# Resolution of Wave and Particle Nature of Electro-magnetic Radiations from Maxwell's Theory

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**Abstract:**

The implications of Maxwell's theory that combine magnetic, electrical and optical properties of electromagnetic radiations were not understood properly at the time of its inception. It is shown here that mathematical restriction helps to resolve this centuries-old controversy about wave-particle duality of electromagnetic radiation. This goes against the usually accepted notion that particles have wave properties and vice versa. The distinguishing feature lies in the fact that particle motion requires no medium and is thus free from Doppler effect. On the other hand, the wave motion depends on the medium of propagation and is, therefore, affected by Doppler effect. The particle motion is guided by particle (quantum) mechanics and the wave motion is guided by wave mechanics.

The particle description of electromagnetic radiation was advanced by Einstein in proving the constancy of the velocity of light which is independent of the medium and the perception of simultaneity of events in different inertial frames. On the contrary, the wave mechanical approach was used by the adversaries of Einstein's idea who pleaded for the spatial and temporal description as the result of Doppler effect. The arguments of both the sides are equally valid as the same problem was examined from opposite angles.

The ideas of Red Shift, Tunnel effect, Photoelectric effect and Magnetic forces are examined considering above viewpoints. The Red Shift conforms to the ideas of particle (Q) mechanics while the Tunnel effect can be interpreted in terms of wave mechanical perception. Photoelectric effect and magnetic forces are contributed by both wave and particle mechanics. The idea of electron spin, however, remains bizarre even around the centenary celebration year of wave and quantum mechanics.

*Key words: Distinction of Wave and Particle (Q) mechanics, Wave Particle duality, Red Shift, Tunnel Effect, Photoelectric effect, Magnetic forces, Electron Spin.*

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**Introduction:**

More than 60 years before the development of quantum mechanics by Max Born [1], Heisenberg [2] and Schrödinger [3,4], Maxwell [5] derived the properties of electromagnetic radiations from purely physical properties of wave motion. This was done from the consideration of oscillating electric and magnetic fields without involving any optical properties. Not that all the consequences of Maxwell's proposals were fully understood at that time, it is now quite easy to derive most of the properties of light quanta (photon) from analysis of his brilliant proposals without any help of quantum or wave mechanics. Maxwell's theory is utilized in resolving the longstanding debate on wave properties of particles and particle properties of waves.

When the electrical field of a distribution of charges at rest and the magnetic field of a steady current in a conductor do not vary with time, they do not interfere each other and may be treated individually. But when the fields vary with time they cannot be treated independently. A time varying magnetic field acts as a source of electric field (Faraday's Law). Similarly, changing electric field acts as a source of a magnetic field (Ampere's Law). Thus, when either field is changing with time, the other kind of field is induced in space producing electromagnetic disturbance which can travel through space even in the absence of any matter in the intervening region. This is the mechanism by which sun's rays transport energy through space.

At the beginning of the 19th century, different units of electric charges, one for electrostatic and the other for magnetism involving current were employed. But the bewildering fact for scientists was that their ratio shows dimension of velocity and the magnitude of the ratio was a constant which corresponded to the velocity of light ($3 \times 10^8$ m/sec). It was Maxwell [5] who proved theoretically that electrical disturbances are wave motion and they propagate in space with the velocity of light. The exact value of the velocity of light ($2.99792460 \times 10^8$

m/s) was calculated from two perpendicularly oscillating transverse waves, one from electric and the other from magnetic field.

**Particle versus Wave nature of light:**

The actual nature of light became the controversial concept in classical physics. Newton [6] claimed light to be composed of particles while in 1678, Huygens [7] described light as waves. For over a century, a fierce struggle went on among the researchers with no final outcome. Later in 1803 Young [8] proved experimentally that Huygens' theory was right. Still later in 1815 Fresnel [9, 10] provided mathematical equations for Young's experiment. Finally, Maxwell in 1865, combined electricity, magnetism and optics that apparently established the wave theory of light. However, Blackbody radiation, Photoelectric effect and Compton effect definitely point to the corpuscular theory of light. Ultimately, as a compromise it was accepted that there are some experiments in which light behaves as a corpuscle whereas in some other experiments its wave nature prevails. Thus, light quanta sometimes behave as particles and sometimes as waves.

It appears that wave and particle description are incompatible with one another and they are mutually exclusive concepts. Waves are something continuous which fill all space and are characterized by two velocities, a phase velocity $v_{ph} = \omega /k$ and $k = 2 \pi/\lambda$ ($\omega$ = angular frequency, k = angular wave number) indicating structure of the wave, another is the group velocity $v_{gr} = d\omega/dk$ which represents velocity with which the energy of the wave travels. These actually supply kinetic and potential energy to the system.

