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Tracing the Roots of Dual Nature of Matter and Radiation in Science and Religion

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Abstract

Duality (dual nature) is a universal character of our life in this universe. There is an analogy of dual nature of radiation and matter in the domain of Indian Philosophy and Sikh religion, where the ultimate reality is revealed to exist in its dual nature as 'Sarguna and Nirguna Brahman'. The concept of dual nature of radiation has been in existence since the historical times but, it was Max Planck who introduced it on firm footing to explain the black body radiation spectrum. Louis-de-Broglie proposed the concept of dual nature of matter in 1924 in his doctoral thesis. It was established during investigations of photoelectric effect and compton effect. The real break-through in interpreting dual nature of matter and radiation may be ascribed to the advent of quantum mechanics. It was observed that in the microscopic world of particles, classical concepts of wave and particle fails to justify the experimental investigations; hence there is a need to invoke quantum concepts.

Keywords: *God particle (Higgs boson), Higgs field, vedanta philosophy, Guru Nanak's hypothesis, dual nature of matter/radiation, black body radiation, ultimate reality (God or Brahman), nirguna, sarguna, uncertainty principle, complementary principle, Max Planck's law, photoelectric effect*

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INTRODUCTION

It has been established that the duality (dual nature) is a universal character of our life in this universe. The discovery of Higgs boson (God particle) in 2012 has revealed a unique relationship between radiation and matter [1, 2]. Big bang model of the universe predicts the creation of enormous energy in the form of radiation consisting of mass-less photons, neutrinos, quarks and some other particles. Just after the big bang, the Higgs mechanism is responsible for assigning mass to the elementary particles in standard model.

According to the theory, the Higgs field switched on a trillionth of a second after the big bang blasted the universe into existence [3, 4]. Before this moment, all of the particles in the cosmos weighed nothing at all and zipped around chaotically at the speed of light. When the Higgs field switched on, some particles began to feel a "drag" as they moved around, as though caught in cosmic glue. The Higgs field gave them mass due to this drag, making them move around more slowly. This was a crucial moment in the formation of the universe, because it allowed particles to come together and form all the atoms and molecules around today. But, the Higgs field did not influence all the particles. Particles of light or photons move through the Higgs field as if it wasn't there. Because the field does not influence them, they remain weightless and destined to move around at the speed of light forever. The smallest constituents of atoms like quarks and electrons get trapped in the field and gain mass in the process. The field has an enormous implication. Without it, the smallest building blocks of matter, from which all else is made, would forever rush around at the speed of light. They would never come together to make stars, planets, or life as we know it. The field accounts for only one or two percent of the mass of more complex things like atoms, molecules and everyday objects we use. The vast majority of mass comes from the energy needed to hold quarks together inside the atoms.

If God particle is not there, the creation process will not advance further and there will be no life in the universe. Big bang created a

lot of energy but material particles are created by the intervention of Higgs field and Higgs boson. According to Einstein's famous equation, $E=mc^2$, the energy and matter are equivalent and inter-convertible. It is evident that dual nature or concept of duality existed in the primordial state of the universe.

Surprisingly, in the beginning of 11^{th} century, Alhazen, the Arab scientist wrote the first comprehensive treatise on optics describing reflection, refraction and transmission of light from its source to the eye as composed of light particles. After 1670, Issac Newton championed his corpuscular theory of light to explain the reflection and refraction phenomena on an assumption that only particles can travel in straight lines as was evident during his investigations. However, the Newton's contemporaries, Robert Hooke and Christian Huygens, rejected Newton's corpuscular hypothesis and forwarded wave theory of light firmly on mathematical basis to explain not only reflection and refraction but also interference and diffraction phenomena of light. Corpuscular theory of light was given a burial for almost two centuries until Max Planck came to its rescue towards the end of nineteenth century by proposing his quantum hypothesis to explain black body radiation spectrum.

The real breakthrough in interpreting dual nature of matter and radiation may be ascribed to the advent of quantum mechanics. It was observed that in the microscopic world of particles, classical concepts of wave and particle fail to justify the experimental investigations; hence there is a need to invoke quantum concepts.

Niels Bohr and Werner Heisenberg captured the dual wave-particle nature of light in the form of two fundamental principles in physics that the complementarity principle and the uncertainty principle, respectively [5]. According to Bohr's complementarity principle, the wave and the particle nature of light complement rather than contradict each other. Heisenberg's uncertainty principle asserts that it is not possible for us to view both the particle and the wave nature of light simultaneously with certainty.

