Maxwell's Equation, Wave-Particle Enigma and Heisenberg's Uncertainty Principle Interrelated to find an Unambiguous Description of Electromagnetic Radiation

Bijon Kumar Sen*

Department of Chemistry, University of Calcutta, Kolkata, INDIA

Abstract

Electromagnetic radiation posed a problem to the scientists for more than three centuries in that it exhibited particle and wave property at the same time. Sir Isaac Newton's corpuscular theory reigned supreme for more than a century but later wave theory gained momentum and a heavy tussle prevailed with no conclusive verdict for either approach. At last as a compromise it was accepted that both the descriptions are acceptable but unambiguous solution of the problem of duality remained allusive. Wave property being the root for uncertainty, the principle of Heisenberg squarely blamed the microscopic inadequacy as a root cause although wave properties of the radiation may also be the cause of uncertainty. De Broglie intervened with his matter waves to account for the wave-particle duality and invoked quantum and wave mechanics to solve the dilemma. This was an imposed description which delayed the unambiguous solution for about a century.

It was the brilliant proposal of Maxwell's equations which on analysis unveiled the enigma of wave-particle duality of electromagnetic radiation. These radiations are not of single component but actually two components exist simultaneously which are not interconvertible. One is guided by quantum mechanics and the other by wave mechanics. While the wave character may make up for 100% of the rays, the particle part due to its quantum nature is not able to contribute to make it 100%. This bi-component model of electromagnetic radiation is able to explain the occurrence of different phenomena like Red Shift, Tunnel Effect, Photoelectric Effect, magnetic properties, electron spin etc., in an unambiguous manner without contradicting any of the accepted theories of electromagnetic radiation.

Key words: Maxwell's Equations, Heisenberg's Uncertainty principle, Wave-particle duality, Electromagnetic Radiation

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*Retired, Address for correspondence DD - 114, Street no. 269, Action Area I, Newtown, Kolkata 700156, INDIA, E-mail: bk_sen@yahoo.com

Introduction

The famous British theoretical physicist James Clark Maxwell [1,2] who correctly predicted the distribution of molecular velocities at different temperatures, came out with another significant discovery that light waves are certainly electrical and magnetic in nature. Michael Faraday [3] observed that glass which does not polarize rays transmitted through it becomes slightly polarized when placed in a strong magnetic field. In 1965, Maxwell formulated equations which related electrical charge, magnetism and light rays. This has been discussed in an earlier communication [4] from which the following results are obtained.

1) While magnetic and electric charges are transverse, the light rays move in a longitudinal direction.
2) Light rays need no 'ether' or electrons or field and can move through vacuum, while electrons are waves and require a medium for transmission.
3) Maxwell's equation which was proposed some 60 years earlier, on analysis, shows the difference between wave and particle (Q) mechanics.
4) In Heisenberg's uncertainty principle wave properties were also responsible for the uncertainty which arises in addition to microscopic inadequacy.
5) It contains the roots of the solution of the enigma of wave-particle duality.

Starting from the time of Sir Issa Newton's proposal that electromagnetic radiation is corpuscular in nature, a long-drawn centuries old controversy about its actual nature resulted from the proposition of wave theory which continued up to the present time. It has been found that in some experiments, electromagnetic radiation behaves as a particle while in some other experiments its wave nature predominates. Ultimately, a temporary compromise was accepted in which the radiation exhibited its dual nature as wave and particle though the mechanism remained bizarre.

Heisenberg's uncertainty principle

In describing the microscopic world, one cannot use a concept of classical mechanics in that the exact values of the coordinates of the particle and its velocity cannot be simultaneously determined. Heisenberg's uncertainty relation ascribes that a particle cannot have simultaneously a definite coordinate and a definite momentum. This can be expressed in the form of an inequality $\Delta x.\ \Delta p_x \geq h$.

At that time the radiation was considered to be of single component for which Heisenberg in his uncertainty principle squarely blamed the inadequacy of the microscopic system for the inability of simultaneous determination of the position and its velocity of an electromagnetic radiation.

