

Wave-particle duality

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(Preprint - v1.0 July 2026)

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Preprint link: <https://zenodo.org/records/21708976>

DOI: [10.5281/zenodo.21708976](https://doi.org/10.5281/zenodo.21708976)

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Source: <https://drive.proton.me/urls/XG5ZKT94A8#ijnqZsisCgju>

Abstract:

Wave-particle duality remains one of the central unresolved questions of quantum mechanics. This paper examines whether the particle interpretation is fundamentally necessary and argues that wave phenomena alone may explain observations traditionally attributed to particles, including interference, superposition, and the photoelectric effect. It proposes that quantum entities are fundamentally wave-like and that the particle concept is an effective description of their interaction with measuring devices.

1. Introduction:

The aftermath of the double-slit experiment led to the conclusion that, at the quantum level, both particles and waves change their behaviour and can behave either as waves or as particles [1]. Although this has not yet been explained, it still sounds mystical. Of course, we know of scenarios in which liquids turn into solids (frozen water), liquids turn into gases (propane), and solids turn directly into vapour (sublimation). However, all of these have well-understood physical and logical explanations: they are caused by changes in temperature, pressure, and other environmental conditions. In the double-slit experiment, however, there appears to be nothing that can cause such a change in behaviour.

2. Wave vs. Particle

Waves are easy to recognise because they all share the same characteristics: frequency and amplitude. It is easy to understand how a wave can exist in two places at the same time, and this supports the principle of superposition. It also explains the pattern left on the screen in the double-slit experiment.

Particles, on the other hand, are described as entities with a distinct and well-defined structure. They are sometimes described as having mass but no physical size. An obvious question arises: how can such an entity behave like a wave?

If we look at the macroscopic world, almost every creature follows the same general pattern: legs, arms, wings, fins, and so on. Their motion is not associated with a wave pattern. There are very few creatures that do not follow this rule, such as worms and snakes. However, when we zoom into the microscopic world, living organisms begin to look more alike: essentially "blobs" with no legs or arms, sometimes possessing a cilium. They move with a wriggling motion that closely resembles a wave.

Based on the preceding discussion, we propose that quantum particles do not exist in the conventional sense. Instead, all quantum entities are fundamentally waves, while the particle concept is an effective description of how they interact with measuring devices. This, again, raises the question: what about the particles we know, such as electrons and photons? De Broglie's matter-wave hypothesis suggests that electrons possess an intrinsic wave nature [2]. This motivates reconsidering whether the particle concept is fundamental or only a useful description.

But what is an electron? It is "something" that possesses energy but has no measurable size. Nobody has been able to measure the size of an electron. All that has been measured is the disturbance or interaction caused by the electron. This suggests that the electron is closer to a wave than to a self-contained particle. A wave can carry energy even though it has no mass, and perhaps we have simply mislabelled the "quantum particle".

The photoelectric effect was investigated experimentally by Lenard, who demonstrated that light can eject electrons from a metal surface [3]. Einstein explained these observations by proposing that light transfers energy in discrete quanta, an interpretation that later developed into the concept of the photon [4]. However, waves are also capable of carrying and transferring energy. This raises the possibility that the photoelectric effect may admit an alternative explanation that does not require light to be fundamentally particulate.

Consider sound. It is unquestionably a wave rather than a particle. Nevertheless, sound at the right frequency can break a wine glass, as experiments have demonstrated. It does not matter how loud the sound is, nor how long it is played; the glass breaks only when the appropriate frequency is reached. This suggests that the energy carried by a wave depends on its frequency rather than on any "particle-like" structure.

The same reasoning can be applied to the photon. In **Figure 1**, we can see red and blue light waves (pink and cyan lines). In the classical interpretation, the red and blue dots represent photons, and there is apparently no difference between them. However, if we treat the photon as a wave rather than as a particle, we can see that the red wave (representing the red photon) and the blue wave (representing the blue photon) are fundamentally different. The blue wave oscillates twice as many times over the same distance as the red wave, indicating a higher frequency and therefore greater energy.

In Schrödinger's example [5], the cat cannot literally be in two states at the same time because the cat is not itself a quantum object. If the scenario were instead interpreted using a wave rather than a cat, then the principle of superposition would make much more sense.

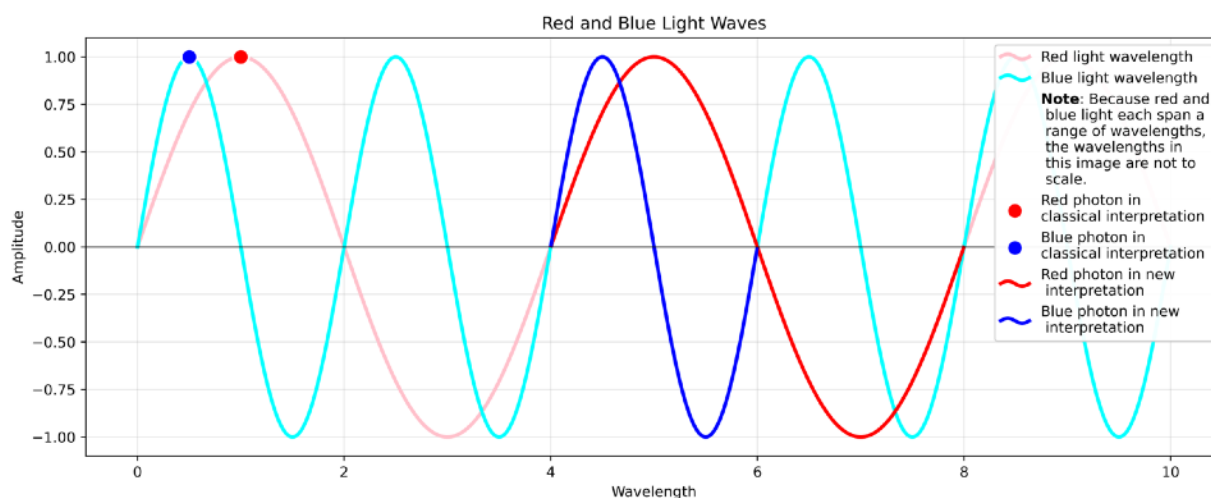


Figure 1. Schematic comparison of red and blue light waves, highlighting the difference in wavelength and contrasting classical and conceptual photon representations (not to scale).

3. Conclusion

- Waves can carry the same amount of energy and produce the same effects as particles.
- We may have mislabelled certain waves as particles, particularly in the quantum world.
- If we accept that only waves exist at the quantum level, rather than particles, then phenomena such as the double-slit experiment and superposition can be explained in a more logical way.

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