Werner Heisenberg (L) and Niels Bohr (R)

It is obvious from Copenhagen interpretation of quantum mechanics that this paradox of wave-particle duality is a fundamental property of our universe. Both theoretical predictions and experimental investigations led by Albert Einstein, Niels Bohr, Heisenberg, Louis de Broglie, Arthur Compton, Davisson and Germer and many others proved that all particles (including atoms and molecules) have wave nature and vice-versa.

CONCEPT OF DUAL NATURE OF ULTIMATE REALITY (GOD OR BRAHMAN)

J.B. Rajam [6] commented on enigma of dual nature of matter and radiation in a philosophical manner: *"Reality, whether matter or radiation, is made up of a subtle and almost indefinable fusion of two antagonistic but complementary factors, the continuous wave and the discontinuous particle; it is a discontinuous continuity or a continuous discontinuity and hence not a simple but complex unity!"* This complex unity is seen in myriad examples in nature. Eye is an excellent example that demonstrates this complex unity. In an eye the gathering and focusing of light is understood in terms of waves and the absorption of light by rods and cones is understood in terms of photons. Similarly in laser, light is treated as waves in achieving amplification and as photons in achieving stimulated emission [7].

It looks strange that there is an analogy of dual nature of radiation and matter in the domain of Indian philosophy or eastern religions, where ultimate reality is revealed to exist in its dual

nature. As early as the vedic times, the Rishis investigated the nature of reality from two levels of experience, one of which may be called the absolute, acosmic or transcendental level and the other relative, cosmic or phenomenal level. At the phenomenal level, one perceives the universe of diversity and is aware of one's own individual ego, whereas at the transcendental level, the differences merge into an inexplicable non-dual consciousness. Both of these levels of experiences are real from their respective standpoints, though both levels may be incompatible with each other.

Reality experienced at the transcendental level is of higher quality and called *Brahman* [8]. This term denotes the non-dual *Pure Consciousness* which pervades the universe yet remains outside it. (Just as the sun pervades all life on earth yet remains outside it). *Brahman* is described as the first principle; from it all things are derived, by it all are supported, and into it all finally disappear. In Brahman alone, the apparent differences of the phenomenal world are unified. *Brahman* is identical with the self of man, known as *Atman*. The word *Atman* signifies the consciousness in man which experiences gross objects during the waking state, subtle objects during the dream state and the bliss arising from absence of the duality of subject and object in dreamless sleep [8].

The Upanishads speak of the transcendental *Brahman* as devoid of qualifying attributes or indicative marks, and of the phenomenal *Brahman* as endowed with them. The attributes less Brahman is called the supreme or unconditioned *Brahman*, and the other the inferior or conditioned *Brahman*. Vedanta philosophy often uses the word *Maya* to describe the creation. *Maya*, which is not essentially different from *Brahman*, is the material cause, and *Brahman* as pure intelligence, is the efficient cause of the universe. After projecting all material forms, *Brahman* enters into them as life and consciousness and animates them. Thus *Brahman*, which is transcendental, becomes immanent in the universe.

In Sikh religion, Guru Nanak's hypothesis [9, 10] about nature of reality is also based on dual nature, namely, *nirguna* and *sarguna Brahman*. The *nirguna* state represents the pure consciousness or transcendental nature of reality while *sarguna* state represents the phenomenal or physical aspect of reality. It is clearly stated in Gurbani that God exists in both *nirgun* (transcendent) and *sargun* (immanent) states simultaneously. During pre-creation, God is in *nirgun* state, aka *sünya* state, which is devoid of matter but not of energy. The Sikh philosophy dialectically unites these two aspects of reality. Transcendence shows that God is prior to and distinct from the world. Immanence of God represents God's connection with the world. God himself transforms into creation i.e., changing his *nirguna* form into *sarguna* form [11]:

sargun nirgun nirankaar sunn samaaDhee aap
aapan kee-aa naankaa aapay hee fir jaap.
The Formless is attributed and un-attributed;
And gone into absorption in the cosmic void;
Saith Nanak: He has made creation, himself on it meditates.
(SGGS, M. 5, P. 290)

In a similar vein, Guru Arjun [12] also refers to these two states of ultimate reality. He confirms the hypothesis of Guru Nanak by his own assertion that the formless reality (God) in the *nirguna* state assumes the form (*sarguna*state) at his own will:

Nirankaar aakaar aap nirgun sargun ayk
He himself is formless and also formed;
The one lord is without attributes and also with attributes.
(SGGS, M. 5, p. 250)

In Gurbani, God is referred to exist in two phases: subtle (*sukham*) and solid (*asthool*). These phases are compatible with *nirgun* and *sargun* states of God. Guru Arjun illustrates this characteristic of God in his beautiful hymns recorded in Gurbani [13, 14]:

Naanak so sookham so-eeasthool.
O Nanak, he is the subtle, and he is also the manifest.
(SGGS, M.5, p. 281)

Rav rahi-aa sarbat thaa-ee sookhmo asthool.
He is the source of life. He is all-pervading, permeating all places.
He is in subtle essence and manifest form.

