# My Explanation for the observed Wave-Particle-Duality of Light

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This letter proposes an explanation for the century-old puzzle of the wave-particle-duality of light, which thousands of physicists, including Einstein, Plank, Feynman …, have been trying to resolve. Since a 'particle' is localized in space, it is mathematically characterized here as an impulse-function in space. Then it is argued that if this 'particle' has anything to do with waves then we can know it by taking Fourier-transform of the impulse-function in space. When Fourier-transformed into wave-number-domain; we find that a 'particle' should contain a wide 'set' of waves, and not just a single frequency. Then we show that in the experiments performed so far [1] the red lasers had significantly wide line-width, means the sources have been producing a wide set of waves, and not just a pure single frequency. Similarly, in the single-particle interference-experiments incandescent filament-lamps were used with green filters inserted to isolate single photons; but it is obvious that at the frequencies of light very narrow-band-filters are not yet technically feasible, so the green filters used allowed significantly wide band of waves. So in the experiments performed so far we got 'particles' localized in space. And in the double-slit-interference-experiments this wide band of waves passed from both the slits, interfered like waves, and whenever and wherever they got coherently added, a 'particle' called 'photon' got detected. Atoms emit short-duration pulses of radiation, so their Fourier transform contains a wide band of frequencies. And at the time of detection, an atom needs only a small piece of continuous 'wave', of a suitable duration, amplitude and frequency, for ejection of an electron. ***So it is concluded here that: emission and detection of light is in the form of 'photons'; whereas its propagation in space is in the form of a wide band of 'waves'.***

## Introduction

Sir Isaac Newton had presented an argument, that the straight-line motion of a ray suggests that light must be in the form of ‘particles’. But the experiments by Huygens, Fresnel… demonstrated ‘wave’ nature of light. Then, to explain ‘black-body-radiation-curves’, Max Planck proposed that light seems to be in the form of ‘quanta’, of energy $h\nu$. Einstein used this ‘quanta’ of light to explain ‘photo electricity’; and won the Nobel Prize. Prince Louis de Broglie proposed a wavelength associated with every ‘particle’ of matter, which Davisson and Germer experimentally proved to be true. Debate continued for decades, whether light and electrons are ‘waves’ or ‘particles’. Ultimately, currently it is mutually agreed that light is both, ‘wave’ as well, as ‘particles’; but at a given moment it is either detected as ‘wave’ or a ‘particle’; and both ‘wave’ and ‘particle’ descriptions are ‘complementary’ to full description of light. So, currently, the physicists believe in the wave-particle dual nature of light, and all other ‘elementary particles’. Albert Einstein once told: “Twenty years of brooding has brought me no closer to the answer, what is the photon. Some rascals think, they know, but they are deluding themselves.” According to Feynman, “The double-slit interference-pattern of single particles is the biggest puzzle of science.” The latest attempt made to resolve this duality was by Partho Ghose and Deepankar Home in a paper titled “Wave-particle-duality of single photon state”. Published in Foundations of Physics [2]. They used a pair of prisms with a tunneling gape to separate ‘particles’ and ‘wave’, assuming that if light is ‘particles’ then photons will get bounced from the surface of the prism towards the detector-1, and if light is ‘wave’ then it will tunnel through the tunneling-gape, and get detected by detector-2. But to their surprise both the detectors detected single photons. When detector-1 clicked, detector-2 remained silent; and when detector-2 clicked detector-1 remained silent! It meant that detections were mutually-exclusive, the coincidence-counter connected to both the detectors counted zero count! In my opinion, waves get reflected too. When light gets partly reflected and partly transmitted then it also gets separated into horizontal and vertical polarizations. Whether such polarization-domain-separation produced this result? They should have also measured the ratio of detections by detector-1 and detectoter-2. The fig.2 in this manuscript suggests that light assumes the ‘particle’ form only for short durations ; for most of the distance traveled it is in the form of ‘wave’.

