lambda T)}]}\right) d\lambda, \text{ K and a being constants}$$

which is Wien's law given by equation (2)

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For long wavelengths, $[e^{\frac{hc}{(k\lambda T)}} - 1]$ becomes nearly equal to $\left[\frac{hc}{(k\lambda T)}\right] [\, e^{\frac{hc}{(k\lambda T)}}]$ so that

$$dE = 8\,\pi\, h\, c\, \lambda^{-5} \left(\frac{k\,\lambda\, T}{h\, c}\right) e^{-[\frac{hc}{(k\lambda T)}]}\, d\lambda = B\, \lambda^{-4}\, T\, e^{-(\frac{a}{\lambda T})}\, d\lambda$$

where B and a are constants which is Rayleigh-Jean's formula.

2.3.1. Idea of Photons:

The concept of Quantum of Radiation suggested by Max Planck was successfully applied by Einstein in the year 1905 to the photoelectric effect, in the year 1907 by Peter Debye to the theory of specific heats, in the year 1913 by Niels Bohr to the theory of atom and in the year 1922 to the scattering of x-rays. From these applications, it became clear that not only radiation is emitted or absorbed in discrete amounts of quanta but also the same quantum structure is retained by radiation while traveling through space, very much

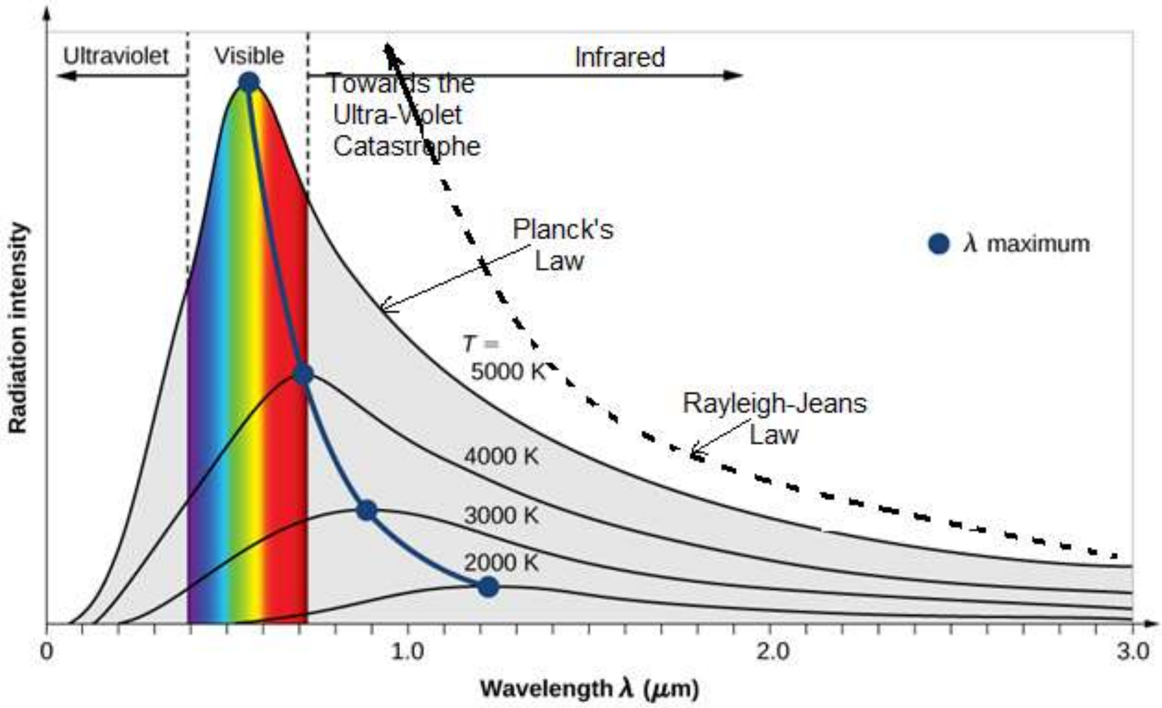

Fig.18. The Graphs of Thermal Radiation [47]

like a shot fired from a gun. This is an extension of Planck's original hypothesis and according to it radiation is considered corpuscular in nature, made up of discrete quanta or photons, as christened in 1926 by Prof. Gilbert N. Lewis (1875=1946) (Fig.20) the American physical chemist of the University of California at Berkeley. The photons are shot up in space with velocity of light

The corpuscular nature of radiation was verified by Einstein in his famous photoelectric effect for which he was awarded the Nobel Prize in 1921. If the electron is to be knocked out of a metal, simply energy of the quantum is not sufficient, but it should have material

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Fig.19 Otto Stern (1888-1969) Fig.20 Gilber N. Lewis (1875-1946)

properties. For example, a man having enough energy to climb a coconut tree cannot get the coconut unless and until he personally climbs the tree and plucks it.

If radiation is corpuscular, then the question is, what is the difference between *Matter* and *Radiation?* The difference is that the rest mass of a material body is always finite and greater than zero whereas the rest mass of a photon is zero as shown below:

We have for a photon moving with velocity v

$$E = h\nu = m c^2 = \frac{m_0 c^2}{\sqrt{(1-\frac{v^2}{c^2})}}$$

$$\therefore \frac{h\nu}{m_0} = \frac{c^2}{\sqrt{(1-\frac{v^2}{c^2})}}$$

As c is constant, we have when v tends to c, the quantity on the right tends to infinity in which case $(\frac{h\nu}{m_0})$ must also tend to infinity. This is possible if m_0 tends to zero. If the rest mass is zero, then it means that there is no light quantum.

From the above treatment, it is amply clear that 'Quantum' is the right answer (in accordance with the Title of the Paper) for both 'matter' and 'radiation'. The exact synthesis between matter and radiation is not simple but really complex.

Equation (4), $dE = \frac{8\pi h c \lambda^{-5}}{[e^{\frac{hc}{(k\lambda T)}}-1]} d\lambda$, the mean energy of an oscillator of wavelength, λ at temperature, T can be written as $E_\lambda = [\frac{(\frac{hc}{\lambda})}{(e^{\frac{hc}{k\lambda T}}-1)}]$ As velocity, $c = \nu\lambda$, this can be written in terms of frequency, ν as

$$E_\nu = [\frac{h\nu}{(e^{\frac{h\nu}{kT}}-1)}] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

Mathematics as the language of Physics, in the year 1911, Max Planck paid his attention to the exponential term in the denominator of equation, ( ) and as a result of his arm-chair philosophy and using simple Mathematics, expanded the term into a series as,

$$e^x = 1 + x + \frac{x^2}{2} + \ldots\ldots\ldots \text{ i.e.,}$$

$$e^{\frac{h\nu}{kT}} = 1 + \frac{h\nu}{kT} + \frac{1}{2}(\frac{h^2\nu^2}{k^2T^2}) + \ldots\ldots$$

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Thus, he equation becomes $E_\nu = \dfrac{h\nu}{(1+\frac{h\nu}{kT}+\frac{1}{2}(\frac{h^2\nu^2}{k^2T^2})+\ldots\ -1)} = \dfrac{h\nu}{(\frac{h\nu}{kT}+\frac{1}{2}(\frac{h^2\nu^2}{k^2T^2})}$

$$= \frac{h\nu}{\frac{h\nu}{kT}[1+\frac{1}{2}\left(\frac{h\nu}{kT}\right)]} = \frac{kT}{[1+\frac{1}{2}\left(\frac{h\nu}{kT}\right)]}$$

Now bring the denominator to the numerator so that

$$E_\nu = kT\,[1+\frac{1}{2}\left(\frac{h\nu}{kT}\right)]^{-1}$$

Using Binomial expansion, this becomes

$$E_\nu = kT\,[1-\frac{1}{2}(\frac{h\nu}{kT}) + \ldots\ldots]$$
$$= kT - \frac{1}{2}h\nu \quad \text{or}$$

$$E_\nu + \frac{1}{2}h\nu = kT \quad \ldots\ldots\ \ldots\ldots\ldots\ldots\ldots\ldots.(6)$$

This is a wonderful result of the arm-chair philosophy of Max Planck in which a quantity, $\frac{1}{2}$ hν gets added to the mean energy of the oscillator. At Absolute Zero, the energy never becomes zero. On the contrary, an energy, $\frac{1}{2}$ hν gets added. German-American Physicists, Albert Einstein (1879-1955) (Fig.13) and Otto Stern (1888-1969) (Fig.19) in the year 1913 coined the term, ($\frac{1}{2}$ hν) as *Nullspunktenergie* in German language meaning as Zero Point Energy (ZPE). It is sometimes called as the vacuum energy and denoted by $E_0 = \frac{1}{2}h\nu$ and played wonders in Astronomy and Astrophysics bringing out new concepts such as 'Dark Matter' and 'Dark Energy'.

The above result obtained by Max Planck is sometimes called his second derivation which he published at the German Academy of Sciences on 3 February 1911.

When Planck introduced the idea of energy quanta to the scientific community, it is unclear whether he really understood the relevance of quantum discontinuity: He was mostly interested in the accuracy displayed by his new law and its constant. Later, he called his equation "a fortuitous guess."
After the birth of the Quantum, there was no immediate acceptance for Planck's theory of Quanta, Albert Einstein, even though he applied the Quantum theory in the explanation of the photoelectric effect for which he was awarded the 1921 Nobel Prize. There was less acceptance than attacks on the theory. It is said in the earlier days,

"Einstein was quantum physics' worst enemy"

Albert Einstein was one of several scientists who worked out quantum theory in the early 20th century, sometimes in public debates that made newspaper headlines, such as this May

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4, 1935 story from the *New York Times*. NEW YORK TIMES/WIKIMEDIA COMMONS[27]

Poor old Albert Einstein is often depicted as having been a virulent opponent of quantum physics, probably because of his famous quote, "God does not play dice with the universe." Yet he wasn't against it and what's more, he created it! In 1905 Einstein wrote his foundational article, "On a Heuristic Viewpoint Concerning the Production and Transformation of Light", based on the work of Max Planck. In it, he proposed that light was made of small, individual and quantified bodies, called photons. This is what won him the Nobel Prize, in fact, not his work on the theory of relativity.

EINSTEIN ATTACKS QUANTUM THEORY

Scientist and Two Colleagues Find It Is Not 'Complete' Even Though 'Correct.'

SEE FULLER ONE POSSIBLE

Believe a Whole Description of 'the Physical Reality' Can Be Provided Eventually.

III FREQUENTLY APPEARING TERMS WITH QUANTUM AS PREFIX

3.1*Quantizaion: Immediately after the announcement of the Quantum theory by Max Planck, physicists started applying the Quantum theory to classical systems using the

Lagrangian and the Hamiltonian of the system and this process is called 'Quantization'. The Newtonian concept of 'Continuity of Action' is discarded and the quantized energy levels for atoms as done by Niels Bohr started appearing. The introduction of 'Matrix Mechanics' and 'Wave Mechanics' are the results of Quantization.

3.1.1 Quantization is the systematic transition procedure from a classical understanding of physical phenomena to a newer understanding known as quantum mechanics. It is a procedure for constructing quantum mechanics from classical mechanics.

3.2 Quantum Mechanics (QM):

The Wikipedia [48] gives in short the meaning of Quantum Mechanics.

Quantum mechanics is a fundamental theory in physics that provides a description of the physical properties of nature at the scale of atoms and subatomic particles. It is the

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foundation of all quantum physics including quantum chemistry, quantum field theory, quantum technology, and quantum information science.