(SGGS, M.5, p.987)

CONCEPT OF DUAL NATURE OF RADIATION

Radiation is the emission or transmission of energy in the form of waves or particles through space or through a material medium. This includes:

- electro-magnetic radiation such as radio waves, visible light, x-rays, and gamma radiation (γ)
- acoustic radiation such as ultrasound, sound and seismic waves (dependent on a physical transmission medium)

The wave theory was successful and held its sway for over two centuries in investigating radiation related effects in case of sound, light and heat radiations. Historically, one of the earliest experiments that indicated that something was wrong with the wave theory was the study of what is known as *blackbody radiation*. The laws of black body radiation, namely Rayleigh-Jeans and Wien's were found to hold good in their different domains of frequency but they failed to explain radiation spectra over full frequency range. Hence, a need arose for formulation of a comprehensive law to explain black body spectra over all ranges.

In 1896, assuming the wave nature of light and using general thermodynamic principles, Wien made one of the first greatest attempts to explain the spectrum of blackbody radiation. His predictions were in an agreement for lower wavelengths but broke down for longer wavelengths. In 1900, Rayleigh and Jeans advanced a theory which agreed with experimental results for higher wavelengths. But, their theory predicted infinite intensity for low wavelength radiation ($\lambda \rightarrow 0$). This failure of Rayleigh-Jeans theory is often described as the *ultraviolet catastrophe*. The black body spectrum observed by Lumer and Pringsheim in 1900 is shown in Figure 1 [6].

It shows limitations of Rayleigh-Jeans and Wien's Law and validity of Planck's Law over full spectral range. Calculating the black-body spectral curve was a major challenge in theoretical physics during the late nineteenth century. The problem was solved in 1900 by Max Planck in the formalism now known as Planck's law of blackbody radiation. By making changes to Wien's radiation law (not to be confused with Wien's displacement law) consistent with thermodynamics and electromagnetism, he found a mathematical expression fitting the experimental data satisfactorily. Planck had to assume that the energy of the oscillators in the cavity was quantized i.e., it existed in integer multiples of some quantity. Einstein built on this idea and proposed the quantization of electromagnetic radiation itself in 1905 to explain the photoelectric effect.

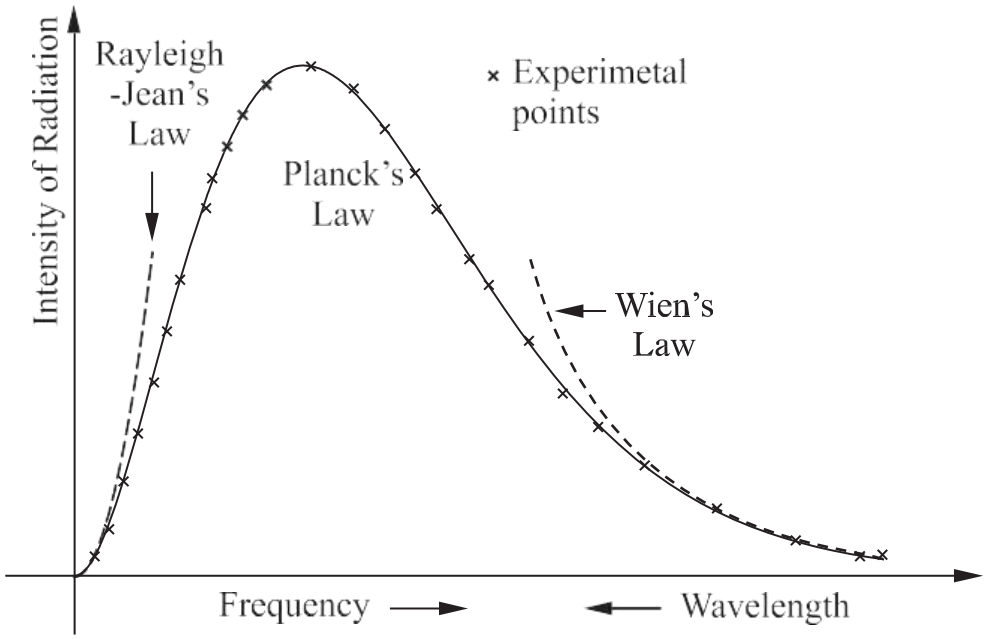

Fig. 1: *Comparison of Experiment with Theory in Blackbody Radiation.*

Max Planck (1900) successfully explained blackbody radiation and derived the following equation [15, 16] to accurately describe the experimental results (refer to Figure 2):

