Quantum fluctuation of the vacuum offers a feasible explanation for all of the features of the double split experiences

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Abstract

The double split experiences reveal some strange features of nature, which contradict with our everyday experiences. The physics establishment offers a mathematical description of this weird quantum world, but claims that the understanding of the underlying physics is beyond the realm of science. Despite this general skepticism an attempt is made here to unveil the physics of the double-slit experiments.

Keywords: double slit experiments • wave-particle duality • particle-field interactions • quantum vacuum field • fundamentals of quantum mechanics

1. Historical overview

Young conducted the first double-slit experiments with light in 1804. Based on the observed interference he concluded that the propagating light has wave-like characteristics. The wave characteristic of light could not explain the photoelectric effect; therefore, in 1905 Einstein asserted that light is a particle containing energy, which corresponds to their wavelength. Compton (1923) electron scattering confirmed Einstein particle description of light. The particle nature of light can also be concluded from 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. Our current understanding assumes that light consists of photons, which have both wave and particle characteristics. This duality description of light is consistent with the double-slit experiences, which produce an interference fringe even with single photons (Tsuchiya, 1982). De Broglie had extended the wave-particle duality characteristics of photons to electrons and to all matter. He postulated in his 1924 PhD thesis that all matter has wave properties, that he defined as:

$$\lambda = \frac{h}{p}, \qquad (1)$$

where λ is the wavelength, h is the Planck constant, and p is the momentum of the object. 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 in Germany in 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. in 1976, and Tonomura et al. in 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 by Zeilinger et al. in 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 a., 2019). Observation of the path of the particles in the single photon and electron experiments diminishes the interference. If all the particles are observed then no interference occurs at all. Based on the percentage of the observed particles any combination is possible between the total and no interference (Wootters, and Zurek, 1979; Mittelstaed et al., 1987).

2. Experiments and observations

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). The characteristic features of the experiments are summarized here. The first experiments were conducted with light, and then with the following matter particles:

a./ light
    a_a. beam of monochromatic
    a_b. single photon
b./ charged particles
    b_a. stream
    b_b. single
c./ neutral particles (neutrons, atoms)
    c_a. stream
    c_b. single
d./ 1. antimatter particles
    d_a. stream
    d_b. single

The investigated experimental set ups were the followings:

A./ one of the slits is open but not both (Fig. 1-2/a)
B./ both slits are open (Fig. 1-2/b)
C./ both slits are open and the position of all of the particles are measured (Fig. 3)
D./ both slits are open and the position of certain percent of the particles are measured

The experimental results were the followings:

I./ interference was not observed

for all particles (a-d) in experiments A
for all particles (a-d) in experiments C
for the measured part of the particles (a-d) in experiments D

II./ interference occurred

for all particles (a-d) in experiments B
for the not measured particles (a-d) in experiments D

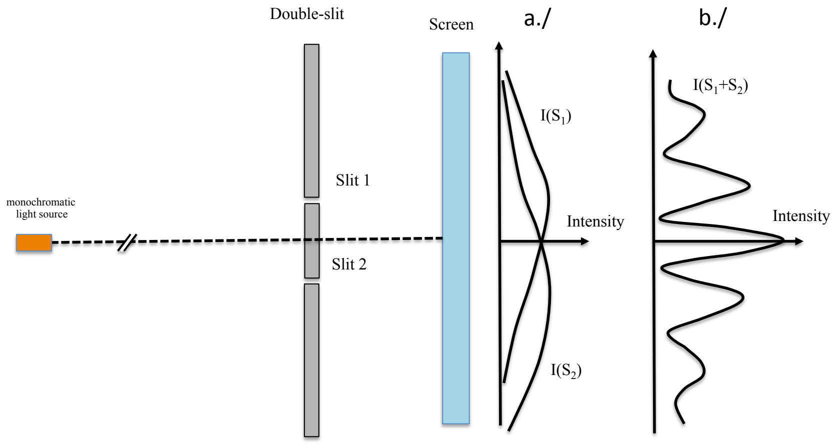

Figure 1. Experimental set up of the double split experience. **a./** The intensity of the light is shown for a single slit opening. **b./** The observed intensity is plotted, when both of the slits are open.