On the other hand, a particle is something very small, position of which is fixed at a point at an instant which is moving with a definite speed. The moving particle exerts a radiation pressure and supplies kinetic energy to the system.

A major distinction between the properties of wave and particle is that when two (or more) waves interact with one another, they show interference. For two (or more) particles this process is absolutely impossible, they could be added up but never interfere one another.

**De Broglie's hypothesis and its limitation:**

De Broglie's hypothesis [11] of matter waves gives a relation between particle and wave nature of electromagnetic waves (light). His formula $\lambda = h/mv$ produced a wave length $\lambda$ of mass m (corpuscle) moving with a velocity v. But this $\lambda$ does not represent a real wave as shown by Max Born and Heisenberg from consideration of quantum mechanical arguments which proves this to be a probability wave. De Broglie's attempt to depict the particle as a combination of wave packet (pilot wave) was untenable. No matter how compact the wave packets may be, they cannot form a particle as they disintegrate rapidly in time. Thus, the mechanical combination of two such mutually exclusive entities as wave and particle into a single frame was not possible. De Broglie's waves are neither material waves nor electromagnetic waves, but they are probability waves. De Broglie's hypothesis was ridiculed and in 1924 about 60 years after the proposition of Maxwell's equations, Max Born, Heisenberg and Schrödinger entered into the field with quantum and wave mechanical principles.

**Derivations from Maxwell's Theory:**

Most of the characteristic properties of a photon (quantum of light) can be derived from Maxwell's equations [5]. These results are obtained from the simple mathematical fact that simultaneous occurrence of three mutually perpendicular transverse waves is not possible keeping the direction of propagation fixed for a particle. Thus (100) and (110) may be transverse but the direction of motion along (111) is automatically fixed as longitudinal.

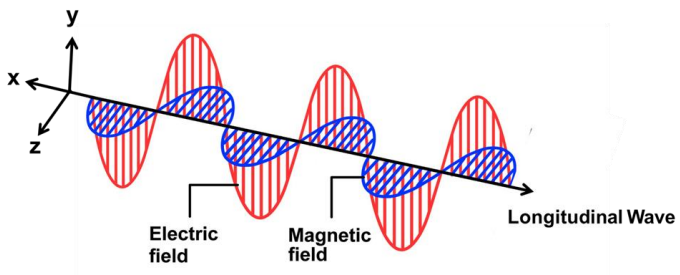


**Fig. I: Maxwell's theory showing components of electromagnetic radiations**

Fig. I shows that electric and magnetic fields which oscillate along mutually perpendicular xz and xy planes fixes the direction of propagation of light along x- axis. This restricts the propagation of light rays along a longitudinal wave (similar will be the case for propagation along y and z axes).

Transverse waves and longitudinal waves differ from one another by some characteristic properties. While transverse waves will show diffraction and interference properties (which are the properties of wave motion) the longitudinal wave shows polarizing properties and will pass through vacuum with nothing to obstruct its motion and these will exhibit particle properties of light.

This shows clearly that the wave and particle properties of light (electromagnetic radiation) coexist simultaneously and it is not a case of either/or but both persist at the same time. In some experiments the wave properties and in some other the particle properties are exhibited. Moreover, the velocity of light (~3 x 108 m/sec) was derived by Maxwell without any consideration of optical properties. So, the propagation of a photon may be compared to a bird flying with the help of its two wings which are the oscillating components of electric and magnetic field. The longitudinal component of light moves through vacuum with nothing to restrict its speed. The concept of 'ether' as a medium was discarded by scientists after vain attempts to prove Michelson – Morley experiment. The ether was later proposed to be substituted by Dirac with electron filling the space which was not accepted and still later the

proposal of ‘fields’ filling the vacuum also produced no better results. These suggestions could not change the velocity of light which already attained the maximum value from the calculation of Maxwell.

It is to be accepted that longitudinal portion of light travels through vacuum without any obstacle from anywhere. This is the mechanism by which sun rays pass through space and reach earth. Let us suppose that the velocity of light is being measured by two observers, one at rest and the other moving with light. Both are in the same inertial frame and according to Einstein’s theory of general relativity the speed of light must be same in both frames. It is proposed that $c = c' + u = c' - u$ where ‘c’ is the velocity of light and ‘u’ is the contribution from the Doppler effect of the medium. This is a genuine inconsistency and demands an acceptable explanation. The most obvious solution is that $u = 0$ which means that there is no contribution from Doppler effect of the medium and velocity of light is not dependent on the medium through which it passes ($c = c'$).