3.2.1 De Broglie Theory of Matter Waves:

In 1924, Louis de Broglie (Fig.14) presented his research thesis, in which he proposed electrons have properties of both waves and particles, like light. He rearranged the terms of the Plank-Einstein relation to apply to all types of matter.

The de Broglie equation is an equation used to describe the wave properties of matter, specifically, the wave nature of the electron:

$$\lambda = \frac{h}{mv}$$

where λ is wavelength, h is Planck's constant, m is the mass of a particle, moving at a velocity v.
de Broglie suggested that particles can exhibit properties of waves.

The de Broglie hypothesis was verified when matter waves were observed in George Paget Thomson's cathode ray diffraction experiment and the Davisson-Germer experiment, which specifically applied to electrons. Since then, the de Broglie equation has been shown to apply to elementary particles, neutral atoms, and molecules.

3.2.2 The Heisenberg Uncertainty Principle:
In quantum mechanics, the uncertainty principle is any of a variety of mathematical inequalities asserting a fundamental limit to the accuracy with which the values for certain pairs of physical quantities of a particle, such as position, x, and momentum, p, can be predicted from initial conditions

$$\Delta X \times \Delta p \geq \frac{h}{4\pi}$$

ΔX **= Uncertainty in position**

Δp **= Uncertainty in momentum**

h **= Planck's constant**

3.2.3 The Schrodinger Wave Equaions

Schrodinger wave equation is a mathematical expression describing the energy and position of the electron in space and time, taking into account the matter wave nature of

the electron inside an atom. The equation gives us a detailed account of the form of the wave functions or probability waves that control the motion of some smaller particles. The equation also describes how these waves are influenced by external factors. Moreover, the

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equation makes use of the energy conservation concept that offers details about the behavior of an electron that is attached to the nucleus.

There are two types of Schrodinger equations:

i) Time independent and ii) time dependent equations.
[These equations are derived systematically from first principles by Rajam J.B [37]. 'Atomic Physics', S. Chand & Co., 1958 Ed., Chapter VIII, The Wave Nature of Matter., p. 446-449.

Following Dirac's notation in Quantum Mechanics, the Planck's constant, h used is the reduced Planck's constant, $\hbar = \frac{h}{2\pi} = 1.05 \times 10^{-34}$ Js and in terms of this, the Schrodinger equations are written as follows:

i) Schrodinger's time independent wave equation:

$$\nabla^2\Psi + \frac{2m}{\hbar^2}(E - V)\Psi = 0$$

is a fundamental wave equation of Schrodinger and

ii) Schrodinger's time dependent wave equation is:

$$i\hbar\frac{\partial\Psi}{\partial t} = [-\frac{h^2}{2\,m}\nabla^2 + V]\,\Psi \;\ldots\ldots\ldots\ldots\ldots(7)$$

The quantity in the square bracket on the right is the Hamiltonian operator, H and $i\hbar\frac{\partial}{\partial t}$ is the energy E so that the equation can be written in the reduced form as,

$$H\,\Psi = E\,\Psi \ldots\ldots\ldots\ldots\ldots\ldots\ldots(8)$$

where in the above equations, Ψ is the Schrodingers's famous wave function, m mass of particle, E the total energy, V the potential energy thereby making (E – V) as the kinetic energy, h the Planck's constant, i = $\sqrt{-1}$ and $\nabla^2\Psi = \frac{\partial^2\Psi}{\partial x^2} + \frac{\partial^2\Psi}{\partial y^2} + \frac{\partial^2\Psi}{\partial z^2}$ is the Laplacian operator.

Equation (7) is the same as equation 6.16, Chapter-II, p.21 of Quantum Mechanics by Leonard Schiff, 2nd Ed., McGraw Hill Pub.
The jugglery of Quantum Mechanics is illustrated in the Fig.21

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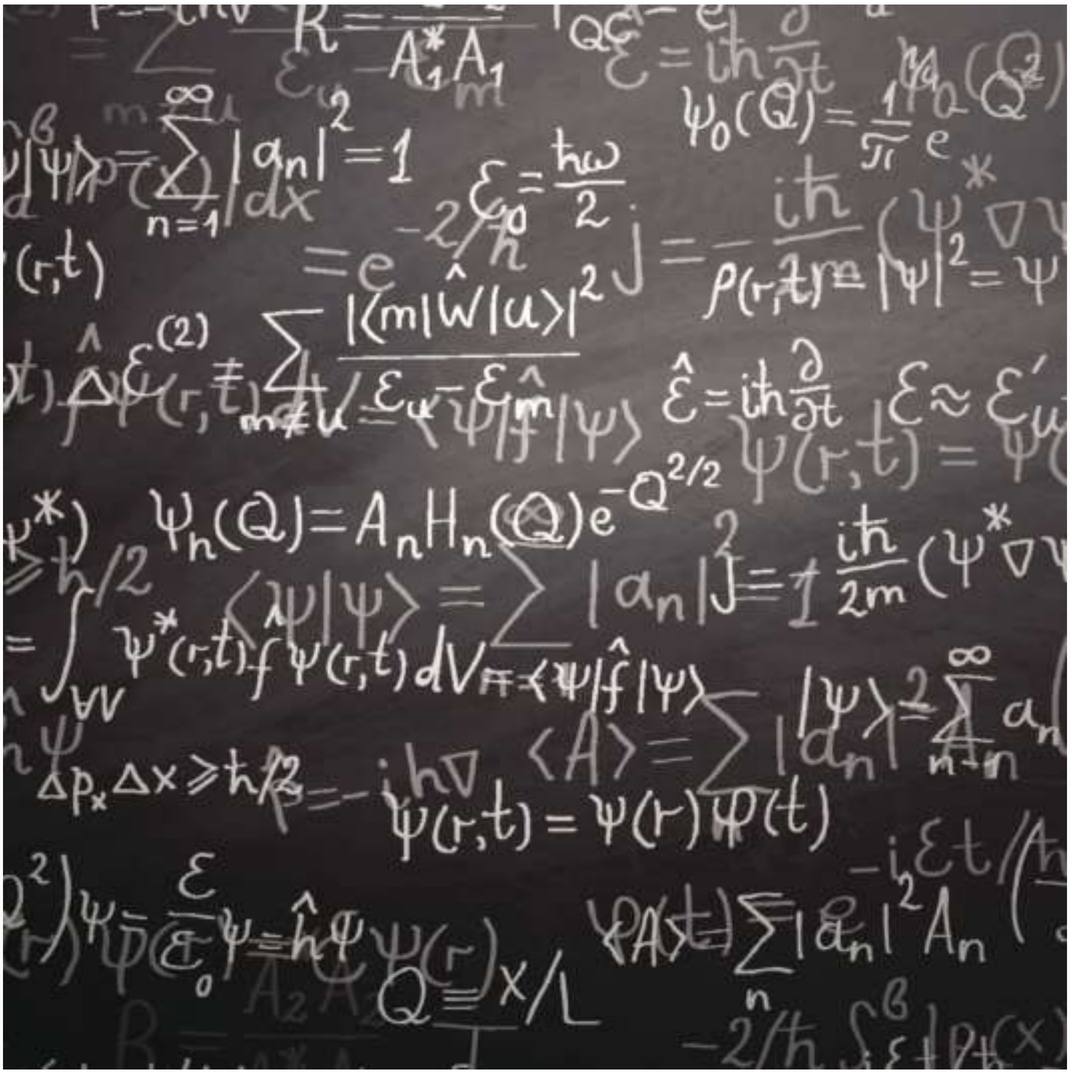

Fig.21 Picture illustrating the jugglery of Quantum Mechanics Nair V.C.A [25] IARJSET Vol.7, Issue-10, Oct.20, p.48]

3.3 *Quanum Field (QF): Quantum field is any region of space within which he quantum effects are sudied. The entire universe is governed by quantum rules and hence the universe itself can be taken as a quantum field. That is to say that the quantum fills everywhere.

3.4* Quantum field theory (QFT)- Britannica [3] (Editors of) gives:

Quantum field theory is the result of the combination of classical field theory, quantum mechanics, and special relativity

3.4.1 Stanford Encyclopedia of Philosophy [40]. *First published Thu Jun 22, 2006;* substantive revision Mon Aug 10, 2020 gives:

Quantum Field Theory (QFT) is the mathematical and conceptual framework for contemporary elementary particle physics. It is also a framework used in other areas of theoretical physics, such as condensed matter physics and statistical mechanics. In a rather informal sense QFT is the extension of quantum mechanics (QM), dealing with particles, over to fields, i.e. systems with an infinite number of degrees of freedom. (See the entry on quantum mechanics.) In the last decade QFT has become a more widely discussed topic in

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philosophy of science, with questions ranging from methodology and semantics to ontology. QFT taken seriously in its metaphysical implications seems to give a picture of the world which is at variance with central classical conceptions of particles and fields, and even with some features of QM.

3.4.2 A comprehensive understanding of QFT is gained by dwelling on its relation to other physical theories, foremost with respect to QM, but also with respect to classical electrodynamics, Special Relativity Theory (SRT) and Solid State Physics or more generally Statistical Physics. However, the connection between QFT and these theories is also complex and cannot be neatly described step by step.

3.5 *Quantum Elecrodynamics (QED):

Quantum electrodynamics, or QED, is a quantum theory of the interactions of charged particles with the electromagnetic field. It describes mathematically not only all interactions of light with matter but also those of charged particles with one another. QED is a relativistic theory in that Albert Einstein's theory of special relativity is built into each of its equations. Because the behavior of atoms and molecules is primarily electromagnetic in nature, all of atomic physics can be considered a test laboratory for the theory. Agreement of such high accuracy makes QED one of the most successful physical theories so far devised.

3.5.1 In 1926 the British physicist P.A.M. Dirac laid the foundations for QED with his discovery of an equation describing the motion and spin of electrons that incorporated both the quantum theory and the theory of special relativity. The QED theory was refined and fully developed in the late 1940s by Richard P. Feynman, Julian S. Schwinger, and Shin'ichiro Tomonaga, independently of one another. QED rests on the idea that charged particles (e.g., electrons and positrons) interact by emitting and absorbing photons, the particles of light that transmit electromagnetic forces. These photons are virtual; that is, they cannot be seen or detected in any way because their existence violates the conservation of energy and momentum. The particle exchange is merely the "force" of the interaction, because the interacting particles change their speed and direction of travel as they release or absorb the energy of a photon. Photons also can be emitted in a free state, in which case they may be observed. The interaction of two charged particles occurs in a series of processes of increasing complexity. In the simplest, only one virtual photon is involved; in a second-order process, there are two; and so forth. The processes correspond to all the possible ways in which the particles can interact by the exchange of virtual photons, and each of them can be represented graphically by means of the diagrams developed by Feynman. Besides furnishing an intuitive picture of the process being considered, this type of diagram prescribes precisely how to calculate the variable involved.