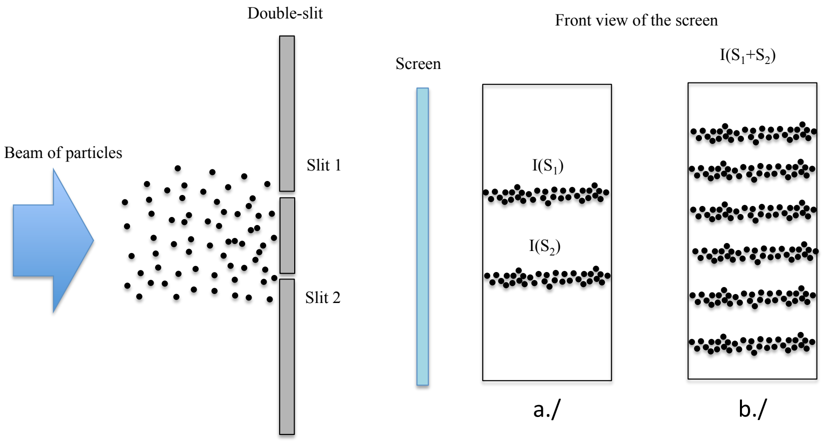

Figure 2. Double slit experiences with particles. **a./** Distribution of the particles if one of the slits is open. **b./** Interference pattern develops when both of the slits are open. The interference pattern develops in case of a single photon or particle as well.

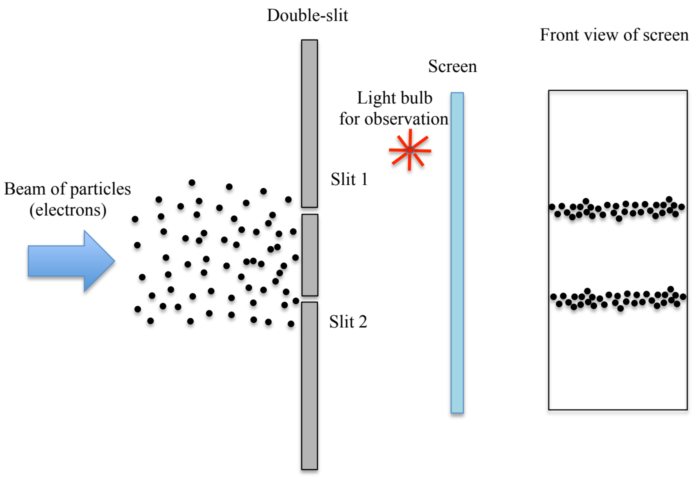

Figure 3. Upon measurement or observation the interference pattern does not develop despite both the slits being open.

The experimental outcomes, which has to be explained by any proposed theory are:
- single particles develop interference pattern when both slits are open
- this interference is destroyed by measurement
- the charge of the particles have no effect on the outcome of the experiment
- particles hitting the screen have well defined position and momentum despite the developed interference pattern.

3. Current interpretation of the experiments

The current interpretation of the single photon/electron interference is that the photon/electron comes through both of the slits at the same time in order to develop an interference pattern. This is known as the "Copenhagen" interpretation, developed by Niels Bohr, Werner Heisenberg, Max Born and other physicists. The probability distribution of the position of the particles is described by the wave function, which predicts that the single particle can be present at both splits at 50-50 probabilities. Measuring the position of the particles causes the collapse of the wave function, resulting in a well-defined position of the particle. According to this interpretation the particles are waves and exist everywhere, and upon measurement their position can be defined. Thus the wave function is not a real wave, just mathematically describes the probability of the position of the particle. This physical explanation is quite absurd and contradicts with observations, which show that the electron passes through at one of the slits but never both.
It is even more absurd the many-worlds interpretation of quantum mechanics, which holds that there are many worlds, which exist in parallel at the same space and time as our own (Everett 1957). These absurd explanations indicate that despite the correct mathematical description, our understanding of the quantum world is still incomplete.

4. Vacuum fluctuation of the quantum field

Based on the Heisenberg uncertainty principle, tiny fluctuations in the vacuum can occur resulting in the creation and annihilation of particles. The created particle-antiparticle pairs, despite their very short time existence, create a randomly fluctuating dielectric field in the vacuum. This process is described by relativistic quantum field theory, which also predicts that the empty space is filled with fluctuating electromagnetic waves, with all possible wavelengths (Mainland & Mulligan, 2019). The created particle-antiparticle pairs are below the detection limit but their cumulative effect is measurable. The existence of the predicted static quantum vacuum fluctuation has been indicated by various experiments, like the spontaneous decay of higher energy states to ground states, the Lamb shift (1947), and the Casimir force (1948). The dynamical Casimir effect had also been detected (Lähteenmäki et al., 2013; Wilson et al., 2011). The quantum fluctuation or zero point energy had been directly detected by measuring the quantum noise in circuits (Koch et al., 1980, 1982). Based on these experiments, the existence of the vacuum fluctuation of the quantum field is well established. Consequently, the effect of this field must be taken into consideration, when one describes the behavior of a particle, which is surrounded by a quantum vacuum field.