$d\rho(\nu,T) = 8\pi h/c^3 (\nu^3 d\nu/e^{h\nu/\kappa_B T} - 1)$

where, $d\rho(\nu,T)$, radiant energy density is the radiant energy per unit volume; h is the Planck constant; c is the speed of light in a vacuum; κ_B is the Boltzmann constant; ν is the frequency of an electromagnetic radiation and T is the absolute temperature of the body. Planck was able to derive this formula by assuming that the energies of the oscillators were quantized (i.e., $E = nh\nu$). Planck's quantization of energy was a revolutionary assumption that marked the beginning of a new field of quantum physics. Prominent among the experiments that supported Planck's quantum theory of radiation were the photoelectric effect, compton effect and line spectra.

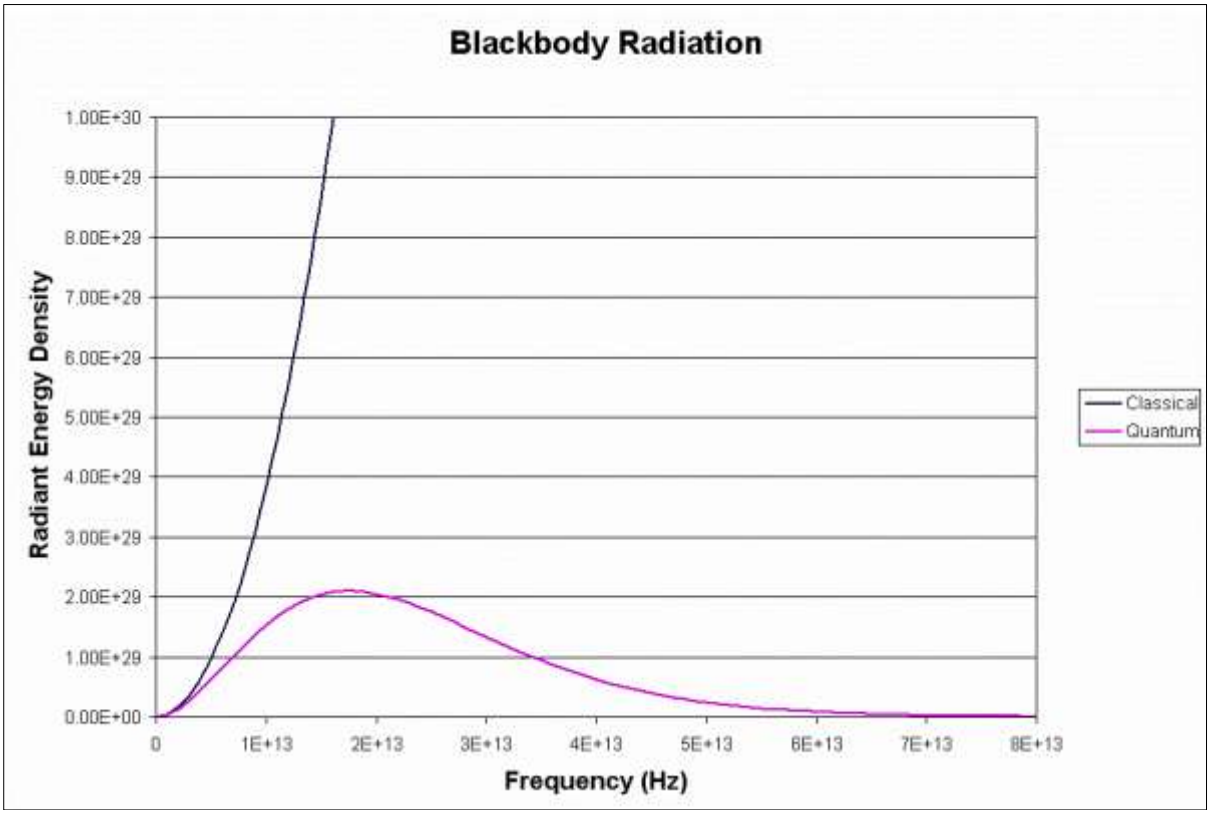

Fig. 2: *A Comparison of the Classical and the Quantum Models of Blackbody Radiation.*

The quantum model explains experimental values at all ranges of frequencies whereas the classical model fails at high frequencies. Classical model and quantum models agree at very low frequencies.

