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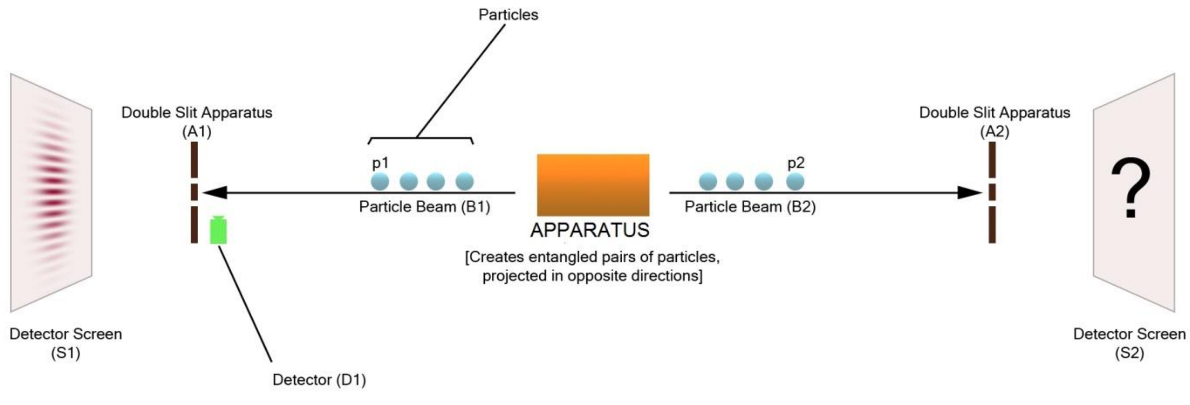
# Quantum Entanglement: Does it work ? *By Dilip D James*

Quantum entanglement remains the flagship experiment of quantum mechanics. It is the final undeniable explanation, illustrating that at the level of the very small things behave in a manner that is completely incomprehensible at the macro level. Quantum entanglement, the spooky action at a distance that promises to be so useful for things like high-powered computing and security, is generally considered a function of the tiny world. It's possible to take two particles or two microscopic things and intertwine their fates. Quantum entanglement is the physical phenomenon that occurs when a pair of particles is generated and interact, or share spatial proximity in a way such that the quantum state of each particle of the pair cannot be described independently of the state of the others, even when the particles are separated by a large distance. When two particles, like a pair of electrons, are entangled, it's impossible to measure one without learning something about the other. Their properties, like momentum and position, are inextricably linked. The topic of quantum entanglement is at the heart of the disparity between classical and quantum physics.

Quantum entanglement has been experimentally confirmed time and again. While physicists have learned to control and study quantum entanglement, they've yet to find a mechanism to explain it or to reach consensus on what it means about the nature of reality. Sometimes it doesn't work.




Look at the above drawing. The apparatus is beaming two streams of entangled particle pairs (B1 and B2) in opposite directions (e.g.: Particle no. 1 (p1) goes left, Particle no. 2 (p2) goes right, where p1 and p2 are making up an entangled particle pair). When B1 encounters the Double Slit Apparatus (A1) in its way, an interference pattern will form on the Screen (S1) behind the plate with the Double slit. There is a switchable Detector (D1) that can monitor the Double Slit Apparatus (A1) and determine through which slit p1 is passing through. If D1 is switched off, the interference pattern prevails; however, if D1 is active, the wave function collapses and draws a ballistic pattern over time.

The question is as follows. Would the switching on of D1 affect the pattern on Screen 2. If quantum entanglement is to be believed then surely anything that affects p1 should also affect p2. Common sense tells us that the switching on of the detector should not affect the result at Screen 2. Because it would mean that information would have to travel faster than the speed of light.  Unfortunately, accurate experiments of this type have not been performed, so the most that can be said is that the experiment is inconclusive.

The world of quantum mechanics—the physics that governs the behaviour of the universe at the very smallest scales—is often described as exceedingly weird. According to its laws, nature's building blocks are simultaneously waves and particles, with no definite location in space. It takes an outside system observing or measuring them to push them to "choose" a definitive state. And entangled particles seem to affect one another's "choices" instantaneously, no matter how far apart they are.