5. Wave-particle duality

Our current understanding assumes that light consists of photons, which have both wave and particle characteristics. Particles of matter exhibit the same wave-particle dual nature. Einstein concluded that the two contradictory pictures of reality; separately neither of them fully explains the phenomena of light, but together they do.
Previous double-slit experiments, which were indicating exclusively either wave or particle behavior of light have been analyzed (Garai, 2022). Based on this study it has been suggested that the wave nature of the light/particles emerge from interaction with the field, and the particle behavior resulting from the interactions with matter. The interaction occurs at the interface of the particle and the surrounding. Field surrounds the particle; therefore, the interaction occurs at the entire surface, "surface" interaction. The interaction of the particles with matter 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). The experiments, the behavior, and the interactions of the particles are summarized in Table 1.

Table 1. The physical processes, the related particle behavior, and interactions in the experiments are listed.

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

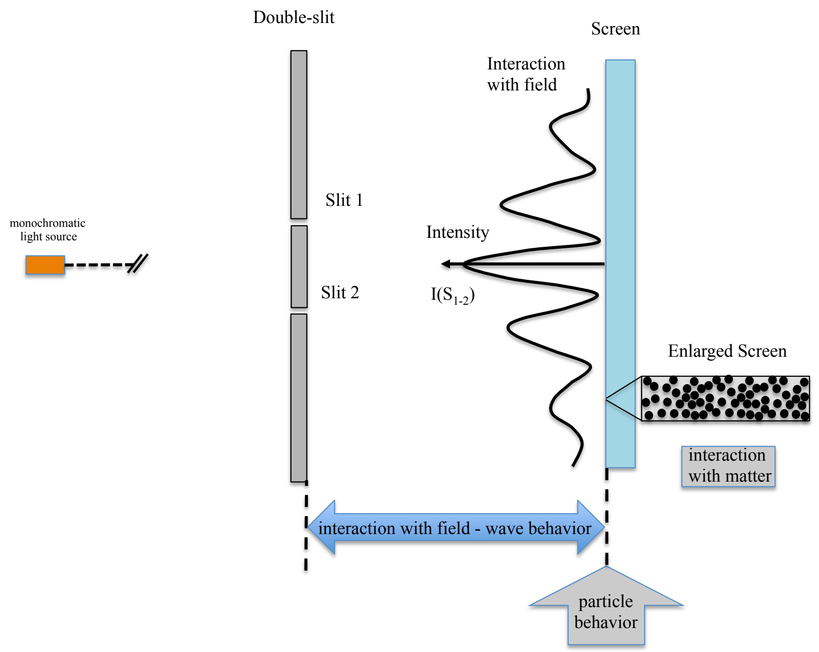

Figure 4. The areas of the wave and the particle behavior of photons, or electrons in the double-slit experiment. The area of wave behavior relates to particle-field interaction, while the particle behavior relates to particle-matter interaction.

The suggested categorization for the wave and particle behavior is consistent with the observations of the double split experiences. As long as the particle, light or electron, interacts with the field the behavior of the particle can be described as a wave. When the particle hits the screen interacts with matter, then behaves like a particle, with well-defined position and momentum (Fig. 4).

6. Proposed physical model

When only one slit is open, then the photon/s or particle/s behavior is consistent with the laws of classical physics. Opening the second slit leads to the development of an interference pattern even in the case of a single photon or particle. The question is that what physical conditions have been changed or modified by the opening of the additional slit, leading to the development of interference patterns even for single particles?
The developing interference implies wave behavior for the particle/s. The wave behavior can be activated by field interaction. Thus the opening of the second slit should induce a new field, or new feature of the field, which was not present when only one of the slits was open. The vacuum fluctuation of the quantum field is present everywhere. It is speculated that the opening of the second slit induces vacuum field fluctuations through the opening. The resonant frequency of these fluctuations interacts with the particle resulting in interference. This speculation is consistent with the measurement effect, which cancels the development of interference. The emitted photons used for the measurement interact with the induced vacuum field fluctuation-particle interference and override this effect. This hypothesis is consistent with experimental results, which show that the unobserved part of the single particles still develop an inference pattern (Wootters, and Zurek, 1979; Mittelstaed et al., 1987).

7. Conclusions

The existence of quantum vacuum field fluctuation is well established, and this effect cannot be dismissed when one describes the behavior of particles, especially if they are small. The proposed quantum vacuum fluctuation-particle interaction model is consistent with all of the features of the double-split experiences, and offers a coherent physical explanation to all quantum effects. The validity of the hypothesis is testable by shielding the effect of the quantum vacuum fluctuation, which should prevent the development of interference.

References

Casimir, H. B. G. (1948) On the attraction between two perfectly conducting plates. Proc. Kon. Nederland Akad. Wetensch 51, 793–795.