3.5.2 Under QED, charged particles interact by the exchange of virtual photons, photons that do not exist outside of the interaction and only serve as carriers of momentum/force

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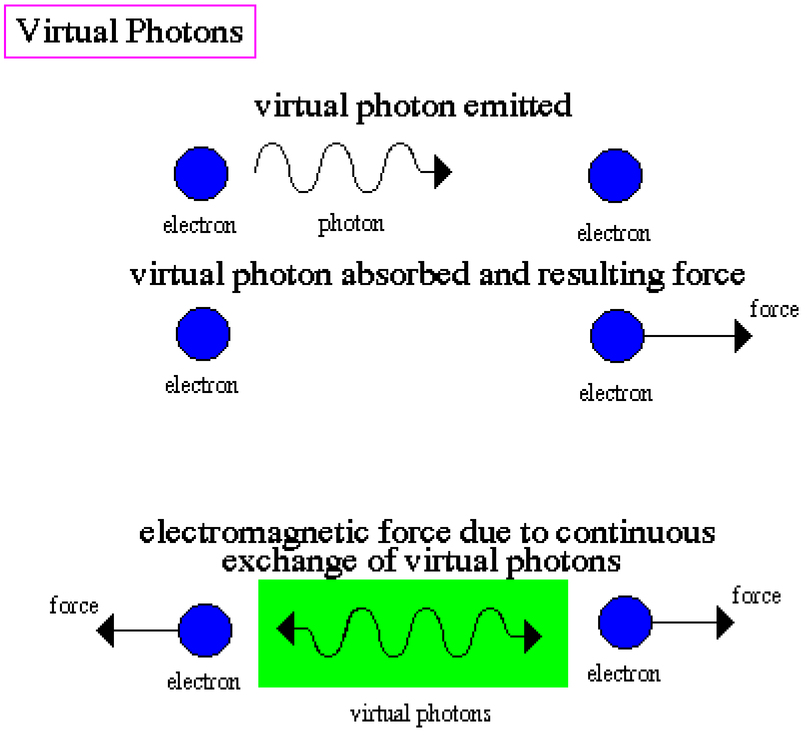

Fig.22

as shown in Fig.22. Notice the elimination of action at a distance, the interaction is due to direct contact of the photons.

In the 1960's, a formulation of QED led to the unification of the theories of weak and electromagnetic interactions. This new force, called electroweak, occurs at extremely high temperatures such as those found in the early Universe and reproduced in particle accelerators. Unification means that the weak and electromagnetic forces become symmetric at this point, they behave as if they were one force.

Electroweak unification gave rise to the belief that the weak, electromagnetic and strongforces can be unified into what is called the Standard Model of matter.

3.6 *Quantum Chromodynamics (QCD)

In QCD, one deals with Quarks. The origin of the word, 'Quark' is from an Irish novelist, James Joyce (1882-1941) (Fig.30) who was in the habit of making peculiar words like 'squeak' and 'squork' for certain objects and a word like 'quork' resembling 'pork' which later on Murray- Gel Mann christened as QUARK for particles smaller than proton or neutron.

3.6.1 Encyclopedia.com [11] up dated May 18, 2018] quotes:

Quantum chromodynamics (QCD) is the component of the Standard Model that describes the strong interactions. QCD is the theory of quarks and gluons. Quarks carry a new charge, called color, that enables them to emit and absorb gluons. (This is the origin of the name chromodynamics, although the "color" of QCD should in no way be confused with

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the colors of light.) The quarks are also electrically charged and like electrons, are fermions, and carry a spin, or intrinsic angular momentum, of one-half in units of Planck's constant. The gluons are electrically neutral, and, like photons, are bosons of spin one. Together, the fields of quarks and gluons make up a non-abelian gauge theory. In QCD, quarks interact by the exchange of gluons in much the same way that electrons interact by the exchange of the quanta of light, photons. Like photons, the gluons have no mass and travel at the speed of light. Unlike photons, however, the gluons carry the very color charge that produces them, so gluons can emit and absorb more gluons. The resulting strong force is thus more complicated to analyze than the electromagnetic force.

3.6.2 The Oxford Dictionary [33] gives:

The color is analogous to electric charge and the gluon being analogous to photon. QCD has the important property of 'asymptotic freedom, i.e to say that at high energies at short distances, the interaction between quarks tend to zero. The high energy aspects of strong interactions can be calculated by perturbation theory

This model helps to explain many phenomena, such as why the only possible hadrons are baryons (consisting of three quarks), antibaryons (consisting of three antiquarks) and mesons (consisting of one quark and one antiquark).

Each of these composite particles has a net color charge of zero. Any baryon must contain one quark with a red color charge, one quark with a green color charge, and one quark with a blue color charge. By analogy with conventional colors: red + green + blue = white, a neutral color with a net color charge of zero. Likewise, antibaryons must contain one antiquark with an anti-red color charge, one antiquark with an anti-green color charge, and one antiquark with an anti-blue color charge. Again, this gives a net color charge of zero. The color combination is shown in Fig.23 below:

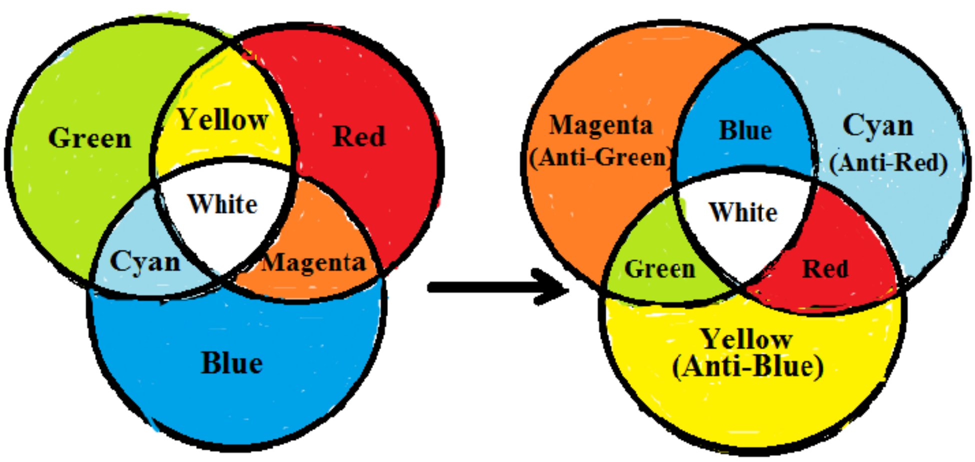

Fig.23 The Color combination in Quantum Chromodynamics (QCD)

Wikipedia [49] gives the following information:

3.6.3 In quantum chromodynamics (QCD), a quark's color can take one of three values or charges: red, green, and blue. An antiquark can take one of three anticolors: called antired, antigreen, and antiblue (represented as cyan, magenta, and yellow, respectively). Gluons are

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mixtures of two colors, such as red and antigreen, which constitutes their color charge. QCD considers eight gluons of the possible nine color–anticolor combinations to be unique;

Fig.24 Harald Fritzsch (Born: 1943….)

Fig.25Heinrich Leutwyler (Born: 1938…)

Fig.26 Murray Gell-Man (1929-2019)

Fig.27 James Joyce (1882-1941)

3.6.4 The theory of Quantum Chromodynamics is abstract, complicated and hence confusing even for a general physicist (of course, I am one). A common and a simple question that arises is "What Color has to do with Physics ?" But, a theory developed in 1973 by some pioneers like German physicists, Harald Fritzsch (Born: 1943) (Fig.24), Heinrich Leutwyler (Born 1938) (Fig.25) together with an American physicist, Murray Gell-Mann.(1929-2019) (Fig.26) brought out a fantastic theory of QCD using concept of colors. The credit of developing the present day Particle Physics related to the Standard Model goes to these physicists supported by many others. The word 'Color' is not taken in the usual sense of looking at the colors of, say, a Rainbow.

3.6.5 Three color charges combine to produce a net color charge of zero (i.e. white). (b) Three anti-color charges combine to produce a net color charge of zero (i.e. white).

Similarly, the quark–antiquark pairs that constitute a meson must have the opposite color charge to each other: red + anti-red (cyan) = white for instance, which is a net color charge of zero again.

Only particles with a net color charge of zero are allowed to exist in an independent state, and this explains why single quarks and antiquarks are not seen in isolation. The locking up of quarks inside hadrons is referred to as confinement. Gluons do not have a net color charge of zero either, so they too do not escape from strong interactions. Instead, gluons will decay into quark–antiquark pairs, which in turn create further hadrons.

3.6.6 Now, coming to the language of Physics, that is Mathematics, "Is there any Mathematics related the Quantum Chromodynamics? Well !!! Readers, things will go above your head. Just glance over the following Fig.28 from Wikimedia Commons[53-A] giving the Lagrangian in QCD and the Strong Force.

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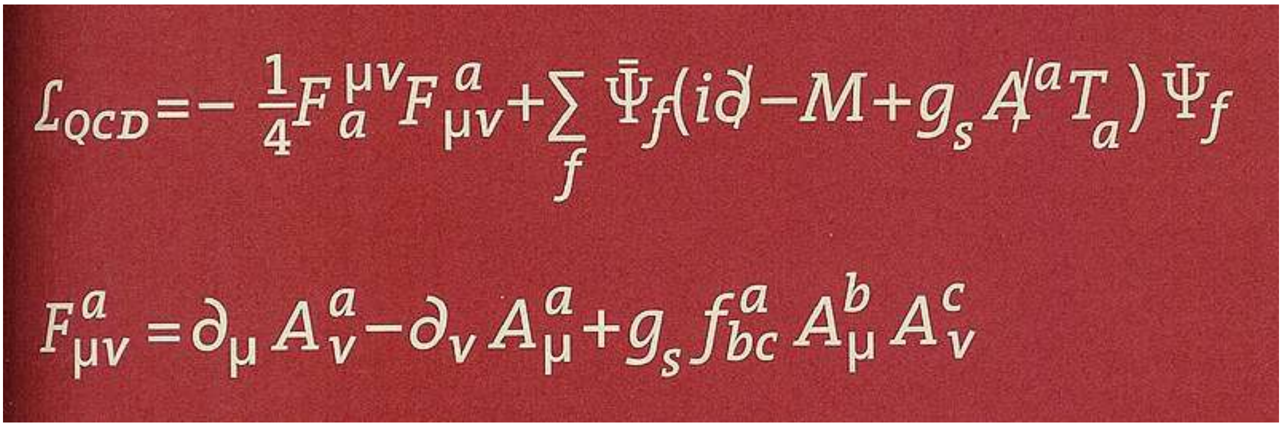

$$\mathcal{L}_{QCD} = -\frac{1}{4} F_a^{\mu\nu} F_{\mu\nu}^a + \sum_f \bar{\Psi}_f (i\partial\!\!\!/ - M + g_s A\!\!\!/^a T_a) \Psi_f$$

$$F_{\mu\nu}^a = \partial_\mu A_\nu^a - \partial_\nu A_\mu^a + g_s f_{bc}^a A_\mu^b A_\nu^c$$

Fig. 28 The Lagrangian (above) and the Strong Force Formula (below)

3.7*Quantum Interpretation: Generally known as the Copenhagen Interpretation

The Copenhagen interpretation—due largely to the Danish theoretical physicist Niels Bohr (Fig.29), shown in —remains a quantum mechanical formalism that is widely accepted amongst physicists, some 75 years after its enunciation. According to this interpretation, the probabilistic nature of quantum mechanics is not a temporary feature which will eventually be replaced by a deterministic theory, but instead must be considered a final renunciation of the classical idea of causality. The Copenhagen interpretation has philosophical implications to the concept of determinism. According to the theory of determinism, for everything that happens there are conditions such that, given those

conditions, nothing else could happen. Determinism and free-will seem to be mutually exclusive. If the universe, and any person in it are governed by strict and universal laws , then that means that a person's behavior could be predicted based on sufficient knowledge of the circumstances obtained prior to that person's behavior. However, the Copenhagen interpretation suggests a universe in which outcomes are not fully determined by prior circumstances but also by probability. This gave thinkers alternatives to strictly bound possibilities, proposing a model for a universe that follows general rules but never had a predetermined future.

