QUANTUM MECHANICS

So now we come to the theory which has quite literally revolutionised all our lives- even though most of us are unaware of it. In what follows we will cover the following:

(1) The basic features of Quantum Mechanics- superposition, interference, entanglement; the wave-particle duality; spin, fermions & bosons, & indistinguishability.

(2) The historical development of the subject, and the deep philosophical questions that were and still are raised, about the nature of physical reality, by quantum phenomena.

(3) The way in which quantum mechanics has allowed us to understand how the universe works, from scales ranging from quarks to the universe- a range of some 42 orders of magnitude (10^{42}, or 1 followed by 42 zeroes) in length scale.

BRIEF INTRODUCTORY SURVEY of QUANTUM MECHANICS

The Fisherman & the Genie (Arabian Nights)

Quantum Mechanics is unique in the intellectual history of the world, because

(i) It has no known limits to its validity

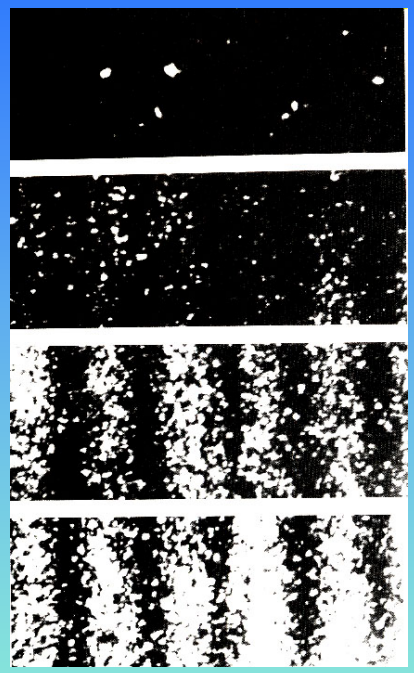
(ii) Fundamentally, we do not understand it at all!

Walt Disney saw it as a Djinni ("genie"), for Good or Bad.

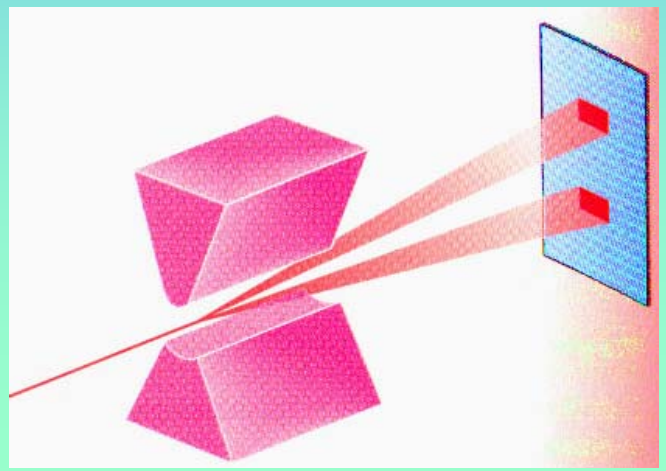
The Genie of Power (Disney)

Q.M. Mysteries: Superposition, Interference, and Spin

The best way to appreciate Quantum Mechanics is to look at it. Here are 2 examples of quantum behaviour.



(1) If one fires electrons through a pair of slits, in the same way as we saw for light, then, we get the result shown at right. The electrons arrive on a screen behind the slits in "lumps" (causing flashes on the screen), as we would expect for particles. However the pattern of arrivals is not what we would expect- in fact they arrive preferentially in band-like regions, as though they were being guided by interfering waves. Even more remarkably, WE SEE THE SAME RESULT FOR LIGHT- the lumps here being called PHOTONS.