Compton, A. H. (1923) The Spectrum of Scattered X-Rays, Phys. Rev. 22, 409-413

Davisson, C. & Germer, L. H. (1927) Diffraction of electrons by a crystal of nickel, The Physical Review, 30 (6) 705-741

de Broglie, L. (1924) "Recherches sur la Théorie des Quanta," PhD Thesis, Masson, Paris; L. de Broglie, The wave nature of the electron, Nobel Lecture, December 12, 1929

Einstein, A. (1905) Über einen die Erzeugung und Verwandlung des Lichtes betreffenden heuristischen Gesichtspunkt, (On a Heuristic Point of View Concerning the Production and Transformation of Light) Ann. d. Phys. (4) 17, 132-148

Everett, H. (1957) 'Relative State Formulation of Quantum Mechanics', *Review of Modern Physics*, 29: 454–462; see also 'The Theory of the Universal Wave Function', in B. De Witt and N. Graham (eds.), *The Many-Worlds Interpretation of Quantum Mechanics*, Princeton: Princeton University Press, 1973.

Garai, J. (2017). The electronic structures of the atoms, *Physics Essays, 30*(4), 455-460.

Garai, J. (2022). The type of the interaction of the particle can explain the wave-particle duality, submitted to Foundations of Science.

Jönsson, C. (1961) Elektroneninterferenzen an mehreren künstlich hergestellten Feinspalten, Zeitschrift für Physik 161 454-474

Koch, R. H., Van Harlingen, D. J., Clarke, J. (1980) Quantum-noise theory for the resistively shunted Josephson junction. Phys. Rev. Lett. 45, 2132–2135

Koch R. H., Van Harlingen D. J., Clarke J., (1982) Measurements of quantum noise in resistively shunted Josephson junctions. Phys. Rev. B 26, 74–87.

Lamb, W. E. & Retherford, R. C. (1947) Fine structure of the hydrogen atom by a microwave method. Phys. Rev. 72:241-243.; Lamb, W. E., Fine structure of the hydrogen atom. (Nobel Lecture, Dec. 12, 1955.) Science 123:439-442. (1956)

Lähteenmäki, P., Paraoanu, G. S., Hassel, J. & Hakonen, P.J. (2013) Dynamical Casimir effect in a Josephson metamaterial, Proceedings of the National Academy of Sciences Mar 2013, 110 (11) 4234-4238; DOI:10.1073/pnas.1212705110

Mainland, G. B. & Mulligan, B. (2019) How vacuum fluctuations determine the properties of the vacuum, J. Phys.: Conf. Ser. 1239 012016

Merli, P.G., Missiroli, G. F. & Pozzi, G. (1976) On the statistical aspect of electron interference phenomena Am. J. Phys. 44 306-7

Mittelstaed, P., Prieur, A. & Schieder, R. (1987) Unsharp particle-wave duality in a photon split-beam experiment, Foundaton of Physics, 17 (9) 891-903

Sala, S., Ariga, A., Ereditato, A., Ferragut, R., Giammarchi, M., Leone, M., Pistillo, C., & Scampoli, P. (2019). First demonstration of antimatter wave interferometry, *Science Advances. 5*(5), eaav7610.

Tsuchiya, Y., Inuzuka, E., Kurono, T. & Hosoda, M. (1982) in Advances in Electronics and Electron Physics, edited by P. Hawkes (Academic, New York) Vol. 64A. p. 21

Tonomura, A., Endo, J., Matsuda, T., Kawasaki, T. & Ezawa, H. (1989) Demonstration of single-electron buildup of an interference pattern, Am. J. Phys. 57 (2) 117-120

Wilson, C M, Johansson, G., Pourkabirian, A., Simonen, M., Johansson, J.R., Duty, T., Nori, F. & Delsing, P. (2011), "Observation of the dynamical casimir effect in a superconducting circuit," Nature 479, 376

Wootters W. K. & Zurek, W. H. (1979) Complementarity in the double-slit experiment: Quantum nonseparability and a quantitative statement of Bohr's principle, Phys. Rev. D 19, 473

Yaakov Y. F., Geyer; P., Zwick, P., Kiałka, F., Pedalino, S., Mayor, M., Gerlich, S., & Arndt, M. (2019). Quantum superposition of molecules beyond 25 kDa, *Nature Physics. 15*(12), 1242–1245.

Young, T. (1804) The Bakerian Lecture. Experiments and calculations relative to physical optics, Phil. Trans. R. Soc. Lond. 94, 1-16.

Zeilinger, A., Gaehler, R., Shull, C. G. & Treimer, W. (1981) in Proceedings of the Conference on Neutron Scattering, Argonne, 1981, edited by J. Faber, Jr. (AIP, New York, 1982, p. 93.