The x component of the error = $\Delta x \sim \lambda/\sin \alpha$

To make the error as small as possible, light of very short wavelength (X-ray or γ-ray) should be used. However, this produces Compton recoil of the γ-ray scattering by the electron and the resultant momentum will be of the order of the magnitude $p = h/\lambda$. The uncertainty of the x component of the momentum of the electron is given by $\Delta x.\ \Delta p_x \sim h \sin \alpha/\lambda$. The product of the error of position and momentum is equal to $\Delta x.\ \Delta p_{x} = \lambda/\sin \alpha \times h \sin \alpha/\lambda \sim h$.

This description is crucial for 100% single component radiation like photon (rest mass m = 0) or electron (wave property only) for which the uncertainty must result from Heisenberg's uncertainty principle.

But as the rays are shown to be bi-component [4] the electromagnetic radiation will include various degree of wave property which will hinder the determination of position and momentum producing uncertainty irrespective of the failure of microscopic arrangement. Thus, uncertainty of determination is hidden in the description of the radiation itself with little exception. Uncertainty is a property which depend on the wave part.

Light rays are such that they show particle and wave properties as exhibited in different experiments for centuries together. Whether a particle or it is a wave was not properly known. It is not true that sometimes it is a particle and in sometimes it is a wave. The wave and particle properties are not inter-convertible. They exist simultaneously as shown by the analysis of Maxwell's equation. Electromagnetic radiations are a combination of two independent identities, a wave description guided by wave mechanics and the other a particle description guided by particle (quantum) mechanics. They are complementary in only one direction (Fig. I).

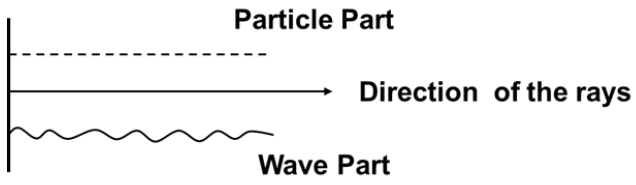

Fig. I: Wave and particle component of Electromagnetic Radiation

To make up 100% of light with wave and particle contribution an analogy may be considered. While building up of a wall with bricks and mortars, any amount of mortar may be added to make it 100% but with a certain quantity of mortar 100% cannot be made up with bricks which cannot be broken up because they are quantum in nature. Thus, wave is complementary to particle but not the other way around.

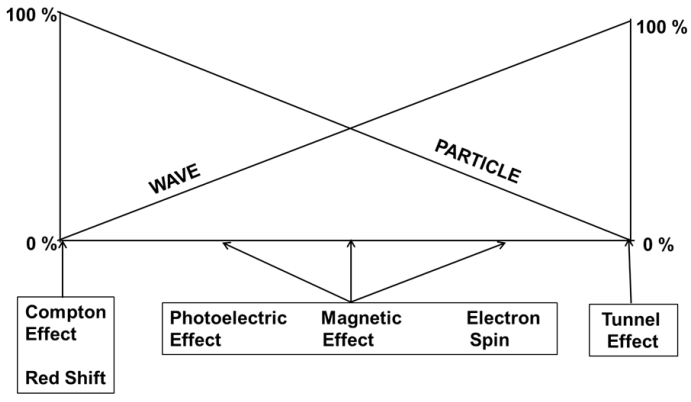

Fig. II. Schematic presentation of the contribution of wave-particle properties in different phenomena

Table 1: Contribution of wave and particle components to make up 100% of electromagnetic radiation in some typical phenomenon

Wave	Phenomenon	Particle
No contribution from wave property	Compton effect	Almost fully contributed by particle property
No contribution from wave property	Red Shift	Almost fully contributed by particle property
Wave part is responsible for the frequency which regulates the magnitude of the current	Photoelectric effect	The particle part is responsible for increasing value of the emission of the electrons
Wave part directs the attraction of magnetic material to the magnet and is active at comparatively short distance	Magnetic property	Particle pat is responsible for the long-distance celestial property of directing the compass needle.
The derivation of quantum numbers n, l, m for the electrons as a result of wave properties	Electron Spin	Particle part of the radiation is responsible for the quantum contribution to the addition of vectors to explain hyperfine splitting of Hydrogen spectrum.
Almost completely contributed by wave properties of electrons,	Tunnel Effect	Almost no contribution form particle properties

This distribution is schematically shown in Figure II.