The expression for the Doppler shift for light is given by $F_L = [(c-u)/(c+u)]^{1/2} F_S$ where $F_L$ is the frequency received by the listener and $F_S$ denotes the frequency of the source. When ‘v’ is positive, the source moves away from the listener and then $F_L < F_S$. When ‘v’ is negative, the source moves towards the listener and then $F_L > F_S$. If $v = 0$, then $F_L = F_S = 0$ there is no Doppler effect.

These results have far reaching consequences. The Doppler effect is a result of the medium through which a wave passes and if there is no medium, Doppler effect will not be effective. Applied to light as a particle which requires no medium, it is not affected by Doppler principles. This goes against the principle of simultaneity proposed by Einstein [12,13].

The arguments for and against the conception of simultaneity are both acceptable. The root of this is amply supplied from the theory of Maxwell which shows that light wave consists

of two independent parts; one is the wave motion originating from oscillating electric and magnetic fields and the other is the particle motion originating from longitudinal wave. The wave part regulates the spatial and temporal consideration while the particle part exhibits the simultaneity of events and the constancy of the velocity of light. As such the longstanding debate against simultaneity and the dependency of spatial and temporal considerations appears meaningless. Both the approaches are correct and depend only on the viewpoint of the observer.

Even today, it is believed that particles show wave properties and waves show the characteristics of a particle. *This is absolutely wrong; waves are waves and particles are particles. They exist separately and simultaneously with no interconversion between them. Waves are guided by wave mechanics (Schrödinger) and particles are guided by particle (Q) mechanics (Born – Heisenberg).* Born together as twins, particles and waves travel separately but simultaneously preserving their own identity (characteristics). They cannot be interchanged.

**Red Shift:**

The phenomenon shows the corpuscular properties of the longitudinal waves and is guided by particle (Q) mechanics.

In astronomical studies, the spectra of light coming from distant stars exhibit shift in wave lengths towards red end in comparison to the spectral lines of the same element existing in earth. This has also been taken as the evidence of expanding universe which was thought to be evolved as a result of a great explosion (Big Bang) some billion years ago. It is assumed that Doppler shift of the medium was the reason for the expansion. But these rays coming from the stars are the longitudinal part of the light wave and are guided by particle (Q) mechanics.

The red shift can be explained from the relaxation effect on the binding force of the universe arising from the centripetal force as has been discussed earlier [14]. An alternative explanation of the formation of the universe was the implosion of the fourth state of matter (plasma). It is not necessary to consider the Doppler effect on the motion of light particles as the expanding universe automatically shows the shift towards the red end of the spectrum.

**Tunnel effect:**

This phenomenon shows the wave theory of electromagnetic radiation produced by transverse waves and is guided by wave mechanical principle.

This problem is similar to that of the particle in a box in wave mechanics where the particles of energy less than the potential barrier at the box boundary can escape out of the box with small but finite probability. This is possible at the boundary if the potential barrier is not infinitely high or infinitely wide. As a result of this, the particle is able to pass the boundary as if passing through a tunnel in the barrier (Fig. II).

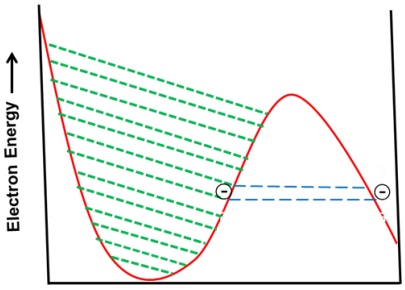


**Fig. II: Tunnel effect showing wave mechanical contribution**

In the world of the ultra-small, the position of a particle affects its potential energy and its velocity determines the kinetic energy. It is impossible to measure accurately the kinetic and potential energies of a particle. But the particle in a potential well has a certain probability of getting outside the well. The laws of the Tunnel effect are similar to the laws of reflection and the transmission of light waves through the boundaries of different substances.

**Properties of electromagnetic radiations:**

Photons, electrons and neutrinos are guided by a combination of wave and particle properties, the combination of which vary in proportion.

Photons and neutrinos – are mostly guided by particle (Q) mechanics with some contribution from wave mechanical properties.

Electrons – are contributed mostly by wave properties (Tunnel effect) with limited contribution from particle mechanics.