3.8 *Quantum Computing (Quantum Computer)

Richard Feynman (1918-1988) (Fig.29-A) and David Deutsch (Born: 1953….) (Fig. 29-B) are the two fathers of the quantum computer. Feynman proposed their possibility in 1982 and in 1985, Deutsch how to build one.

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Fig. 29 Einstein sitting at ease and relaxing but disagreeing with Niels Bohr on Quantum Mechanics especially on is interpretation

3.8.1 Quantum computing is the study of how to use phenomena in quantum physics to create new ways of computing.
Quantum computing is made up of qubits.

Unlike a normal computer bit, which can be 0 or 1, a qubit can be either of those, or a superposition of both 0 and 1.

The power of quantum computers grows exponentially with more qubits.
This is unlike classical computers, where adding more transistors only adds power linearly.

Quantum computing is a type of computation that harnesses the collective properties of quantum states, such as superposition, interference, and entanglement, to perform calculations. The devices that perform quantum computations are known as quantum computers.

3.8.2 Alphabet [1] Has a Second, Secretive Quantum Computing Team

In a paper today in Nature, and a company blog post, Google researchers claim to have attained "quantum supremacy" for the first time. Their 53-bit quantum computer, named

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Sycamore, took 200 seconds to perform a calculation that, according to Google, would have taken the world's fastest supercomputer 10,000 years.

Google and rivals like IBM are investing in quantum computing because they believe it can catalyze major advances in many fields of science and industry, such as drug development and artificial intelligence. That was both notable science and a chance for Google to show prominence in a contest among big tech companies, including IBM and Microsoft, to deliver the wild new power promised by quantum computing. The usually low-profile Pichai threw himself into marking the moment, penning a blog post, taking part in a rare media interview, and posting an Instagram photo of himself alongside the shiny machine that scored the result.

Fig. 29-A Richard Feynman (1918-1988)

29-B David Deutsch (Born:1953…..)

Fig. 29-C Sundar Pichai (Born: 1972….)

Quantum researchers need to cool the qubits to close to absolute zero to limit vibration — or "noise" — that causes errors to creep into their calculations. It's in this extremely challenging task that the research team at Google, a unit of Alphabet Inc. has made significant progress. CEO Sundar Pichai (Born:1972…..) (Fig. 29-C) compared the achievement to building the firs rocket to leave the Earth's atmosphere and touch the edge of space, an advance that brought interplanetary travel into the realm of the possible.

In an exclusive interview with MIT Technology Review, Pichai explains why Quantum Computing as important for Google.

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Fig.30. Sundar Pichai, the CEO Google with Daniel Sank fixing up one of the Quantum Computers in the Santa Barbara Lab., California, US
(Photo credit: GOOGLE/HANDOUT VIA REUTERS)

[Just look at the concentration of observation by the two physicists. There is no doubt that a physicist has to be really an Observer.]

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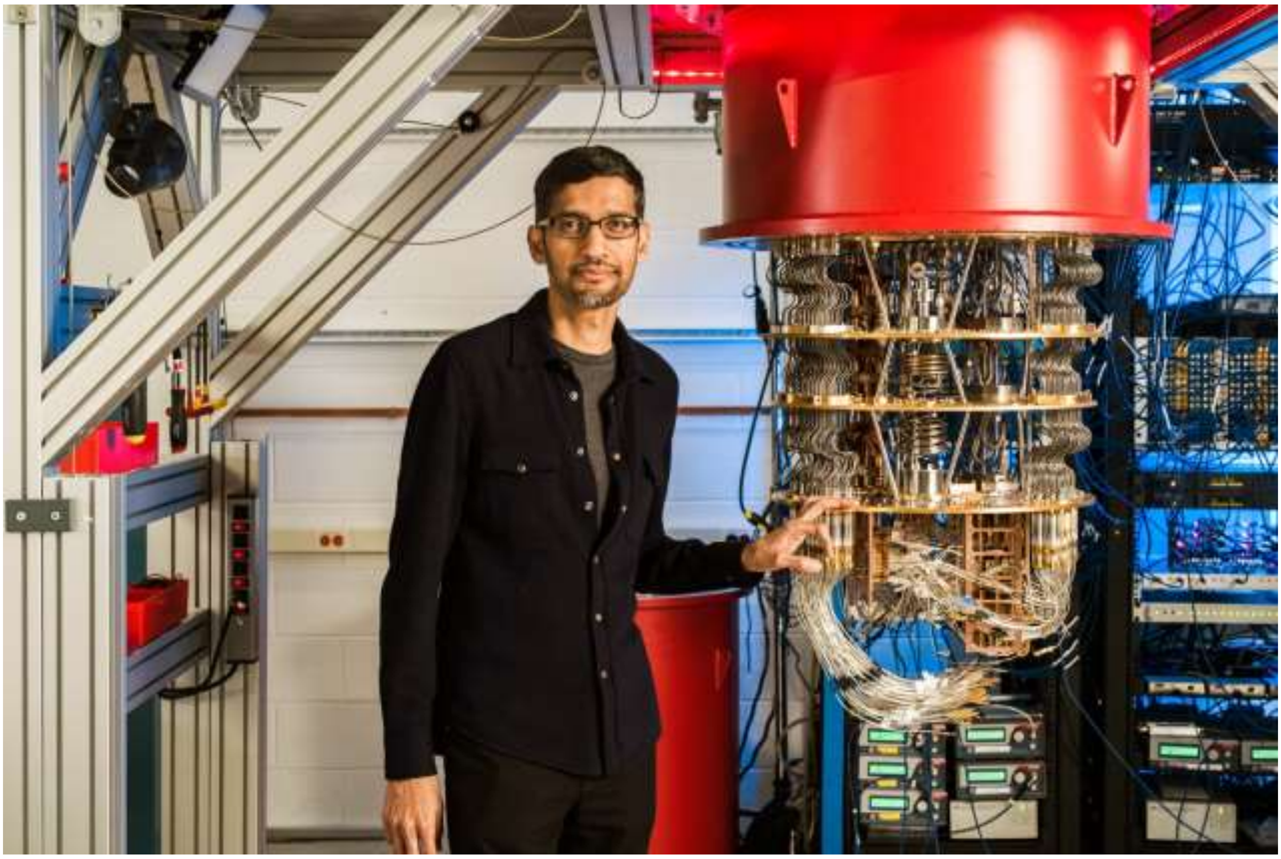

Fig. 31. Alphabet CEO Sundar Pichai touted the company's achievements in quantum computing in posts on a blog and social media last year.COURTESY OF GOOGLE

Times of India, Mumbai [43] has published the following news item

Quantum Leap For Quantum Computing

IBM in November unveiled a quantum processor of 127 qubits, or quantum bits, while startup QuEra, created by MIT and Harvard, announced an even more powerful machine of 256 qubits. This quantum leap for quantum computing far exceeded the power of previous quantum processors, which had peaked at 100 qubits. With Azure Quantum and Braket respectively, Microsoft and Amazon already offer quantum computing services. Google even aims to create a quantum computer with 1 million qubits by 2029

News Item from Times of India, Mumbai, dated 6th January 2022, p. 13

Fig.32

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3.9 *Quantum Cryptography: Cryptography is the process of encrypting data, or converting plain text into scrambled text so that only someone who has the right "key" can read it. Quantum cryptography, by extension, simply uses the principles of quantum mechanics to encrypt data and transmit it in a way that cannot be hacked.

3.9.1 John Gribbin [19] gives: The technique of using Quantum Physics to create an uncrackable code. The code is something like assigning numbers to letters such as number 1 to letter A, 2 to letter B and so on. The random numbers taken from a particular predetermined page in a book of random numbers are added to the numbers corresponding to the message before it is transmitted. At the other end, any one equipped with the same book of random numbers who knows which page has been used can subtract the random numbers to reveal the message. In Quantum Cryptography, the random numbers themselves are transmitted in a quantum form perhaps as a stream of polarized photons. Quantum Cryptography is still in a developing stage.

3.10 *Quantum Graviy: Andrew Zimmerman Jones [54] Updated on March 21, 2018 gives: Quantum gravity generally posits a theoretical entity, a graviton, which is a virtual particle Quantum gravity is an overall term for theories that attempt to unify gravity with the other fundamental forces of physics which are that mediates the gravitational force. This is what distinguishes quantum gravity from certain other unified field theories -- although, in fairness, some theories that are typically classified as quantum gravity don't necessarily require a graviton. An answer to the question, 'What is Graviton?'

3.11 *Quantum Entanglement: Caltex Science Exchange[5] gives: Entanglement is at the heart of quantum physics and future quantum technologies. Like other aspects of quantum science, the phenomenon of entanglement reveals itself at very tiny, subatomic scales. When two particles, such as a pair of photons or electrons, become entangled, they remain connected even when separated by vast distances. In the same way that a ballet or tango emerges from individual dancers, entanglement arises from the connection between particles. It is what scientists call an emergent property.

3.12 *Quantum Electronics: A branch of Quantum Physics dealing with applications of Quantum Optics and the specifically quantum mechanical properties of electrons to the design of electronic circuits and devices.

3.13 *Quantum Number: Chemistry Libre Text [7] A total of four quantum numbers are used to describe completely the movement and trajectories of each electron within an atom. The combination of all quantum numbers of all electrons in an atom is described by a wave function that complies with the Schrödinger equation. Each electron in an atom has a unique set of quantum numbers; according to the Pauli Exclusion Principle, no two electrons can share the same combination of four quantum numbers. Quantum numbers are important because they can be used to determine the electron configuration of an atom and the probable location of the atom's electrons. Quantum numbers are also used to understand other characteristics of atoms, such as ionization energy and the atomic radius.

In atoms, there are a total of four quantum numbers: the principal quantum number (n), the orbital angular momentum quantum number (l), the magnetic quantum number (m_l), and the electron spin quantum number (m_s).

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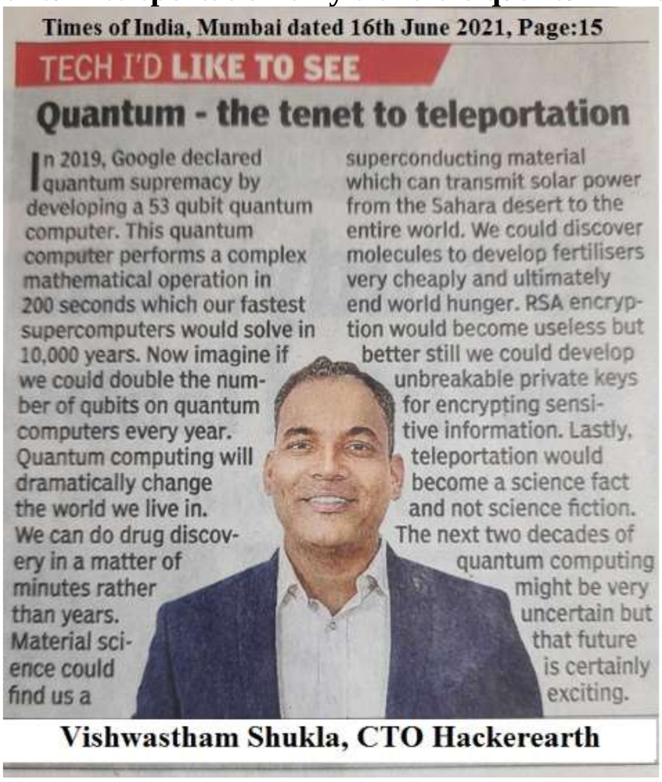
3.14 *Quantum Tunneling: The phenomenon of tunneling, which has no counterpart in classical physics, is an important consequence of quantum mechanics. Consider a particle with energy E in the inner region of a one-dimensional potential well V(x). (A potential well is a potential that has a lower value in a certain region of space than in the neighboring regions.) In classical mechanics, if E < V (the maximum height of the potential barrier), the particle remains in the well forever; if E > V , the particle escapes. In quantum mechanics, the situation is not so simple. The particle can escape even if its energy E is below the height of the barrier V, although the probability of escape is small unless E is close to V . In that case, the particle may tunnel through the potential barrier and emerge with the same energy E.

