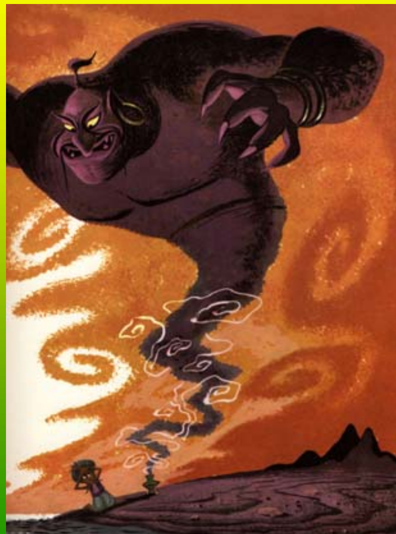
QUANTUM MECHANICS on the LARGE SCALE

(PWIAS Exploratory Workshop)

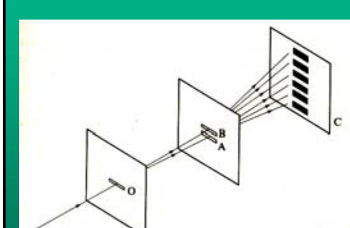


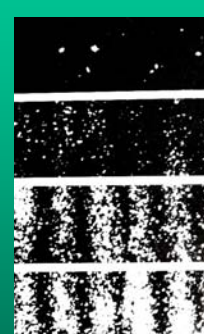
Quantum Mechanics is unique in the intellectual history of the world, because

(i) It has no known limits to its validity
(ii) Fundamentally, we do not understand it at all!

A Q.M. Mystery: Superposition & Interference

The best way to appreciate Quantum Mechanics is to look at it.

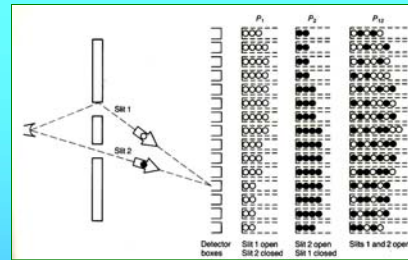


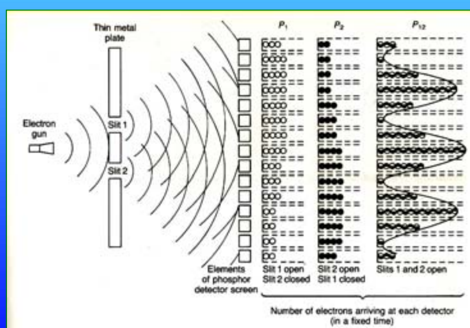


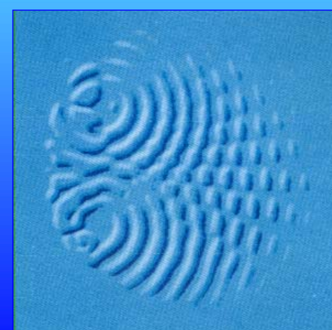
Particles vs Waves

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

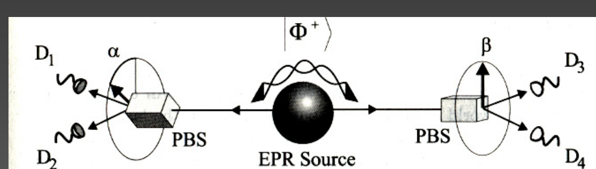
On the other hand there is no way that one can understand their propagation as mere waves either.







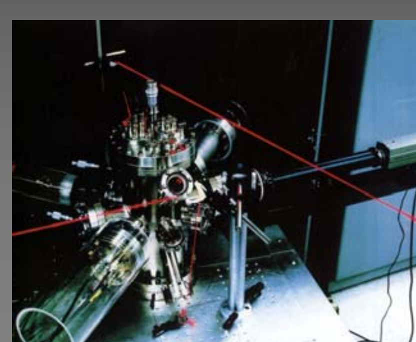
Quantum Entanglement



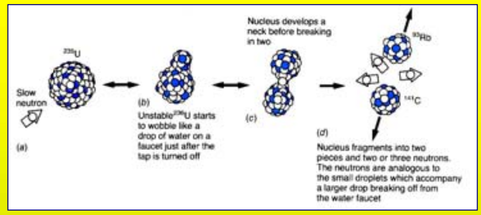
Just as bizarre is the phenomenon of non-local “entanglement”.

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).

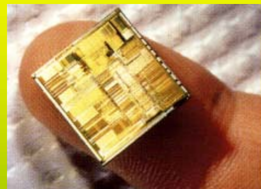
Such experiments are now done in the lab (usually with photons).



Q.M. on the Small Scale



At the atomic and sub-atomic scales, interference and superposition are everywhere.



Pentium 2 processor

The understanding of all physical processes at these scales has already begun to revolutionise the way we live.

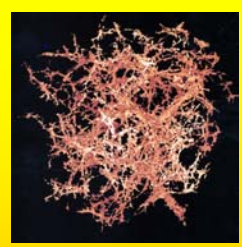
This process has hardly begun.

Nuclear fission

A Quantum Corral

Effects of Q.M. on the large Scale

Although quantum effects like interference and entanglement were not expected at the macroscopic scale by the founders of Q.M., the indirect effect of Q.M. is very clear, at scales up to the cosmological. In fact, one can't understand physical processes at the large scale without Q.M.