The physicist John Bell came up with three assumptions about classical physics, which, if violated, would prove quantum mechanics to be true. These were:

1) That objects maintained their identity whether being observed or not. This was the classical assumption of 'realism' that assumed that objects maintain their properties regardless of whether they were being observed or not.
2) The assumption that nothing, no information or signal, could move to affect two separated objects faster than light.
3) The third assumption that Bell made was that of freedom of choice, it assumes for instance that scientists can make measurements freely, without being affected by hidden variables.

A key tool that can be used to test these assumptions is entanglement. If experiments show that nature obeys these assumptions, then we live in a world we can understand classically, and hidden variables are only creating the illusion of quantum entanglement. If experiments show that the world does not follow them, then quantum entanglement is real and the subatomic world is truly as strange as it seems.

The classical quantum entanglement experiment takes place when two quantum entangled photons are produced and sent through two polarisers. The result of this experiment shows indisputably that if one of the photons is polarised in the horizontal direction that the other will be polarised in the vertical direction. The truly amazing thing about quantum entanglement is that the two photons can be separated by practically any distance, even some claim at two ends of the Universe and they will always produce the same results, if one entangled photon is vertically polarised the other will be horizontally polarised and vice-versa.

If looked at as it is explained here, this experiment lends a certain inevitability to the conclusion that quantum mechanics has everything figured out and that this is surely the key to the

solution as to how the world works. BUT, if one goes back to basics and examines how these photons are entangled, things become more complicated. Let us start with polarisers. What happens to polarised light? How is it produced?

The polarisation of light takes place when it is passed through a polarising medium. This polarising medium is inevitably a dichroic crystal. The one thing to remember is that when photons travel through a medium, they do not just go straight through, they are absorbed and re-emitted. In optics, a dichroic material is either one which causes visible light to be split up into distinct beams of different wavelengths (colours) (not to be confused with dispersion), or one in which light rays having different polarizations are absorbed by different amounts. In dispersion the colours are separated but are transmitted with their original energies and frequencies intact, while in dichroism, the original photons are absorbed and re-emitted at a different frequency and energy. Therefore, when speaking in terms of polarised light we are actually speaking in terms of the properties of the polariser. In the case of linearly polarised light, the dichroic crystal absorbs, depending on its orientation, almost all of, either the horizontal or vertical, component of light and transmits the remainder. Hence, it is not a question of a ray of light being turned through an angle and continuing on its journey through the crystal but of photons being absorbed and retained or retransmitted.

Taking this a step further, one of the main methods to bring about quantum entanglement that is in use today is to shine a high energy laser through a beta barium borate crystal. What happens next? Just as glass absorbs ultraviolet light, so too does the BBO crystal. The crystal then re-emits two beams of near infra-red light (possibly as a result of heat dissipation) due to its dichroic birefringent property. It is significant to note that this process has nothing at all to do with the laser and everything to do with the property of the BBO crystal. Definitely the emission of two beams of light demonstrates the birefringent properties of the crystal. This property is known as double refraction, whereby a beam of light is split into two identical beams of light, with opposing properties. This means if one beam of light is polarised in one direction, say the vertical direction, the other beam of light will be polarised in the horizontal direction. So, if the polarisation of one beam of light is measured, it is possible to determine the polarisation of the other beam of light because it will be the direct opposite of the polarisation that the first beam of light had. One can state that the two beams are entangled to that extent and that this entanglement holds good for even spatially separated beams of light.

This brings us to the more complicated aspect of quantum mechanics claims, namely that it is possible to change the state of polarisation of one beam of light and so to change the polarisation of the second beam of light. Ideally this would involve measuring the polarisation of the first beam of light by passing it through a polariser and then passing that light through a second polariser, so that the original polarisation of the second beam of light undergoes a change. At present there is inconclusive evidence as to what the result might be.

Whatever the result, it is clear that quantum entanglement is a long way from being proof of quantum weirdness. If anything it falls far short of any such definitive proof. Yet, as always, quantum mechanics insists that quantum entanglement is proof of ALL quantum assumptions, such as superposition, disassociation, the wave-function, wave-particle duality. Yet, it is only too apparent from an examination of the facts, that quantum mechanics has a long, a very long way to go before it can offer decisive proof of its zany theories.