3.14.1 The phenomenon of tunneling has many important applications. For example, it describes a type of radioactive decay in which a nucleus emits an alpha particle (a helium nucleus). According to the quantum explanation given independently by George Gamow and by Ronald W. Gurney and Edward Condon in 1928, the alpha particle is confined before the decay by a potential. For a given nuclear species, it is possible to measure the energy E of the emitted alpha particle and the average lifetime of the nucleus before decay. The lifetime of the nucleus is a measure of the probability of tunneling through the barrier--the shorter the lifetime, the higher the probability.

3.15 *Quantum Jump: A quantum jump corresponds to an orbiting electron in an atom gaining energy after absorption of a photon and jumping to a higher orbit. The electron can also lose energy and jump down and emit a photon.

3.16 *Quantum Teleportation: Quantum teleportation is a technique for transferring quantum information from a sender at one location to a receiver some distance away. While teleportation is portrayed in science fiction as a means to transfer physical objects from one location to the next, quantum teleportation only transfers quantum information.



Times of India, Mumbai dated 16th June 2021, Page:15

TECH I'D LIKE TO SEE

Quantum - the tenet to teleportation

In 2019, Google declared quantum supremacy by developing a 53 qubit quantum computer. This quantum computer performs a complex mathematical operation in 200 seconds which our fastest supercomputers would solve in 10,000 years. Now imagine if we could double the number of qubits on quantum computers every year. Quantum computing will dramatically change the world we live in. We can do drug discovery in a matter of minutes rather than years. Material science could find us a superconducting material which can transmit solar power from the Sahara desert to the entire world. We could discover molecules to develop fertilisers very cheaply and ultimately end world hunger. RSA encryption would become useless but better still we could develop unbreakable private keys for encrypting sensitive information. Lastly, teleportation would become a science fact and not science fiction. The next two decades of quantum computing might be very uncertain but that future is certainly exciting.

Vishwastham Shukla, CTO Hackerearth

Fig. 33

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A news item that appeared in the Times of India, Mumbai [44] dated 16th June 2021, p.15 is given on 'QuantumTeleportation'.

3.17 *Quantum Statistics: An Oxford Reference[28] gives: A statistical description of a system of particles that obeys the rules of quantum mechanics rather than classical mechanics. In quantum statistics, energy states are considered to be quantized. If the particles are treated as indistinguishable, Bose-Einstein statistics apply if any number of particles can occupy a given quantum state. Such particles are called as Bosons. If only one particle may occupy each quantum sate, then he statistics is known as Fermi-Dirac statistics and he corresponding particles are called Fermions.

3.18 *Quantum Probability: A rigorous general definition of quantum probability is given, which is valid not only for elementary events but also for composite events, for operationally testable measurements as well as for inconclusive measurements, and also for non-commuting observables in addition to commutative observables.

The Born rule (also called Born rule) is a key postulate of quantum mechanics which gives the probability that a measurement of a quantum system will yield a given result. In its simplest form, it states that the probability density of finding a particle at a given point, when measured, is proportional to the square of the magnitude of the particle's wave function at that point. It was formulated by German physicist Max Born in 1926.

3.19 *Quantum Chemistry: Quantum chemistry, also called molecular quantum mechanics, is a branch of chemistry focused on the application of quantum mechanics to chemical systems. ... Quantum chemistry studies the ground state of individual atoms and molecules, and the excited states, and transition states that occur during chemical reactions.

Readers are advised to go through a personal copy possessed by author:

"Quantum Chemistry by Henry Eyring, John Walter, George E. Kimball, John Wiley & Sons, INC. Ed. 1944."

3.20 *Quantum Technology: Paul Martin [34], a Quantum Technology Expert quotes:

"Quantum technology is a class of technology that works by using the principles of quantum mechanics (the physics of sub-atomic particles), including quantum entanglement and quantum superposition.'

Such a definition might make your head spin, but the truth is, you don't need to know exactly what quantum technology is to make use of it. Your smartphone is a type of quantum technology – its semiconductors use quantum physics to work – but neither you nor the engineer who designed it need to know the ins and outs of quantum mechanics. J3.20.1 James McKenzie[15] in the Physics World why the future is already on its way? 13 Nov 2020.Appeared as heading: A Quantum Future.

"I'm delighted that here in the UK, construction of the new National Quantum Computing Centre will start this year. The US National Institute of Standards and Technology has already said that quantum computers will be able to crack the existing public-key infrastructure like 128-bit AES encryption by 2029. That prospect means businesses and governments are scrambling to improve the security of conventional networks, for example by using quantum-key cryptography. That's a new market for quantum

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technology that's expected to be worth anything from $214m to $1.3bn by 2024 (depending on which market survey you read).

3.21 *Quantum Cosmology: Quantum cosmology is a theory that uses quantum mechanics to extend gravitational physics beyond Einstein's theory of general relativity.
While Einstein's theory of general relativity can explain a large array of fascinating astrophysical and cosmological phenomena, some aspects of the properties of the universe remain puzzling.

While the differences in the theories occur at the tiniest of scales—much smaller than even a proton—they have consequences at the largest of accessible scales in the universe.
3.21.1 The study in Physical Review Letters [35] also provides new predictions about the universe that future satellite missions could test.
Quantum Cosmology explains anomalies beyond Einstein's Physics

3.21.2 John Gribbin [19. P.307-311] 'Q for Quantum gives The application of Quantum Physics including the ideas of the grand unified theories, to describe the very early stages in the life of the universe and, in some models, he origin of he universe from nothing at all. It deals with the era when what is now the entire visible universe was confined within a volume no bigger across than an atom. This startling development, which brought within the bounds of respectable Physics questions and ideas which had previously seemed to belong in the realms of philosophy and metaphysics (or even religion), developed in the 1980's largely following the introduction of the idea of cosmological inflation.

IV RARELY APPEARING TERMS WITH QUANTUM AS PREFIX

4.1 *Quantum De- Coherence: The Wikipedia [50], the free encyclopedia gives the meaning as:

Quantum de-coherence is the loss of quantum coherence. In quantum mechanics, particles such as electrons are described by a wave function, a mathematical representation of the quantum state of a system; a probabilistic interpretation of the wave function is used to explain various quantum effects. As long as there exists a definite phase relation between different states, the system is said to be coherent. A definite phase relationship is necessary to perform quantum computing on quantum information encoded in quantum states. Coherence is preserved under the laws of quantum physics. De-coherence was first introduced in 1970 by the German physicist H. Dieter Zeh[1] and has been a subject of active research since the 1980s.[2] De-coherence has been developed into a complete framework, but there is controversy as to whether it solves the measurement problem, as the founders of de-coherence theory admit in their seminal papers.

4.1.1 Heinz-Dieter Zeh (German: [tseː]; 8 May 1932 – 15 April 2018), usually referred to as H. Dieter Zeh, was a professor (later professor emeritus) of the University of Heidelberg and theoretical physicist quotes that:

"The job of de-coherence is to bring a quantum system into an apparently classical state. That is, 'Quantum de-coherence is, what especially differentiates a quantum system from a classical system"

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4.2 *Quantum Vibration:

Jennifer Chu [17] MIT News Office Publication Date: October 6, 2019 says:
"When a guitar string is plucked, it vibrates as any vibrating object would, rising and falling like a wave, as the laws of classical physics predict. But under the laws of quantum mechanics, which describe the way physics works at the atomic scale, vibrations should behave not only as waves, but also as particles. The same guitar string, when observed at a quantum level, should vibrate as individual units of energy known as phonons."

Fig.34 Steven Weinberg (1933-2021)

Fig.35 Sheldon Glashow (1932-)

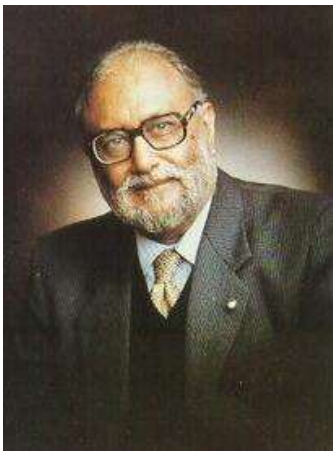

Fig.36 Abdus Salam (1926-1996)

4.3 *Quantum hydrodynamics: is an effective field theory pertaining to interactions between hadrons, that is, hadron-hadron interactions or the inter-hadron force. It is "a framework for describing the nuclear many-body problem as a relativistic system of baryons and mesons". Quantum hydrodynamics is closely related and partly derived from quantum chromodynamics, which is the theory of interactions between quarks and gluons that bind them together to form hadrons, via the strong force.

4.4 *Quantum Flavor Dynamics (QFD): The Particle Physicists came from Color to Flavor. The QFD corresponds to a 'Gauge' theory that gives a unified description of the electromagnetic and weak interactions first proposed in 1967 by Steven Weinber (1933-) (Fig.35) and Abdus Salam (1926-1996) (Fig.37) Their theory was further extended by Sheldon Glashow (1932-) (Fig.36) and hence known as the Glashow-Weinberg-Salam (GWS) model This theory later on led to the discovery of the Higgs Boson.

4.5 *Quantum Suicide: Quantum suicide is a thought experiment, originally published independently by Hans Moraveil [14] in 1987 and Bruno Marchal in 1988, and independently developed further by Max Tegmark in 1998.
4.5.1 From Study.com [42], Quantum suicide is a thought experiment. The scenario imagines that a researcher is inside a box closed to outside observations, which has a 50% probability of killing him or her in a certain time frame from radiation. According to the current interpretation, the system inside would exist simultaneously in both outcomes until it was observed, at which point it would "collapse" into one specific outcome. There are many hypotheses for how this would work in reality, but quantum suicide specifically invokes the many-worlds interpretation.

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According to this idea, the universe would split into two timelines: One where the researcher died and one where he or she did not. If so, there would always be a universe.

where the researcher survives. The implication is that a person would have "quantum immortality"; in any situation where he or she might die, there would necessarily be a universe where he or she would continue to live. Therefore, some version of the individual's consciousness would continue to survive indefinitely, even though many different versions of him or her die constantly.

4.6 *Quantum Chaos: An Oxford reference [28] gives; The quantum mechanics of systems for which the corresponding classical system can exhibit chaos. This subject was initiated by Einstein in 1917, who showed that the quantization conditions associated with the Bohr theory need to be modified for systems that show chaos in classical mechanics. The subject of quantum chaos is an active field of research in which many basic issues still require clarification. It appears that systems exhibiting chaos in classical mechanics do not necessarily exhibit chaos in quantum mechanics.

4.6.1 An addendum from Oxford Dictionary of Physics [30] In Quantum Mechanics, Chaos can be investigated in terms of randomness, either of the evolution in terms of the Schrodinger equation or its eigen functions or eigenvalues.

4.7 *Quantum Dance:

PRINCETON (US)—For years scientists have suspected that atoms placed in certain configurations would trigger electrons to perform a quantum dance of sorts. Now an international team of scientists has observed swarms of electrons spinning in a synchronized quantum dance within a new material. They are hopeful the discovery could be harnessed to transform computing and electronics.