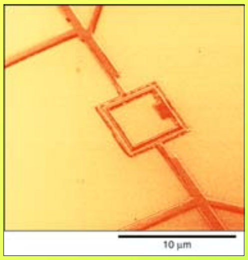
Galaxy distribution

Superfluid fountain

Hubble deep space field

Experiments on SQUIDs

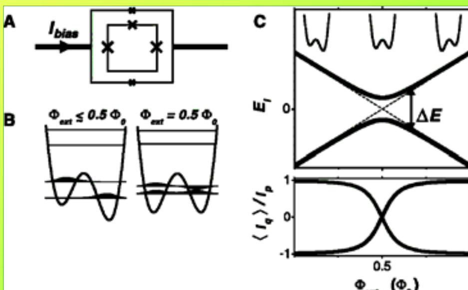
J.E. Mooij et al, Science 285, 1036 (1999)
C. Van der Wal et al., Science 290, 773 (2000)

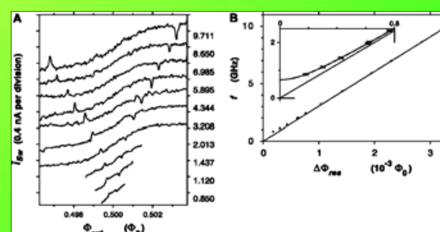


MACROSCOPIC QUANTUM INTERFERENCE

$\Psi_+ \sim \psi_1 + \psi_2$ and $\Psi_- \sim \psi_1 - \psi_2$

where ψ_1 and ψ_2 are the 2 flux states.
More recently "Rabi oscillations" have been observed between these states.

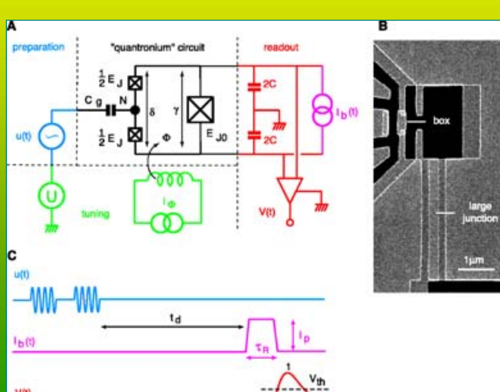


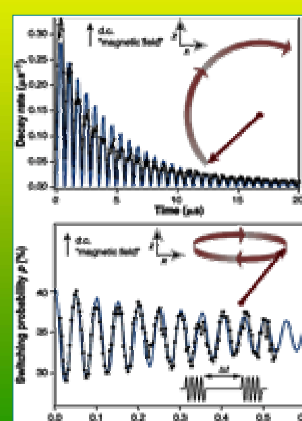


Superconducting Qubits

MACROSCOPIC QUANTUM ENTANGLEMENT?

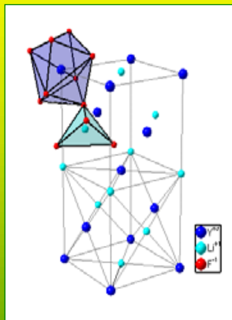
Here the idea is to harness many quantum systems together, such that one gets entanglement between all of them. If each is itself in a superposition the resulting states can be incredibly complex.
Here this is done with SQUIDs.



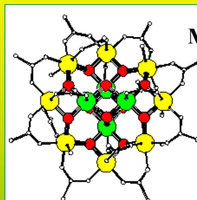


The Quest for Magnetic Qubits

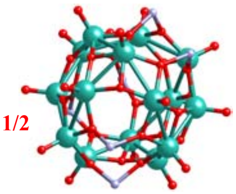
Another way of trying to set up complex entangled states is to use Nanomagnetic systems- here is some of the cast of characters.



Ho ions in $LiYF_4$ host



Mn_{12} S = 10

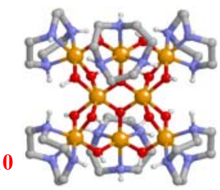


V_{15} S = 1/2

Single-molecule magnets (SMM)

Giant spins

Ni_{12} S = 12



Fe_8 S = 10

QUANTUM INFORMATION PROCESSING

The basic ideas of quantum information processing were developed by Feynman, Benioff, Deutsch, etc., in the period 1980-1990. The idea was that one could use a superposition of N entangled qubit states to do information processing/ computation- ie., states of the form

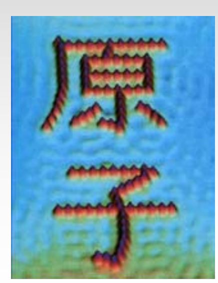
$$\Psi = \alpha_{++}|++> + \alpha_{+-}|+-> + \alpha_{-+}|-+> + \alpha_{--}|-->$$

(this is an entangled state of 2 Qubits)

FEYNMAN

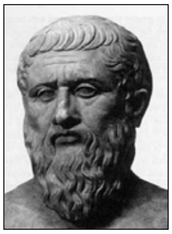
the crucial thing is that we can play with the phases of each of these coefficients (ie., $\alpha_{++} = |\alpha_{++}| \exp(i\phi_{++})$).

Since then algorithms have been developed using such wave-functions, to do computations exponentially powerful in N (by Shor); and "error correction" routines allowing one to correct errors arising from, eg.,decoherence. Decoherence is the crucial problem- a problem involving nanoscience and theoretical condensed matter physics.



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

Nils Bohr

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

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' (N. Bohr)

This is no longer good enough.