Photoelectric Effect

Quantum Physics approach was used to explain the experimental results of the photoelectric effect [17], which is simply ejection of electrons from a metal surface when light beam falls on it. Classical physics describes light as a wave with a set frequency and amplitude where the amplitude is related to the intensity. The classical explanation was that the metal's electrons would oscillate with the light and eventually break away from the surface with a kinetic energy that would depend upon the intensity of the incident radiation. However, the experimental observations show that the kinetic energy of the ejected electrons is independent of the intensity of the radiation. In fact, no electrons were ejected, no matter how intense the incident radiation was, if frequency of light beam is lower than a given threshold frequency for that metal. Planck's concept of quantized energy was used by Einstein in a modified form to describe the experimental results of photoelectric effect. Einstein

proposed that light could travel in small quantized packets of energy (photons) instead of strictly behaving as a classical wave. Einstein showed that the kinetic energy of the ejected electrons was equal to the energy of the incident photon minus the energy barrier (known as work function ϕ) to releasing an electron from that particular metal. This interpretation is described by the following equation:

$KE=1/2\ mv^2 = h\nu-\phi$

Thus, Einstein model was able to fully account for the experimental results including the lack of dependence of the energy of the ejected photons on the intensity of the incident radiation. The failure of some frequencies of light to eject any photons from the metal surface is based on the fact that the incident photons have energy less than the work function of the metal.

Photoelectric effect was used by Einstein to experimentally determine the value of Planck constant h, which proved to be the same as determined by Planck. This gave credence to the idea of quantized energy and quantum physics as a whole, which was still viewed with suspicion by many scientists including Einstein.

CONCEPT OF DUAL NATURE OF MATTER

Louis de Broglie who was a student of history in University of Sorbonne at Paris was motivated to study physics by his elder brother Maurice de Broglie, who was a physicist in the same university. Louis de Broglie was haunted by a thought that if light, which had been assumed to be a wave for the last two centuries can be assumed to be a particle, then why cannot matter which had hitherto been seen as a particle be assumed to have wave nature? Taking a cue from the inherent symmetry and simplicity of nature, de Broglie extended the idea of wave-particle dualism to matter. He proposed a revolutionary idea of `matter waves' in 1924 in his doctoral thesis. The idea was so unique that his examiners were almost reluctant to accept his hypothesis.

The experimental proof for the existence of matter waves was provided almost accidentally by Davisson and Germer of USA in 1927. Along with GP Thomson of Scotland they demonstrated the wave nature of electrons through diffraction experiments. De Broglie was awarded the nobel prize in 1929 after his theory was experimentally validated by these scientists. The wave character of many other particles, including protons, neutrons and some molecules has been studied in great detail since de Broglie's discovery. Using de Broglie's ideas, Erwin Schrodinger developed Wave Mechanics, the theory which explains the phenomena in the microscopic world.

The wave description of a particle was not a simple problem because a wave spreads, whereas a particle is localized in space. In 1927, Werner Heisenberg, a German theoretical physicist, gave deeper thought to these problems and enunciated one of the most fundamental principles in physics known as the `Uncertainty Principle'. Heisenberg's principle uses the concept of a wave packet, rather than a simple wave to describe a particle. Heisenberg's principle asserts that it is not possible for us to view both the particle and wave nature of radiation (or matter) simultaneously with arbitrary accuracy. The experiments that bring out the particle character suppress the wave character and vice versa. Which of the two facets (particle or wave) is revealed to the experimentalist is determined by the experiment itself.

End Note

The riddle of dual nature of matter and radiation continues to attract comments of eminent scientists. They are not yet fully convinced about the real nature of light or electrons. We give their opinions as follows. In 1917, Albert Einstein observed [18], *"For the rest of my life, I will reflect on what light is."*Again in 1951, he remarked [19], *"All the fifty years of conscious brooding have brought me no closer to the answer to the question, 'What are light quanta?' Of course today every rascal thinks he knows the answer, but he is deluding himself."* Light defies its mental picturing as a wave or a particle and physicists also tell us that light is neither a wave nor a particle. Modern theory describes light in an abstract way which cannot be connected with everyday experience; it's not quite like anything we can lay our hands on. Feynmann remarked [20]: *"Newton thought that light was*

made up of particles, but then it was discovered that it behaves like a wave. Later, however, it was found that light did indeed sometimes behave as a particle. Historically, the electron, for example, was thought to behave like a particle, and then it was found that in many respects, it behaved like a wave. So, it really behaves like neither. Now, we have given up. We say: "It is like neither".

Some famous physicist remarked cynically that on Mondays, Wednesdays, and Fridays, one uses the quantum theory, and on Tuesdays, Thursdays and Saturdays the wave theory [21]. What about Sunday? No one knows the answer.

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