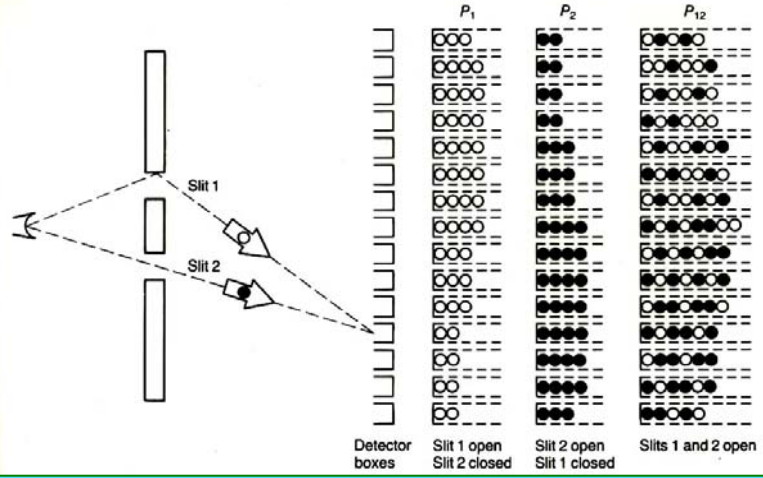


(2) In many cases we also find that only a finite set of states are allowed- this is also completely different from what we are used to in classical physics. At left the famous "Stern-Gerlach" experiment for spin is shown- only 2 values are allowed.

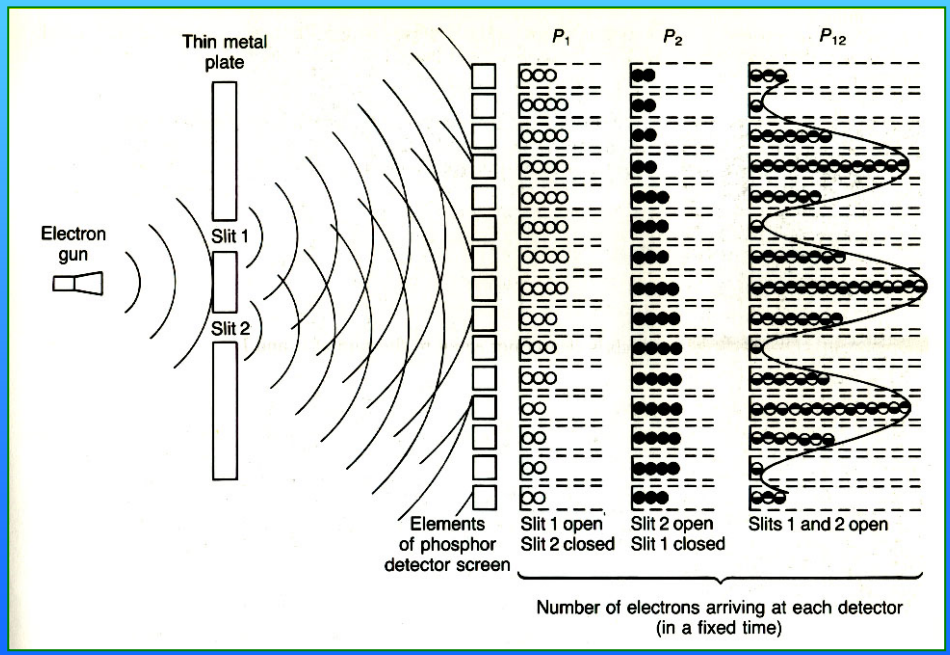
Particles vs Waves

There is NO WAY that one can understand the propagation of the particles through 2 slits as 'particles'.

On the other hand there is no way that one can understand their propagation as mere waves either- the electrons arrive on the screen as discrete "lumps", as do photons. This is the WAVE-PARTICLE DUALITY.



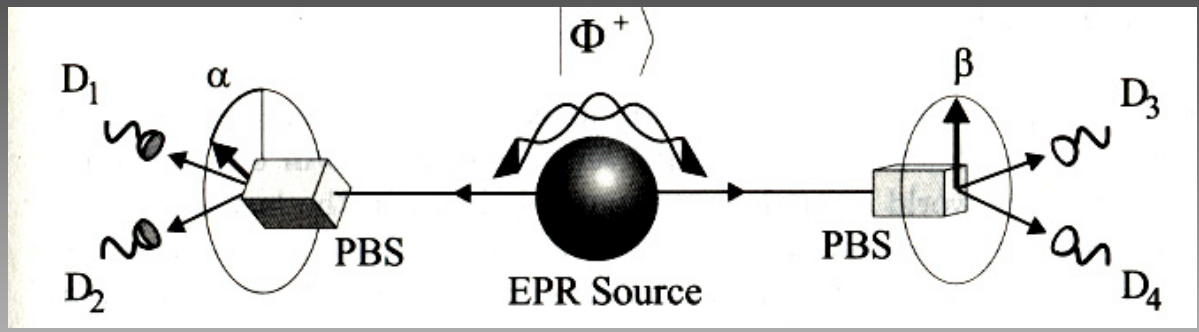
Pattern of arrivals of classical particles when one or other of the slits is open, & when both are open.



