The type of the interaction of the particle can explain the wave-particle duality

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Abstract
Experiments leading to the development of the wave-particle duality concept have been investigated. Analyzing the conditions of these previous experiments, it has been concluded that the wave or particle behavior depends on the type of interaction of the particle with its surroundings. The particle's interaction with “field” results in wave behavior, while interaction with “matter” results in particle behavior. The interaction between the particle and its surroundings occurs at the interface. Field surrounds the entire particle; therefore, the interaction occurs at the surface, “surface” interaction. The interaction of the particles with matter can be considered as point-like interaction, or “bulk” interaction.

Keywords: light • wave-particle duality • double slit experiment • particle interaction • quantum mechanics

1 Introduction

One of the earliest attempts explaining the nature of light was Newton`s corpuscular theory in the 1600's. He was suggesting that light consists of particles “corpuscles” which are traveling in a straight line in all possible directions. The corpuscles theory of light can easily explain the rectilinear propagation and reflection of light but fails to explain optical phenomena such as interference. Huygens (1678) described light as spherical waves, which spread out from the source. Based on Newton`s reputation the corpuscles theory of light remained popular for almost hundred years. The wave nature of light gained acceptance following the double-slit experiments of Young (1804). The double-slit apparatus consists of a thin plate with two closely placed parallel slits, and investigates how light and particles strike the screen behind it (Fig. 1). Based on the observed interference it was concluded that the propagating light has wave-like characteristics. Maxwell electromagnetic theory gave an additional support for the wave-like nature of light. However, the experimental outcomes of the photoelectric effect could not be explained by the wave characteristic of light; therefore, Einstein (1905) asserted that light is a particle containing energy, which corresponds to its wavelength. Compton electron scattering (1923) confirmed Einstein particle description of light. The particle nature of light can also be observed in the double split experiences. Reducing the intensity of the light significantly, the dim light leaves only a dot on the screen, which is an indicator of a particle. Despite the particle behavior on the screen, the single photon double-slit experience still produces an interference fringe (Tsuchiya et al. 1982). Our current understanding assumes that light consists of photons, which have both wave and particle characteristics. Einstein concluded that the two contradictory pictures of reality; separately neither of them fully explains the phenomena of light, but together they do. The wave-particle duality characteristics of photons had been extended to electrons and to all matter. De Broglie (1924) postulated in his PhD thesis that all matter has wave properties. The predicted wave-like property of the electron had been confirmed by Davisson and Germer (1927). The first double-slit experiment with a beam of electrons was performed by Claus Jönsson (1961). The outcome of the experiment was consistent with the theoretical predictions, producing an interference pattern. The first double-slit experiments with single electrons, passing through the slits one-by-one, were performed by Merli et al. (1976), and Tonomura et al. (1989). The experiments showed that interference fringes are formed gradually, even when electrons pass through the slits individually. The wave-like property of neutrons was confirmed by the observed interference pattern of Zeilinger et al. (1981). Since then particle interference has been demonstrated with atoms and molecules as large as carbon-60 and carbon-70, and even to 2000 atoms (25,000 amu) (Yaakov et al., 2019). Single particle interference for antimatter was also demonstrated (Sala et al., 2019). These experiments indicated that the wave-particle duality behavior is generally applicable to matter.

2 Discussion

The previous experiments, leading to the development of the wave-particle duality concept of light, have been collected and divided into three groups (Table 1.). Group one contains experiments, which can only be explained by particle behavior. This group includes the photoelectric effect and Compton scattering. Group two includes experiments, which can only be explained by wave-like behavior. These experiments are diffraction, interference, and polarization. The third group contains experiments, which can be explained by either wave or particle behavior, like the rectilinear propagation, reflection, and refraction.

The experimental outcomes can be explained exclusively by either particle or wave behavior in groups one and two. These experiments have been investigated by looking for specific features, which can be indicative of either wave or particle behavior. It has been found that there is one fundamental difference between the two groups, which is the substance of the interaction. In experiments resulting in particle behavior (group 1) the particles interact with matter. In experiments explainable by wave-like behavior (group 2) the particles are interacting with the surrounding "field". The interactions, matter or field, occur at the interface of the particle and the medium. The interface is distinctly different when the particle interacts with a field or with matter. The field surrounds the entire particle; therefore, the interaction occurs through the entire surface of the particle, "surface" interaction. The interaction between particle and matter occurs at a limited surface area, which can be considered as point-like interaction, or "bulk" interaction. The surface-bulk interactions of particles had been previously proposed to explain the wave-particle duality for atoms (Garai, 2017).