4.8 Quantum Cloning: A clone is a 'perfect copy of something', and to clone something means 'to produce a perfect copy of it'. Imagine taking a picture of a famous oil painting, says the Mona Lisa, using a camera of the highest quality, then printing it on paper, also using a printer of the highest quality. Would this result in a perfect copy of the original artwork by Leonardo da Vinci? Obviously not.

4.8.1 Wikipedia [51]: Quantum cloning is a process that takes an arbitrary, unknown quantum state and makes an exact copy without altering the original state in any way. Quantum cloning is forbidden by the laws of quantum mechanics as shown by the 'no cloning theorem', which states that

there is no operation for cloning any arbitrary state $\Psi >_A$ perfectly. In Dirac notation, the process of quantum cloning is described by:

$$U|\Psi >_A|e >_B = |\Psi >_A|e >_B$$

where U is the actual cloning operation, $\Psi >_A$ is the state to be cloned, and $e >_B$ is the initial state of the copy. Though perfect quantum cloning is not possible, it is possible to perform imperfect cloning, where the copies have a non-unit (i.e. non-perfect) fidelity. The possibility

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of approximate quantum computing was first addressed by Buzek and Hillery, and theoretical bounds were derived on the fidelity of cloned quantum states.

4.9 *Quantum Eraser Experiment: In quantum mechanics, the quantum eraser experiment is an interferometer experiment that demonstrates several fundamental aspects of quantum mechanics, including quantum entanglement and complementarity. The quantum eraser experiment is a variation of Thomas Young's classic double-slit experiment. It establishes that when action is taken to determine which of 2 slits a photon has passed through, the photon cannot interfere with itself. When a stream of photons is marked in this way, then the interference fringes characteristic of the Young experiment will not be seen. The experiment also creates situations in which a photon that has been "marked" to reveal through which slit it has passed can later be "unmarked." A photon that has been "marked" cannot interfere with itself and will not produce fringe patterns, but a photon that has been "marked" and then "unmarked" will interfere with itself and produce the fringes characteristic of Young's experiment.

4.10 *Quantum Dot (QD): Wikipedia[52] gives: Quantum dots (QDs) are semiconductor particles a few nanometres in size, having optical and electronic properties that differ from larger particles due to quantum mechanics. They are a central topic in nanotechnology. When the quantum dots are illuminated by UV light, an electron in the quantum dot can be excited to a state of higher energy. In the case of a semiconducting quantum dot, this process corresponds to the transition of an electron from the valence band to the conductance band. The excited electron can drop back into the valence band releasing its energy by the emission of light. This light emission (photoluminescence) is illustrated in the figure on the right. The color of that light depends on the energy difference between the conductance band and the valence band, or transition between discretized energy states when band structure is no longer a good definition in QDs.

4.11 *Quantum Group (QG): Wikipedia [53] gives: The term "quantum group" first appeared in the theory of quantum integrable systems, which was then formalized by Vladimir Drinfeld and Michio Jimbo as a particular class of Hopf algebra. The same term is also used for other Hopf algebras that deform or are close to classical Lie groups or Lie algebras, such as a "bicrossproduct" class of quantum groups introduced by Shahn Majid a little after the work of Drinfeld and Jimbo. In mathematics and theoretical physics, the term quantum group denotes one of a few different kinds of noncommutative algebras with additional structure. These include Drinfeld–Jimbo type quantum groups (which are quasitriangular Hopf algebras), compact matrix quantum groups (which are structures on unital separable C*-algebras), and bicrossproduct quantum groups.

4.12 *Quantum Hall Effect: This is a quantum mechanical version of the usual Hall effect The Hall coefficient, R_H is quantized and is given by $\frac{h}{e^2}$, where h is the Planck's constant and e the charge of the electron.

4.13 *Quantum Interferometry (QI): This is similar to interference in classical optics where light behaves as waves. According to the theory of matter waves, elementary particles such as electrons and neutrons also behave as waves and their interference pattern observed. This comes under Quantum Interferometry.

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4.14 *Quantum Well: Wikipedia [53] gives: The concept of quantum well was proposed in 1963 independently by Herbert Kroemer and by Zhores Alferov and R.F. Kazarinov.

A quantum well is a potential well with only discrete energy values. The classic model used to demonstrate a quantum well is to confine particles, which were initially free to move in three dimensions, to two dimensions, by forcing them to occupy a planar region. The effects of quantum confinement take place when the quantum well thickness becomes comparable to the de Broglie wavelength of the carriers (generally electrons and holes), leading to energy levels called "energy sub-bands", i.e., the carriers can only have discrete energy values.

4.15 *Quantum Wire: Oxford Reference [29] gives: A linear conductor that is narrow enough for quantum effects to affect the resistance. If the wire diameter is small then the electrons have quantized energy levels for motion perpendicular to the axis (as for a particle in a box). Consequently the resistance of the wire is also quantized. Carbon nanotubes have been investigated as practical implementations of quantum wires.

4.16*Quantum Phase: Quantum phase transitions
Focus issue [12-A]: Nature March 2008 Volume 4 No 3 pp167-204

Phase transitions are familiar occurrences, such as the freezing of water to ice. When the transition occurs at zero temperature, it is known as a 'quantum phase transition'. As distinct states of matter coexist at a transition, there are quantum fluctuations between them. This Focus explores the resulting – and often surprising – collective behavior.

4.17 *Quantum Zeno Effect: The quantum Zero effect is the inhibition of transitions between quantum states by frequent measurements of the state. The inhibition arises because the measurement causes a collapse (reduction) of the wave function. If the time between measurements is short enough, the wave function usually collapses back to the initial state.

The name is an allusion to a paradox given by the Greek philosopher Zeno of Elia (Born:495 BC) who argued that at every moment of time a moving arrow occupies a definite position and hence immobile in that position. There is also a Zeno effect and an Anti-Zeno effect predicted theoretically in 1977.

4.17.1 The quantum Zeno effect was originally presented in the 1977 paper "The Zeno's Paradox in Quantum Theory" (Journal of Mathematical Physics, PDF), written by Baidyanaith Misra and George Sudarshan.

Unstable quantum systems are predicted to exhibit a short-time deviation from the exponential decay law. ... Subsequently, it was predicted that measurements applied more slowly could also enhance decay rates, a phenomenon known as the quantum anti-Zeno effect.

4.18 *Quantum Confinement: Quantum Confinement is the spatial confinement of electron-hole pairs (excitons) in one or more dimensions within a material and also electronic energy levels are discrete. It is due to the confinement of the electronic wave function to the physical dimensions of the particles.

45.19 *Quantum Logic: Quantum Logic is a set of events that is closed under a countable disjunction of countably many mutually exclusive events.

4.19.1 Karl Svozil [20], Quantum Logic, a brief outline from Cornell University last revised 31 Jul 2005 mentions that Quantum logic has been introduced by Birkhoff and von Neumann as an attempt to base the logical primitives, the propositions and the relations and operations

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among them, on quantum theoretical entities, and thus on the related empirical evidence of the quantum world. Quantum logic has been proposed as the correct logic for propositional inference generally, most notably by the philosopher Hilary Putnam, at least at one point in his career.

4.20 *Quantum World: Stephen Onnes [41], an award-winning science and math writer whose work has appeared in Scientific American, Discover, New Scientist, on Earth, Physics World, and other outlets. September 14, 2017 mentions that

Quantum is the world of the super small. The subatomic bits of matter don't follow the same rules as objects that we can see, feel or hold. These entities are ghostly and strange. Sometimes, they behave like clumps of matter. Think of them as subatomic baseballs. They also can spread out as waves, like ripples on a pond.

We conclude by saying that "Everyday is a" 'Quantum Day' "If you're interested in the smallest things known to scientists, there's something you should know. They are extraordinarily ill-behaved. But that's to be expected. Their home is the quantum world.

The World Quantum Day is an initiative from quantum scientists from 65+ countries, launched on 14 April 2021 as the countdown towards the first global celebration on 14 April 2022

"There is no Quantum World. There is only an abstract quantum physical description. It is wrong to think that the task of Physics is to find out how Nature is.

4.21 *Quantum Universe DOE / NSF High Energy Physics Advisory Panel Quantum Universe Committee reportsd: * Quantum Universe presents the quest to explain the universe in terms of quantum physics, which governs the behavior of the microscopic, subatomic world. It describes a revolution in particle physics and a quantum leap in our understanding of the mystery and beauty of the universe.

What does "Quantum Universe" mean? To discover what the universe is made of and how it works is the challenge of particle physics. Quantum Universe presents the quest to explain the universe in terms of quantum physics, which governs the behavior of the microscopic, subatomic world. It describes a revolution in particle physics and a quantum leap in our understanding of the mystery and beauty of the universe.

4.22 *Quantum Superposition: Wikipedia[53] gives: The principle of quantum superposition states that if a physical system may be in one of many configurations—arrangements of particles or fields—then the most general state is a combination of all of these possibilities, where the amount in each configuration is specified by a complex number.

The general principle of superposition of quantum mechanics applies to the states [that are theoretically possible without mutual interference or contradiction of any one dynamical system. It requires us to assume that between these states there exist peculiar relationships such that whenever the system is definitely in one state we can consider it as being partly in each of two or more other states. The original state must be regarded as the result of a kind of superposition of the two or more new states, in a way that cannot be conceived on classical ideas. Any state may be considered as the result of a superposition of two or more other states, and indeed in an infinite number of ways. Conversely, any two or more states may be superposed to give a new state.

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4.23 *Quantum Rules: Kunal K. Das, Publisher Skyhorse Publishing [21] The Quantum Rules: Section: Physics/Chemistry. How the Laws of Physics Explain Love, Success, and Everyday Life . Date of Pub. 2015-07-21 gives:

4.23.1 The Quantum Rules apply the laws of physics to explain everything from relationships and human nature to the effects of globalization. It achieves the impossible task of making quantum physics deeply relevant to all readers? even those with no interest in science. With a lively and engaging tone.

4.24 *Quantum Laws: Britannica [4] gives: The laws of quantum mechanics
Within a few short years scientists developed a consistent theory of the atom that explained its fundamental structure and its interactions. Crucial to the development of the theory was new evidence indicating that light and matter have both wave and particle characteristics at the atomic and subatomic levels. Theoreticians had objected to the fact that Bohr had used an ad hoc hybrid of classical Newtonian dynamics for the orbits and some quantum postulates to arrive at the energy levels of atomic electrons. The new theory ignored the fact that electrons are particles and treated them as waves. By 1926 physicists had developed the laws of quantum mechanics, also called wave mechanics, to explain atomic and subatomic phenomena.

4.25 *Quantum Spin Liquid: A quantum mechanical system in which a large number of electron spins are coupled together to give distinct quantum system. Quantum spin liquids can be used to investigate aspects of many-body problems in quantum mechanics and have potentially important applications in technology.

4.26 *Quantum Simulation: University of Waterloo [46], Institute for Quantum Computing – Studying quantum systems – gives:

To understand large quantum systems, like complex molecules, we need to understand and model the quantum interactions between their components. To run computer simulations for these problems, we effectively need to teach our computer quantum mechanics, which is very difficult for computers to do.

If, instead, we simulate our quantum system using another quantum system as a simulator, one that is easier to control and study, we could learn about it more efficiently. This is because the quantum simulator doesn't need to "learn" quantum mechanics: it already works by the same rules!
Possible applications of quantum simulation include: Quantum systems for Medicine, Superconducting materials, Quantum for environment, spintronics or spin electronics, etc.

