Do matter and energy behave as particles or as waves?

A curious irregularity exists in Physics, one which has confounded even the greatest minds and to this day seems a most bizarre paradox. The debate as to whether matter and energy behave as particles or as waves has a long and often quarrelsome history which dates back to ancient times when philosophers pondered the fabric of the universe; but it wasn't until the 1600s, when accurate experiments using light were undertaken, that a Physical model was required to explain the effects that had been observed.

Newton suggested that light behaved as a series of particles called 'corpuscles', whereas Huygens claimed that it was made up of waves. The corpuscular theory gained widespread acceptance, in part due to it being easy to visualise. However, evidence as to the failings of the theory was continually mounting and in 1801 Thomas Young conducted an experiment that showed light passing through two slits interferes in an almost identical way to that observed for a similar experiment using water waves.

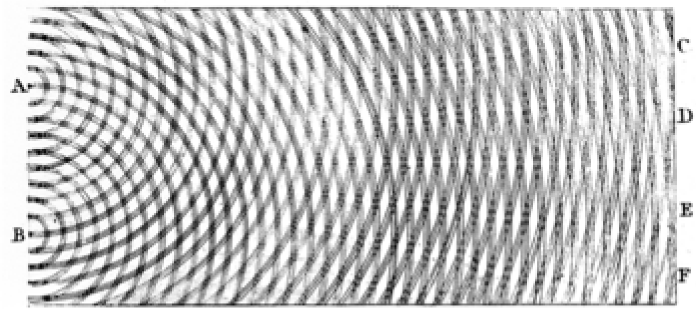

Figure 1 - Thomas Young's sketch of two-slit diffraction and interference

This seemed to be proof and Young concluded that light's propagation was ruled instead by wave theories. This new idea now gained widespread acceptance and remained largely unchallenged until new experiments became possible.

These experiments showed that electrons on a metal surface could be completely removed by shining certain light on it. The ability to remove the electrons seemed to depend not on the brightness of the light but on its energy.   This led Einstein to show that light can be thought of as particles or 'quanta' with certain discrete amounts of energy and only light with a high enough frequency, and therefore energy, would be able to remove the electrons from the metal.

These two theories explained light in two different, yet equally valid, ways - both of which could be experimentally verified - but which one was correct?

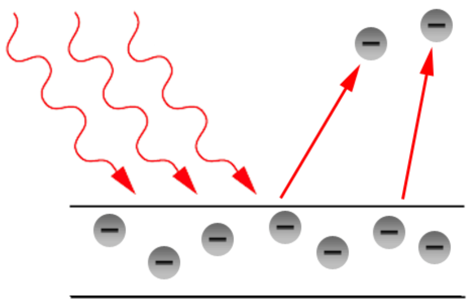

Figure 2 - The Photoelectric Effect

To confuse matters further, in 1923 Louis de Broglie discovered that the wave effects described by Young also applied to particles as well as light and showed that a moving particle such as an electron had an associated wavelength - a theory supported by electron diffraction experiments very similar to Young's which used light. This was the basis for wave mechanics and strongly influenced quantum theories which would follow.

A part solution to the paradox came in 1926 when Erwin Schrödinger explained the two theories in his famous 'wave equation'. Amazingly, it says that far from one theory being right and the other being wrong, it's quite allowable to have two conflicting descriptions of the experiments. Indeed, it seems both are correct.

Niels Bohr interpreted the results as 'complementarities'; individually, neither model can adequately explain what we observe but the wave equation shows that both are valid and draws them together into one mathematically precise description that says energy and matter can and do appear as both particles and waves in different experiments.

Many scientists are not completely satisfied with this result as it is hard to visualise in a 'Newtonian' sense, but the nature of matter and energy is clearly ruled by quantum mechanics, where the probabilities and uncertainties involved are difficult to interpret, and so it is likely that we may never truly understand wave-particle duality.

Sources

All dates quoted from 'Oxford Dictionary of Physics' Fifth edition, 2005
Figure 1 - http://www.answers.com
Figure 2 - http://erik.raunvis.hi.is/nam/uploads/images/skammta03.png

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