Pattern of arrivals of electrons with the same combination of slits open or closed.

In the early days of Quantum Mechanics, a solution to this was proposed by M. Born. According to this idea, the wavelike pattern is a "probability amplitude", which can be used to tell us the probability that a particle will arrive on the screen at some point. In this way it seemed that we had lost the deterministic quality of classical physics.

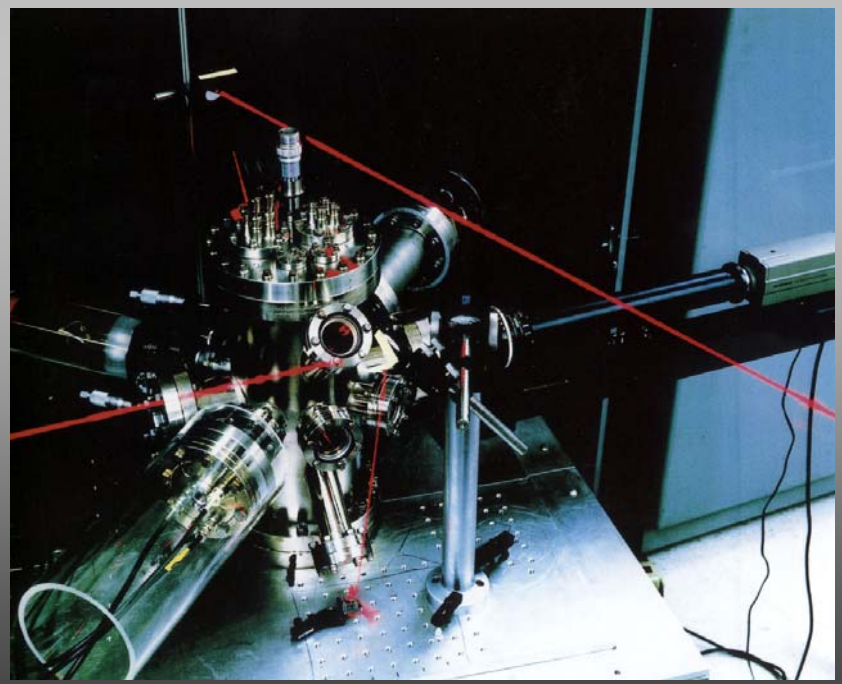
Quantum Entanglement



Just as bizarre is the phenomenon of NON-LOCAL ENTANGLEMENT"

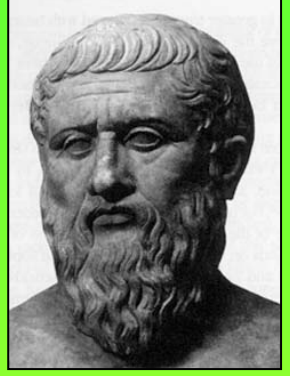
The result here is that the observed behaviour of one of the systems depends on what happens to the other- no matter how far apart they are (such that no signal can propagate between them).

Such experiments are now done in the lab (usually with photons). A major challenge is to achieve this on a larger scale.



A set-up for experiments on EPR-entangled photons

The Philosophical Problem

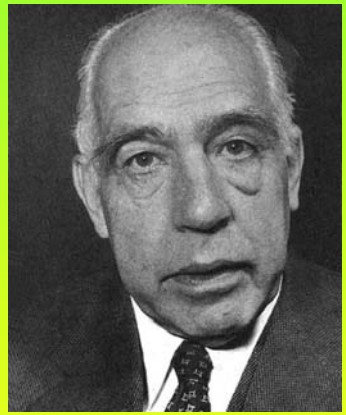


Plato
(428-348 BC)

Some have thrown up their hands and said that Plato got it right all along- that when it comes to understanding physical reality we are all in the cave...

Some new philosophical approaches have evolved

'One may ..limit the use of the word PHENOMENON to refer to observations obtained under specified circumstances, including an account of the whole experiment' (N. Bohr)



N.Bohr (1885-1962)

There is no quantum world. There is only an abstract quantum description. It is wrong to think that the task of physics is to find out how Nature is. Physics concerns what we can say about Nature.

'We are suspended in Language' (attributed to N. Bohr)

These are just a few examples of the strange ideas that have been forced to the surface by QM. We shall attempt to understand these and others, as we go along.