Here, in this paper, an explanation for this long sought problem is proposed, that: at the very high frequencies, of the order of 400-700 nm, generation and filtering of purely mono chromatic light, of one Hz bandwidth, is technically not yet possible; so in the experiments performed so far, there has been quite a wide bandwidth involved. Typical line-width of mono-chromatic laser is of the order of Giga-Hertz to a few kilo-Hertz. So the coherent super-imposition of all the spectral-components, contained in the band, take place at discrete points in space and time. This is the reason why the experiments performed so far [1] showed ‘particle’ nature of light. If electromagnetic radiation were always in the form of both, ‘particles’ as well as ‘waves’, then even at radio frequencies we should see ‘particles of radio-waves’, in addition to the radio-waves seen on oscilloscopes. Actually, atoms emit such short-duration pulses of radiation, so their Fourier transform contains a wide band of frequencies. And at the time of detection, an atom needs only a small piece of continuous ‘wave’, of a suitable duration, amplitude and frequency, for ejection of an electron. So it is concluded here that: emission and detection of light is in the form of ‘photons’; whereas its propagation in space is in the form of a wide band of ‘waves’.

## Detailed discussion:

We know, that ‘light’ is a small band of the electromagnetic spectrum, but in the experiments performed so far, always a ‘particle’ known as ‘photon’, is detected; which is localized in a very small region of space. Since a ’particle’ is localized in space, it can be mathematically represented as an impulse-function, as shown in fig.1: as was first done in [3-5]. And if this 'particle' has anything to do with waves, then we can know it by taking Fourier transform of the impulse-function.

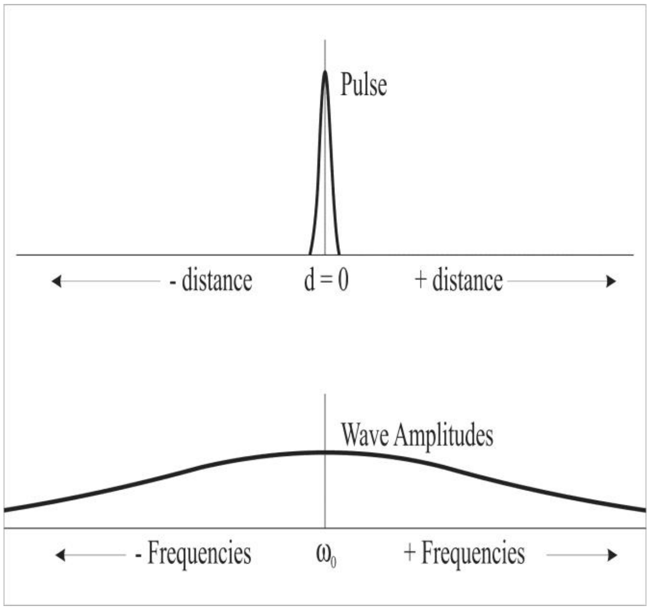


Fig.1: A single photon can be mathematically represented as an impulse-function (top), which can be Fourier-transformed as a wide band of wave-numbers and frequencies (bottom). So a 'particle' called 'photon' is expected to contain a wide band of frequencies.

If we want to convert this wide band of waves back to the impulse, then we will have to constructively-add all the spectral-components of the wide band, having a specific phase-relationship. Of course, in the real world situation, we can expect only a reasonably-wide band of frequencies; so the 'particle' has to be somewhat bigger in size and volume, than the theoretical and mathematical zero volume. Let us try to superimpose a set of sine waves as shown in the fig.2 below, and see whether we get a localized 'particle':