**Photoelectric Effects:**

The photoelectric effect has been interpreted by Einstein as originating from frequency of the rays which does not emit electrons but only increases the magnitude of the current. The intensity of the rays which when crosses a threshold value dislodge electrons from different metals. In view of the proposed distinction between wave and particle individuality of light rays, the wave part of the rays may be identified with frequency and the particle part of the wave contributes to the emission of electrons from the metal by their intensity.

**Magnetic Forces:**

Magnetic forces exhibited as celestial magnetic field strength (H) is medium independent which is covered by particle (Q) mechanics while the magnetic induction produced in a material in a magnetic field is medium dependent and is governed by Doppler effect of wave mechanics. The medium-independent magnetic field extends to the celestial poles and guides the direction of the compass needle. It acts at long distance. On the other hand, the attraction of a magnetic material is guided by the magnetic induction (which is the number of magnetic field lines per square meter also known as magnetic flux density B) and this is covered by wave mechanical principle.

**Electron Spin:**

Around the centenary celebration year of wave and particle (Q) mechanics what remains unexplained is the characterization of electron spin. Idea of spin is incomprehensible from the standpoint of classical physics. The earth moves round the sun and it rotates on its own axis. The electron revolves round the nucleus and rotates on its axis – this analogy does not stand as the electron is a rotating point and the axis of a point has no meaning. However, an attempt can be made for an explanation on the basis of contribution from wave and particle (Q) mechanics. In an atom, two types of electrons can be recognized; one is the electron in which the nucleus is embedded (Dirac's proposal) revolving round the nucleus and supplies the angular momentum (moment of momentum) resulting from the wave motion and is guided by wave mechanics. The quantum numbers n, l, m are deduced from these by Schrödinger. The other type of electron is of Rutherford – Bohr model which revolves round the atom and is guided by particle (Q) mechanics. Oppositely directed cross product vectors arising from revolution of electrons around the nucleus (Dirac), that is $A \otimes B$ are non-commutative. These simply add up with the dot product $A \bullet B$ vector arising from the extranuclear electron (Rutherford - Bohr) to produce two different energy values. This explains the hyperfine doublet splitting of the hydrogen spectrum.

This is a reasonable explanation that can be put forward for explaining electron spin on the basis of wave and particle (Q) mechanics at the present moment until a fool proof explanation is advanced by a future scientist.

**Contribution of particle (Q) mechanics and wave mechanics:**

Contribution of particle (Q) mechanics and wave mechanics for the motion of an electromagnetic radiation will depend on the rest mass of the photon. If this is zero, then it

moves with a velocity of light and there is no contribution of the Doppler effect from the medium. But the rest mass of the photon can be 0/0, which means it may have any value other than zero. In that case, contribution will come from the wave part of the electromagnetic radiation which will vary with the value of the rest mass deviating from zero value. The non-zero rest mass when moving with high velocity will acquire mass from the field according to the *special theory of relativity* of Einstein but as the velocity reaches about 80% of the velocity of light the whole thing will be converted to field quanta.

This gives rise to the idea that the velocity of light is unsurmountable theoretically and therefore, the idea of a time machine for movement through past and future times by attaining a velocity greater than 'c' (and the concept of negative time) is just a pipe dream at the present stage of our knowledge.

**Concluding Remarks:**

1) The terms quantum mechanics and wave mechanics are usually loosely used to indicate same mechanism. Actually, they are different; one approaches the problem from particle (quantum) side and the other from the wave properties. The two mechanisms are distinguishable by the action of Doppler effect of the medium.

2) The notion that particle shows wave properties and waves show the properties of particle is not tenable. They are completely different from one another and are in no way interconvertible.

3) The debate on the concept of simultaneity of Einstein and the opposing side favouring spatial and temporal effect has no meaning as the same problem is being viewed from different angles and both approaches are equally valid.

4) The phenomenon of Red Shift is shown by particle part of the motion whereas Tunnel effect is mostly contributed by the wave part of the motion of electromagnetic radiation.

5) Photoelectric effect and magnetic forces are contributed by both the particle and the wave properties of the electromagnetic radiations. Relative contribution of the particle part of the motion is guided by the strength by which the electrons are bound to a metal, whereas the contribution of the wave part is guided by the nature of the medium which regulates the Doppler effect.

6) Most of the conclusions drawn here are without much help from quantum/wave mechanics. However, these mathematical techniques are important for providing theoretical background not only for electromagnetic radiations but also in various other branches of science.

7) It has been shown here that electromagnetic radiations are not a "duality" but a composite of the wave and particle (Q) mechanical part from independent identity of transverse and longitudinal waves.

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