THE NATURE OF THE VERY SMALL - IS IT A WAVE OR A PARTICLE?

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Understanding the nature of the very small is extremely difficult. Few things in the world are more familiar or basic than light. It is somewhat surprising therefore that physicists are still struggling to understand the fundamental nature of such a familiar phenomenon.

Isaac Newton (1642-1727) visualised the basic nature of light as a stream of particles. Charles Huygens (1629-1695) developed a wave theory of light, but the significance of his work was dimmed by the shadow of Newton's enormous reputation. The wave theory eventually moved centre stage when the brilliant experiments of Thomas Young (1773-1829) unambiguously demonstrated the wave-like properties of light.

In Young's experiment light is directed at a board that contains two small slits. A screen on the far side of the board displays the light that traverses the slits. The light forms a pattern of alternating dark and bright stripes on the screen. This pattern, called an interference pattern, can only be explained by treating light as a wave motion.

Light moves from the light source as a circular wave front (just as waves move outwards in a circle when a pebble is dropped in water). When the light hits the board it can only pass through the two pin-holes, each of which now transmits a circular wave front of light beyond the board. Those two spreading wave fronts overlap and interfere with each other before reaching the screen. The bright stripes on the screen represent places where wave crests from one slit meet wave crests from the other and reinforce each other. The dark stripes represent places where wave crests from one slit meet wave troughs from the other and cancel each other out. By measuring the spacing between the dark and the bright stripes one can calculate the wavelength of the light.

For almost 200 years Young's experiment was cited as proof that light is a wave. Then, in 1905, Albert Einstein proposed that it was sometimes useful to consider that light acts as a stream of particles (called photons or quanta). The electron, a subatomic particle was discovered in 1897 by J.J. Thompson. Not only is it unambiguously a particle, but it also carries a negative electric charge. In 1925, Louis de Broglie published a complementary version of Einstein's proposal, claiming that very small bodies, like electrons, can also behave as waves.

In 1925, quantum mechanics, the physics that describes the behaviour of the very small (atoms, sub-atomic particles, photons) was invented. It formally proposed that all atomic and sub-atomic objects have a dual wave/particle nature. Quantum mechanics describes the behaviour of the sub-atomic world very accurately. However, it has proved extremely difficult to understand the basic nature and concrete reality of things, as opposed to accurately describing and predicting their behaviour.

Young's experiment can also be carried out using electrons and identical results are obtained to those described using ordinary light. This result is completely counter-intuitive. Electrons are definitely particulate; how can they also behave as waves? If you knocked 2 holes in a wall and threw thousands of balls at the wall you would end up with 2 distinct piles of balls on the other side, not a series of lines of balls.

The electrons must travel as waves in Young's experiment in order to produce the interference pattern, but they leave the electron source as particles and arrive at the screen as particles (you can see the individual particles showing up as dots as they arrive at the phosphorescent screen). OK, you may say, put a lot of electrons together and they somehow push and jostle each other into a wave pattern. But, amazingly, if you fire the little particles through the experiment *one at a time* you still get the same interference pattern of alternating dark and light stripes. (This last experiment has been carried out using neutrons, but not yet, I think, using electrons).

Things can get stranger still; if you observe the electrons on their flight through the experiment they react in a very odd manner - the interference pattern disappears and you get a distribution of light on the screen equivalent to the distribution of balls thrown at a wall containing 2 holes. Even stranger, the same thing happens even if you don't watch the electrons, but if you introduce the *potential* for watching them.

Electrons have a magnetic flag associated with them. Place a device at the left slit that flips the magnetic flags of all the electrons passing through to the up direction and place a device at the right slit that flips the magnetic flags of all the electrons passing through to the down position. You now have the potential to identify the slit through which every electron that arrives at the screen passed on its journey. This in itself makes the interference pattern disappear, whether or not you avail of the potential to identify the slits.

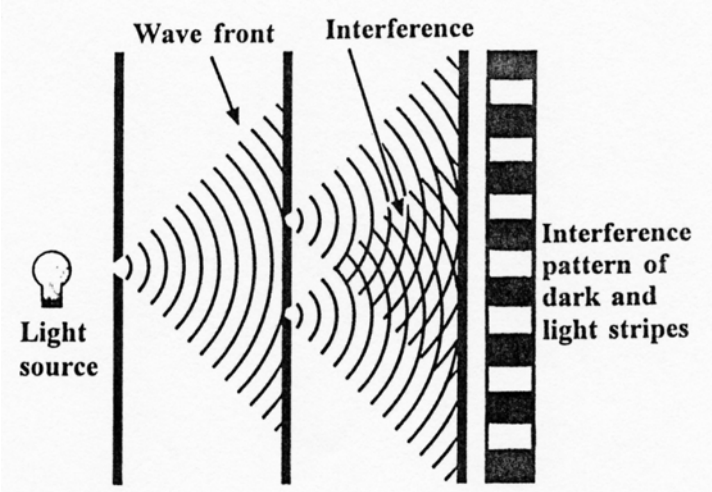
Now go one step further. Interpose a device between the slits and the screen to remove the magnetic flags that would identify the slits. The interference pattern reappears. If you incompletely erase the flag information the sharpness of the interference pattern is degraded to an extent proportional to the extent of removal of the tagging.

It seems that the basic nature of subatomic particles and of light is both (not either/or) wave and particle. The expression of 'waviness' or 'particulateness' depends on the circumstances. At one extreme only particulate properties are expressed, at the other only wave properties are expressed, and in between both wave and particle properties are displayed.

The difficulty in visualising the dual particle/wave nature of the very small stems from the fact that we normally don't encounter this duality in the everyday physical world. However, if we think more generally we can easily identify cases where a characteristic can also express itself in the opposite manifestation. For example, one must sometimes be cruel to be kind.

If you find it difficult to understand what I have been flailing at explaining, don't worry. I don't really understand this stuff myself. But, we are in good company - that of Albert Einstein who said, - 'Fifty years of conscious brooding have brought me no nearer to the answer to the question - What are light quanta? - Nowadays every Tom, Dick and Harry thinks he knows it, but he is mistaken'.

(See illustration below.)



Young's experiment to demonstrate the wave nature of light. If the photons are observed as they pass through the slits, the interference pattern is not formed.

The Youngs slits experiment

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