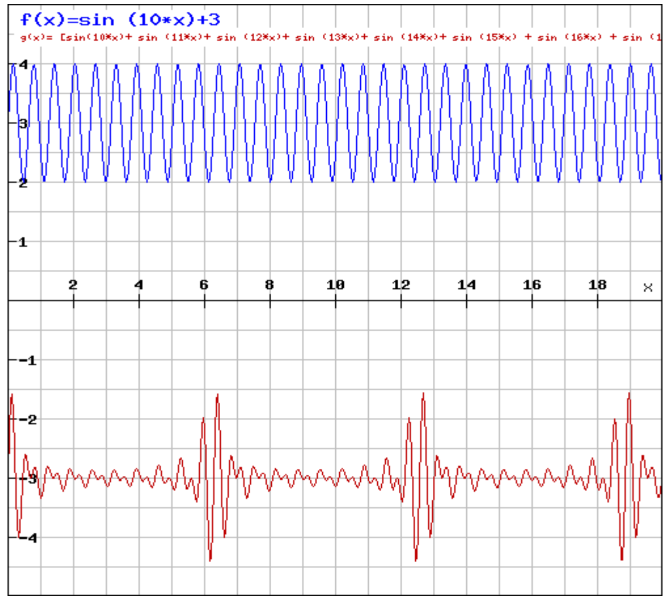


Fig.2: x-axis showing space or time, and y-axis showing amplitude of the waves. The (i) Blue curve, on the top, shows a wave of purely single frequency, Sin (10* x); (ii) and the red curve, at the bottom, shows that when so many waves of slightly different frequencies get added, e.g.: sin(10*x) +Sin(11*x) +sin(12*x) +sin(13*x) +sin(14*x) +sin(15*x) +sin(16*x) +sin(17*x) +sin(18*x), then they coherently add only at discrete places in space and time; and mutually nullify their amplitudes at other points in space and time. Such packets of waves, formed due to superimpositions of a wide band of waves, appear to us as the 'particles'.

**2. Explanation for the observations of 'wave-particle-duality':**

In the physical experiments performed on light, the sources of light contained quite a wide 'band' of frequencies, not just a single frequency; so the superimposition of those wide band of waves formed 'wave-packets' in the time-domain, and in the space-domain, as shown in the fig.2, and got detected as 'particles'. The light emitting atoms emit such wave-packets; and high intensity of light means more number of atoms emitting such packets. At the high frequencies, like those of light, it is not possible to get very narrow-band filters, so there is always some 'line-width' of every source of light; and so we observe localized pulses in the time and space domain. But at radio frequencies narrow-band filters are possible, so we can see low-frequency-electromagnetic-waves as ‘waves’; and not as ‘particles’. If electromagnetic radiation were always in the form of ‘particles’, then even at low frequencies we should see ‘particles’ and not the ‘waves’ like radio waves, seen on oscilloscopes. Of course, we can experimentally emulate ‘photons’ even at microwave frequencies by superimposing a wide ‘band’ of waves. It may be possible to make deterministic predictions of such ‘emulated-photons’ at much lower frequencies.

## Conclusion:

The above discussion leads to the conclusions that: (i) a ‘particle’ is ‘constructive-superimposition’ of a wide band of ‘waves’, forming a pulse in space and time. (ii) Atoms emit such pulses of radiation, so their Fourier transform contains a wide band of frequencies. And at the time of detection, an atom needs only a small piece of continuous ‘wave’, of a suitable duration, amplitude and frequency, for ejection of an electron. ***So we can conclude that emission and detection of light is in the form of ‘photons’; whereas its propagation in space is in the form of a wide band of ‘waves’.***

## References

[1] http://www.teachspin.com/brochures/Two%20Slit.pdf

[2] Ghose P. and Deepankar H. “Wave-particle-duality of single photon states” *Foundations of Physics* (December 1992), Volume 22, Issue 12, pp 1435-1447

[3] Lathi, B. P. Communication Systems, Oxford University Press, 1998.

[4] Tank, H. K. “Some expressions of gravity without the big ‘*G*’” *Astrophysics and Space Science* (2011) **336**, Issue 2, pp 345-346

[5] Tank, H. K. “Some expressions of gravity without the big *G* and their possible wave-theoretical explanation” *Progress in Physics*, vol. **1** (2013) pp 3-6