De Broglie's proposal

An on-stage magician shows the dissection of a girl into two halves inside a wooden box by an electrically driven chainsaw to the horror of innocent spectators. Those in knowledge know that the trick lies in the fact that actually two girls are employed to bluff the viewers. Similarly, bi-component electromagnetic radiations are responsible for the century old

dilemma about particle and wave. Nature plays like a perfect magician as she could make as many sections of the objects as she likes while the on-stage magician can cut an object in two halves only.

Nature's magical influence was aided by the ideas of De Broglie who tried to find a theoretical (mathematical) justification to explain the duality of electromagnetic radiation by invoking quantum/wave mechanical ideas. Electromagnetic field can be concentrated within a small space if a large number of waves are used (wave packets or wave trains). A wave train is characterized by an interval of wave numbers Δk_x required to concentrate the field in a region Δx.

The corpuscular properties of wave motion are expressed in energy of the wave with frequency ω being equal to an integral multiple 'n' of quanta ($E = n\hbar\omega$) and the momentum **p** of the wave being equal to $n\hbar\mathbf{k_x}$.

There exists a formula in wave optics of the form $\Delta x.\ \Delta k_x \geq 1$ (where Δk_x is the wave vector)

Heisenberg's uncertainty principle leads to an equation $\Delta x.\ \Delta k_x \geq h$.

The left hand part of both the equations show uncertainty in position from which De Broglie proposed that the right hand part of the equations can be unified if it i*s assumed to be* equal to $h\ \Delta k_x$ whence a relation is obtained as $\mathbf{p} = \hbar\mathbf{k_x}$ where **p** is the momentum in units of $n\hbar\mathbf{k_x}$. In this way both particle and wave properties may be shown to coexist with the help of quantum/wave mechanics and thus the longstanding wave-particle dilemma could be resolved.

Even Einstein [5] appreciated De Broglie's idea in his foreword of De Broglie's book "*Physics and Microphysics*" as he was the first to realize the connection between quantum states and resonance phenomena. But in reality, this was a blunderful attempt of De Broglie which misguided the scientists to believe that wave and particle properties are the manifestation

of simultaneous occurrence in electromagnetic radiation. This idea lasted for about a century. It was overlooked that no mechanics (be it classical, quantum or wave) has anything to do with the philosophical aspect of any phenomenon. This aspect is derived from rigorous experiments, careful observations and acute hairsplitting diagnosis covering all known facts and predicting new ground to be probed.

Conclusion derived from Maxwell's equation

It is shown that electromagnetic radiation is not a single component entity but it consists of two components. These are born as twins having their own characteristics and are no way interconvertible. One is particle in nature (guided by Q mechanics) and the other is wave in nature (guided by wave mechanical principles). They are complementary in only one direction which is that wave can be combined into particle property but not in the other way around. The effect of the wave properties extend to a comparatively short range when a particle property extends in long range and thus guides the effect of different phenomena. This bi-component form of radiation is contributed to 100% but the extent of contribution is guided by the fact that wave property may contribute to make up to 100% but the corpuscular part due to its quantum nature, cannot make up to 100%.

It is also shown that the wave property which is the basis of the uncertainty principle in the determination of position and momentum simultaneously is not only due to a deficiency of microscopic apparatus but also the root of the uncertainty is hidden in the radiation itself which is mostly contributed by the wave property.

The idea that electromagnetic radiation is enigmatic is completely wrong and all the phenomena involving electromagnetic radiation like Red Shift, Tunnel Effect, Photoelectric Effect, magnetic effect, spin etc can be satisfactorily explained without any mathematical idea like quantum or wave mechanics.

This also draws the fine line of demarcation between quantum and wave mechanics in that the former is free from Doppler Effect while the latter being wavy in properties depends on the medium and thereby subjected to Doppler Effect.

Thus, the bi-component description of electromagnetic radiation explains the duality/enigma/dilemma in a way which does not contradict any accepted principle and may be considered as unambiguous.

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