4.27 *Quantum Algebra: Cesar Augusto Guerra Gutierrez [6] of Wolfram Library Archive 2004-07-02 gives: Quantum Algebra is a package to perform Quantum Calculations using non commutative algebra. For this purpose we added Dirac notations for Bras, Kets, Brackets, and Commutators, were implemented together with proper definitions to perform non commutative "products" with them. The motivation for building this package was to perform long calculations that appear in Quantum Optics and Quantum theory. The basic ideas to build the package were inspired by Quantum Methods with Mathematica by J. Feagin and Creating New Notations in Mathematica by Jason Harris.

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4.28 *Quantum Key Distribution (QKD): The concept of quantum key distribution (QKD) was first proposed in the 1970s when Stephen Wiesner at Columbia University came up with the idea of quantum conjugate coding. Wiesner's paper was published in 1983. Years later, Charles H. Bennett introduced a concept of secure communication, basing his ideas on Wiesner's work. Bennett also came up with BB84 -- the first quantum cryptography protocol -- which worked using nonorthogonal states. Moreover, it was in 1990 that Artur Ekert discovered another method to QKD, basing his idea around quantum entanglement.. The idea was incredibly simple yet it still took until the 1990s, when the connection was made to entanglement, that physicists started to get really interested. Since then the progress has been remarkable and it is now perhaps the most mature quantum technology, being commercially available for over 15 years now.

The principle of QKD is illustrated below (Fig.37)

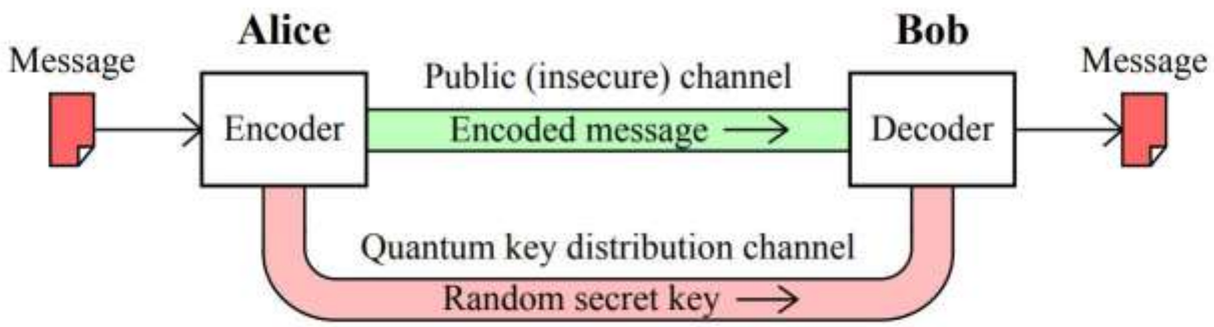

Fig. 37

4.28.1 Quantum Xchange [36] says: Quantum key distribution (QKD) is the only provably secure communication method because it uses physics – not math – to encrypt data.

According to 'Daily Updates in Science and Technology,

"When the photons arrive at the endpoint, the receiver uses beam splitters (horizontal/vertical and diagonal) to "read" the polarization of each photon. The receiver does not know which beam splitter to use for each photon and has to guess which one to use. After the receiver tells the sender which beam splitter was used for each of the photons in the sequence they were sent, the sender then compares that information with the sequence of polarizers used to send the photons. The photons that were read using the wrong beam splitter are discarded, and the resulting sequence of bits becomes a unique optical key that can be used to encrypt data."

4.29 *Quantum Communication: Quantum communication is a field of applied quantum physics closely related to quantum information processing and quantum teleportation. ... Both stations are linked together with a quantum channel and a classical channel. Alice generates a random stream of qubits that are sent over the quantum channel as explained below (Fig.38)

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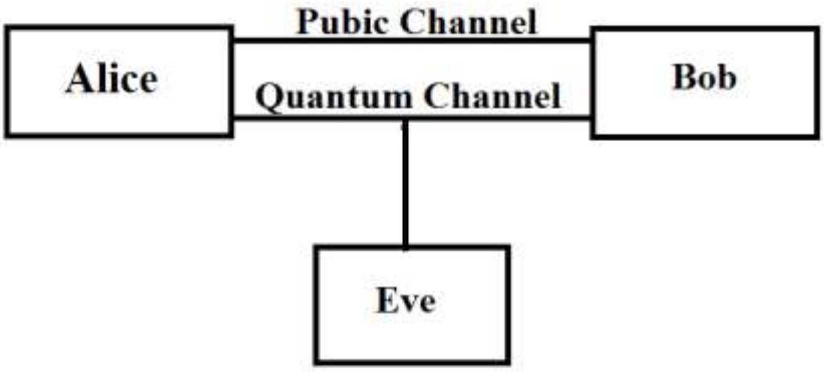

Fig. 38

4.30 Quantum Dynamics: Wikipedia[53] gives: In physics, quantum dynamics is the quantum version of classical dynamics. Quantum dynamics deals with the motions, and energy and momentum exchanges of systems whose behavior is governed by the laws of quantum mechanics. Quantum dynamics is relevant for burgeoning fields, such as quantum computing and atomic optics.

4.30.1 In mathematics, quantum dynamics is the study of the mathematics behind quantum mechanics. Specifically, as a study of *dynamics*, this field investigates how quantum mechanical observables change over time

4.31 *Quantum Displacement: In the quantum mechanics study of optical phase space, the displacement operator for one mode is the shift operator in quantum optics, , where is the amount of displacement in optical phase space, is the complex conjugate of that displacement, and and. are the lowering and raising operators, respectively.

4.32* Quantum Internet: Daphne Leprince-Ringuet, [10] Contributor on September 3, 2020 | Topic: Innovation
The quantum internet is a network that will let quantum devices exchange some information within an environment that harnesses the weird laws of quantum mechanics. In theory, this would lend the quantum internet unprecedented capabilities that are impossible to carry out with today's web applications.

4.33 *Quantum Network: Wikipedia [53] gives: Quantum networks form an important element of quantum computing and quantum communication systems. Quantum networks facilitate the transmission of information in the form of quantum bits, also called qubits, between physically separated quantum processors. A quantum processor is a small quantum computer being able to perform quantum logic gates on a certain number of qubits. Quantum networks work in a similar way to classical networks. The main difference is that quantum networking, like quantum computing, is better at solving certain problems, such as modeling quantum systems.

4.34 *Quantum Circuits: Dan C. Marinescu, Gabriela M. [9] in Classical and Quantum Information, 2012 – Quantum Circuits Preliminaries. Pub. By 'Direct'

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Quantum circuits are collections of *quantum gates* interconnected by *quantum wires.* The actual structure of a quantum circuit, the number and the types of gates, as well as the interconnection scheme are dictated by the unitary transformation, U, carried out by the circuit. In all descriptions of quantum circuits in addition to gates, one uses *quantum wires* that move qubits and allow us to *compose* more complex circuits from simpler ones that, in turn, are composed of quantum gates.. The quantum wires do not perform any transformations in a computational sense.

4.35 *Quantum Thermodynamics: Janet Anders, e.al. [16] Focus on quantum thermodynamics 2017 *New J. Phys.* 19 010201

Thermodynamics has been highly successful, impacting strongly on the natural sciences and enabling the development of technologies that have changed our lives, from fridges to jet planes. Until recently, it was applied to large systems described by the laws of classical physics. However, with modern technologies miniaturizing down to the nanoscale and into the quantum regime, testing the applicability of thermodynamics in this new realm has become an exciting technological challenge.

4.35.1 As a result the field of quantum thermodynamics has recently started to blossom, fueled by new, highly controlled quantum experiments, the availability of powerful numerical methods, and the development of novel theoretical tools, for instance in non-equilibrium thermodynamics and quantum information theory. Important goals of the field are, among others, (i) a better understanding of thermalization in quantum systems, (ii) the characterization of non-equilibrium fluctuations in the quantum regime, and (iii) the design and realization of new experiments exploring quantum thermodynamics using, for example, nuclear spins, cold atoms, trapped ions and opto-mechanic setups.

4.36 *Quantum Vacuum: Nair V.C.A. [26] Readers are advised to go through a Research Paper by the author and tiled, 'The Four Impossibilities in Physics', International Advanced Research Journal in Science, Engineering and Technology, Vol.7, Issue-10, Oct. 2020, 'IV Quantum Vacuum', p.46-56.

Jeremy Munday [18] is a professor in the department of electrical and computer engineering at the University of California, Davis. Says: One usually imagines a vacuum as empty space devoid of any matter. That picture isn't quite accurate when quantum mechanics is taken into account. Emptiness turns out to be an illusion: The real vacuum is full of activity in the form of quantum fluctuations—sometimes thought of as virtual particles that appear and disappear so quickly that they don't violate Heisenberg's uncertainty principle. Physics Today, 01 OCTOBER 2019 • page 74]

4.37 *Quantum Efficiency: Energypedia [12] gives: The "quantum efficiency" (Q.E.) is the ratio of the number of carriers collected by the solar cell to the number of photons of a given energy incident on the solar cell. The quantum efficiency may be given either as a function of wavelength or as energy. If all photons of a certain wavelength are absorbed and the resulting minority carriers are collected, then the quantum efficiency at that particular wavelength is unity. The quantum efficiency for photons with energy below the band gap is zero.

4.37.1 Teledyne Photometrics [45] –Inroduction to Quantum Efficiency gives: Quantum efficiency (QE) is the measure of the effectiveness of an imaging device to convert incident photons into electrons. For example, if a sensor had a QE of 100% and was exposed to 100 photons, it would produce 100 electrons of signal.

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In practice, sensors are never 100% efficient, and different sensor technologies have different QE values. The highest-end scientific cameras can achieve up to 95% QE but this is <u>dependent</u> on the wavelength of light being detected, as seen in figure.39.

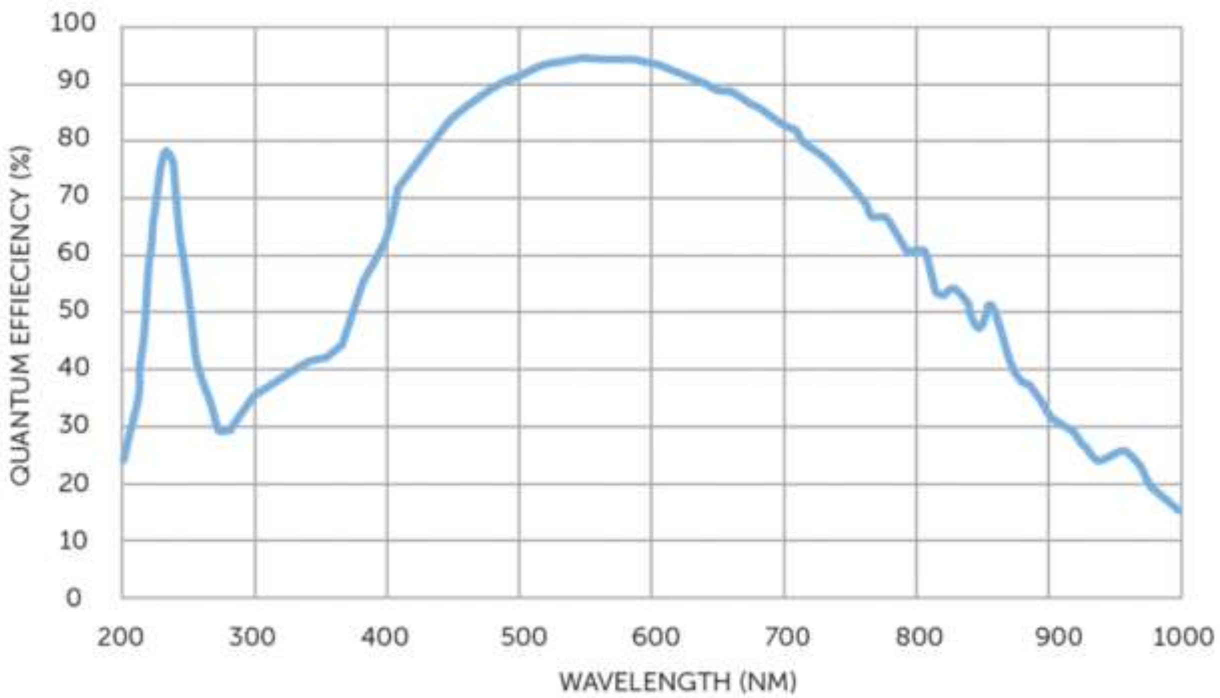

Fig. 39. The quantum efficiency (QE) of a 95% quantum efficient sensor at different photon wavelengths. 95% QE is possible at 500-600 nm wavelengths (green/yellow) but it is less efficient at shorter (violet, 300-400 nm) and longer (infrared, 800-1000 nm) wavelengths. This particular sensor also has a peak in QE at near-UV wavelengths, around 220-250 nm.

