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The Double Slit Experiment: Wavelength, Diameter and Speed of Free Non-Relativistic Subatomic Massive Particle

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In this communication, we consider the relationships between the wavelength, diameter and speed of a free subatomic (massive) particle (from now on particle) in the double-slit thought experiment. We postulate that this particle exhibits both wave and particle properties.

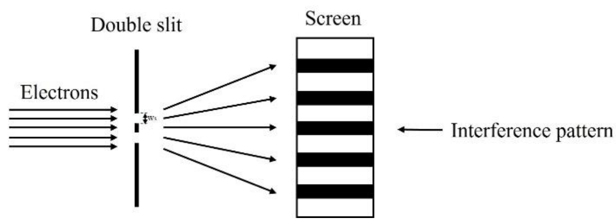

Figure 1. The schematic diagram of the double slit experiment with the beam of monoenergetic "non-relativistic" electrons.

The double slit experiment demonstrates that photons and electrons can behave as either particles or waves. In this communication, we will only deal with this experiment performed using the beam of monoenergetic "non-relativistic" electrons.[1] This beam is set up to point against a screen containing a two very tiny rectangular slits of width w_s. Behind these slits is situated a second screen (or an electron detector). This screen shows the interference pattern made by the electrons. The interference on the second screen depends on the width of the slit, w_S, and de Broglie's wavelength, λ, of the particle and its linear momentum p. In particle double-slit experiments, the slit width and separation must be comparable to or smaller than the de Broglie wavelength ($\lambda = h/p$) of the particles to observe clear interference patterns. For electrons, typical slits are nanometers in size, for example, 62 nm wide [1]

Suppose now that these electrons employed are spherical and has a non-relativistic mass (or at rest) $m_0 = 9.1 \times 10^{-31}$ kg. Mathematically speaking, the observable intereference pattern[2] would be obtained if

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[1] In general, the "non-relativistic" particle is that whose speed υ is far less than the speed of light or $\upsilon << c$ ($\approx 3\times10^8$ m sec^{-1}). Physicists usually assume that the massive particle with $\upsilon/c \leq 0.1$ (or $\upsilon \leq 0.1c$) is "non-relativistic". They also define the massive particle with $\upsilon/c > 0.1$ (or $\upsilon > 0.1c$) as "relativistic".

[2] Of note, no device can transform the interfered monoenergetic electrons back into the beam.

$$\lambda \gtrapprox w_S \quad \ldots (1)^3$$

Elementary physics states that the momentum of a non-relativistic massive particle $p = m_0\upsilon$ where m_0 is the mass of a particle at rest and υ is its speed. Its momentum p and wavelength λ are linked by de Broglie's relation

$$\lambda\ (= h/p) = h/m_0\upsilon \quad \ldots (2)$$

where h (= 6.63×10^{-34} J sec) is Planck's constant, m_0 is the mass of a non-relativistic particle (or at rest) and υ is its speed. Combining exp. (1) and eqn. (2) we get

$$\lambda = h/m_0\upsilon \gtrapprox w_S$$

or

$$h/m_0 w_S \gtrapprox \upsilon \quad \ldots (3).$$

Introducing into this equation the values for h (= 6.63×10^{-34} J sec), m_0 = (9.1×10^{-31} kg) and w_S (= 62 nm), we estimate that

$$\upsilon \gtrapprox 12000\ \text{km sec}^{-1}.$$

As we pointed out above $\lambda \gtrapprox w_S$ [exp. (1)] or $\lambda \gtrapprox 62$ nm = 6.2×10^{-8} m to observe clear interference patterns. However, physicists have been trying experimentally to measure the electron diameter, but until now with no success. It is believed that this diameter less than 10^{-18} m, say about 10^{-14} m. So, $\lambda/10^{-14}$ m $\gtrapprox 10^6$. Moreover, $\lambda \approx 62$ nm corresponds to the photon wavelength within the extreme ultraviolet (EUV) or vacuum ultraviolet (VUV) range of the electromagnetic spectrum. It seems that something is seriously wrong with our perception of the electron as a fundamental particle and its dimensions.

Reference

[1] R. Bach, D. Pope, S.-H. Liou, H. Batelaan, *Controlled double-slit electron diffraction*. New J. Phys. 15, 033018 (2013).

[3] Many books, papers, and other publications state that the slit width is "adequate," "comparable" to the wavelength of the particles, or "of the same order of magnitude" as that. Scientifically speaking, these are rather "vague" formulations. For that reason, we opted for the interpretation given in exp. (1).