Table 1. Experiments, which can be explained exclusively by either particle or wave interactions are listed. Experiments in Group 1 can be explained exclusively by particle interaction, and in Group 2. by wave interactions. The characteristic feature of the experiments is that particles in group 1 interact through matter, while in group 2 through field.

Group	Experiment	Behavior	Interacting medium	Type of Interaction
1	Photoelectric effect	Particle	Matter	Bulk
	Compton scattering			
2	Interference	Wave	Field	Surface
	Diffraction			
	Polarization			

The general applicability of the proposed explanation for wave or particle behavior is well demonstrated in the double split experience. As long as the particle, light or electron, interacts with the field the particle behavior can be described as wave. When the particle hits the screen behaves like a particle, with well-defined position and momentum (Fig. 1).

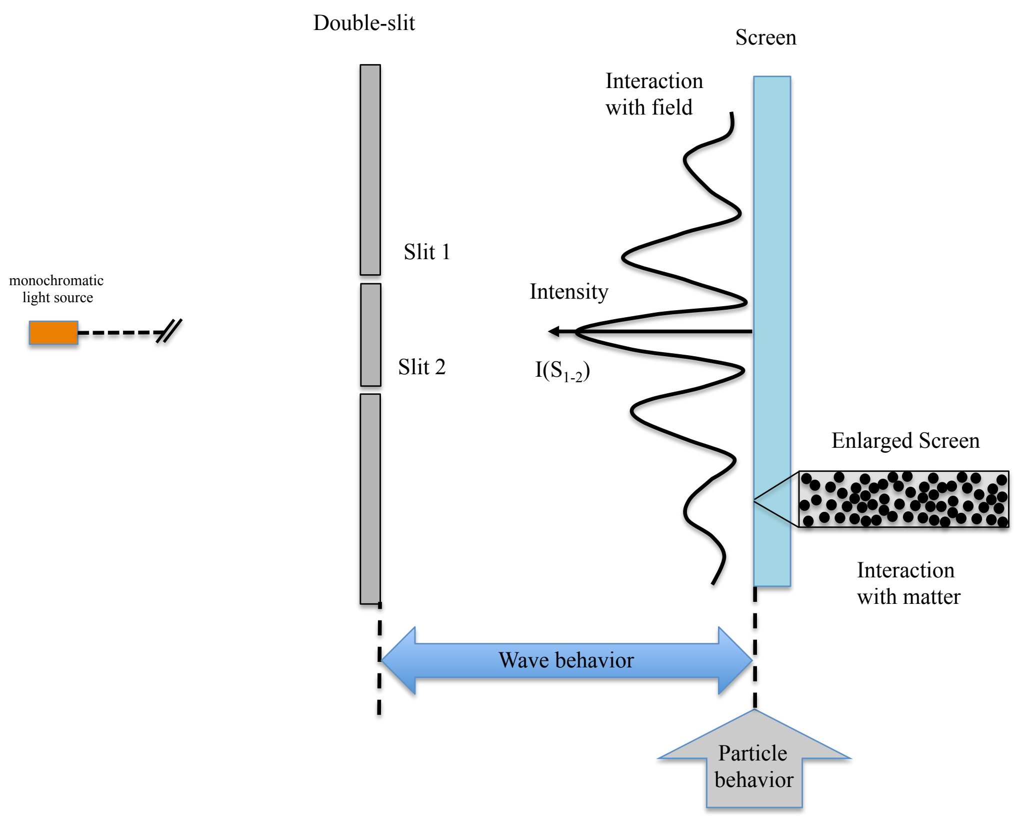

Figure 1. The areas of the wave and the particle behavior of photons or electrons in the double-split experiment. The area of wave behavior relates to particle-field interaction, while the particle behavior relates to particle-matter interaction.

The wave-particle behavior is not exclusive and it is possible that both of the characteristic behaviors of the particles are active. In the Maxwell-Boltzmann kinetic theory of gases the model describes the behavior of ideal gasses by classical particle interactions. However, this interaction induces electromagnetic radiation, which is emitted and absorbed through surface-field interactions of the particles.

3 Conclusion

In summary the dual nature of light and particles emerges from the kind of interaction of the particle with its surrounding medium. The interaction with the field can be characterized as "surface" interaction resulting in wave-like behavior, while the interaction with matter can be characterized as "bulk" interaction resulting in particle-like behavior. Identifying the conditions resulting in wave and/or particle behavior might be the firs major step in our deeper understanding of the physics of the quantum world.

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