95% QE is possible at certain photon wavelengths but photons in the near-red and violet regions of the visible spectrum have a lower QE and therefore the scientific camera would be less sensitive. This is an especially important property when doing low-light imaging.

<u>4.38</u> *<u>Quantum Device</u>: M. Grundmann[13] in Encyclopedia of Condensed Matter Physics, 2005 in the Introduction gives:

A "quantum device" could be defined as a device whose functionality or principle of operation depends essentially on quantum mechanical effects. However, this definition somehow seems too vague. For example, a chair obtains its holding power from the quantum mechanical overlap of the wave functions of its constituents or a toaster relies on quantum mechanical scattering processes for converting electrical current into heat. Therefore a "quantum device" shall be defined here as a "man-made device that intentionally employs or harnesses quantum mechanical effects for its operation." This article is limited to condensed matter devices, thus completely (but intentionally) bypassing the "natural" use of quantum mechanics in living organisms.

<u>4.39</u> *<u>Quantum Magician</u>: Nair V.C.A [26-A] There is no such thing as 'Quantum Magician'. But, I have published a peculiar and interesting Research Paper titled, "Zero-Point Energy, $E_0 = \frac{1}{2} h\nu$, the Quantum Magician of Modern Physics", International Advanced Research

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Journal in Science, Engineering and Technology, Vol.8, Issue-2, Feb.. 2021, p.11-42 (32 pages). Readers are advised to read the entire paper to understand the significance.

4.40 *Quantum Geometrodynamics (QGD: Cornell University gives [8] Quantum geometrodynamics is canonical quantum gravity with the three-metric as the configuration variable. Its central equation is the Wheeler--DeWitt equation. Quantum geometrodynamics is a viable approach and provides insights into both the conceptual and technical aspects of quantum gravity.

4.41 *Quantum Cookery: John Gribbin [19, p. 307] 'Q for Quantum' gives: The use of quantum equations such as the Schrodinger, wave equation as recipes with which to solve problems involving quantum entities, without bothering to try to understand what is going on in the quantum realm and what the equation really mean.

V CONCLUSION

5.1 Coming to the title of the paper, I wish to highlight its inherent and hidden meaning to readers. A question which is also inherent in the title, "the Quantum, hν the right answer", is "to What question", it is the right answer?". My answer is, to "any and all questions solvable and unsolvable in the universe. Only one should know as to how the problem can be analyzed and fitted in the wave function ψ of the Schrodinger equation.

When I teach the topic of 'Electricity' to undergraduate students, a formal question was put to them. "What is Electricity?" I answer the question, by asking a counter question, "What is not Electricity?" As if everything is Electricity and It is true from the point of view of atomic structure of matter with electrons as moving charges around the nucleus constituting a current. Thus current of Electricity is everywhere. So readers, in this paper, I answered the question, "What is the 'Quantum?" The counter question here is, "What is not the "Quantum? and where is not the "Quantum"? The "Quantum" is present in the entire universe. The Zero-Point energy and the Quantum vacuum indicate that the entire universe is full of energy. Dark Matter, Dark Energy and so on. Readers!, I have compared the arrival of the Quantum theory from classical mechanics as a journey as a journey of Alice reaching a wonder land How do you like if I say, "It is all 'Quantum'!, 'Quantum'!!, 'Quantum'!!! everywhere. "We are all 'Alice in a Quantum Wonderland" (See Fig.40).

5.2 The Quantum and the Quantum Field: In sections 3.3 and 3.4 we have dealt with the Quantum Field and the Quantum Field Theory respectively. With the idea of mass-energy equivalence, the Quantum, hν is both energy and particle. It is a hypothetical particle called 'Photon' and what is important with any and every particle is its Field. It is the Field of the particle difficult to understand. Hence in Quantum Mechanics, one has to clearly understand the Quantum Field of the 'Quantum'.

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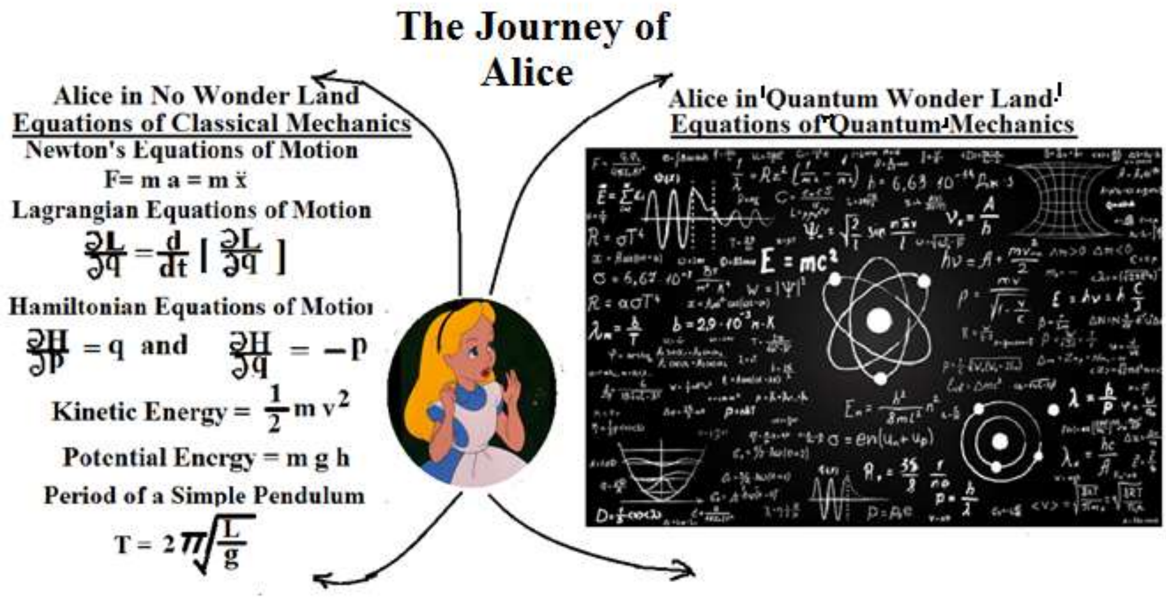

Fig.40 Alice looking at Quantum Wonder Land

I am both a physicist and a philosopher and I want to co-relate the 'Quantum' with the 'Philosophy'. The Physics of the Quantum has been extensively done in the paper. For the Philosophy of the Quantum, I would like the readers to go through the famous Indian epic 'Mahabharata' and focus their attention to the Bhagavad Gita verses recited to Arjuna@ by Lord Krishna# the incarnation of Lord Vishnu*. Readers may or may not believe in the Epic. The non-believers may take it as an imagination, but not as a 'Cock and Bull' Story. In Fig.41 is shown Lord Vishnu relaxing with imagination in the Quantum World and in Fig.43 is shown Lord Krishna, the ever known Quantum Physicist of the time reciting the Quantum verses to Arjuna.. There was no Planck, Schrodinger or Heisenberg. The Lord Krishna embodied as 'All in one' and the 'Only one in all' and as a great Quantum Physicist of the time recited the verses almost like the derivations out of the Schrodinger equation.

***A very small constant of action, h = 6.65 x 10^{-34} Js revolutionalized the entire world of Physics with a mega action much more than the Big Bang.**

***Lord Vishnu (The eternal preserver of the Universe)**
@An important character and disciple of Lord Krishna in the epic, Mahabharata
#Lord Krishna, the incarnation of Lord Vishnu and main character in Bhagavad Gita.

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Fig. 41 Lord Vishnu relaxing in the Quantum Universe (Ref. Krishna.co) [22]

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Fig. 42. Lord Krishna (botom left), he *Quantum Physicist of the Epic,* Mahabharatha reciting the Quantum verses to his disciple, Arjuna (bottom right) In the background at the top is the *"Vishwa Roopam",* the Quantum Universe. What revealed to Arjuna by the Lord were the

Quantum Verses not understood by the former for which the Lord had to show his real form of the Quantum Universe. There was no Heisenberg or Schrodinger in his times, but many things similar to the bombings of Hiroshima and Nagasaki were inherent in the verses of the Gita by the Lord. Picture Ref: Krishna.com [23]

VI ACKNOWLEDGEMENT

Being a peculiar paper, literature on the title of the paper is not freely available from the internet. Hence, I had to depend on "Google Search" in which 'Wikipedia' is a prominent source of information. I sincerely thank the Website, Wikipedia through Google. Sometimes, one has to use a Dictionary of Physics which has been rarely referred except for confirming what has been obtained from Google. Really It has been a herculean task to prepare a paper of this kind and I thank one and all authors quoted in the reference.

I also wish to acknowledge Mr. Shanmugasundaram B [39], the Chief Editor of IARJSET.com in permitting me to submit such a lengthy Paper, publishing and bringing out the copy at an earliest possible time.

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No.	Author/s	Title	Publication & Year	Remarks
1	N.F. Mott and I.N. Sneddon	Wave Mechanics and its Applications	Oxford and the Clarendon Press 1948	Book followed by author during the post-graduate studies
2	Ruark and Urey	Atoms, Molecules and Quanta	McGraw Hill Book Company Inc. 1930	Book followed by author during the graduate studies
3	Heisenberg	Quantum Theory	Dover Publications INC	A general reference book during graduate studies
4	J.K Roberts	Heat and Thermodynamics	Blackie and Son Limited 1943	A Classical Text Book followed in graduate studies
5	Michael Brooks Series Editor Simon Blackburn	The Big Questions Physics	Metro Books, New York 2011 Ed.	For Special Reading
6	Robert Andrews Millikan	The Electron	Phoenix Science Series, University of Chicago Press	For Special Reading
7	Kitty Ferguson	The Fire in the Equations	William B Eerdmans Publishing Company, Grand Rapids, Michigan 1994	For Special Reading
8	Max Born	The Restless Universe	Blackie & Son Limited 1935	For Special Reading
9	John Gribbin	'Q' is for Quantum	A Touchstone Book Published by Simon and Schuster	The Main Reference for the title
10	J.B. Rajam	Atomic Physics	S Chand & CO. 1958	The Main Reference for the title
11	David Bohm	Quantum Theory	Asia Publishing House 1960	For Special Reading
12	Leonard I Schiff	Quantum Mechanics	McGraw Hill Book Company INC. 1955	For General Reading
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			Inc. 1958	Reading
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