# QUANTUM PHILOSOPHY

**Perhaps the most difficult things to understand about QM are (i) how to reconcile our common sense ideas about physical reality with phenomena such as entanglement, & (ii) how to make sense of the distinction between the language of classical physics used to describe macroscopic objects & phenomena (such as tables, chairs, and measuring devices), and the QM description. We may express the puzzles as follows:**

**(a) Most of us accept that tables or measuring devices are physical systems made from atoms, & describable therefore in entirely quantum-mechanical terms. So why are they described in classical terms in QM- & why is it that we cannot say what is happening in a quantum system except by reference to classical concepts & classical systems like measuring devices?**

**(b) We are used to thinking of spatially isolated physical objects as existing in their own right, with independent physical properties & description- ie., Nature is made from building blocks. How is this compatible with entanglement- which seems to imply some sort of 'holistic' picture of Nature, in which the properties of systems are not defined independently of each other?**

……………..

**COPENHAGEN INTERPRETATION: due to Bohr, this denies that one can discuss a physical system in isolation from the MEANS of determining its properties- & this 'means' must be expressed in CLASSICAL terms:**

**'It is decisive to recognize that, *however far the phenomena transcend the scope of classical physical explanation, the account of all evidence must be expressed in classical terms*' (Bohr 1949).**

**'The essentially new feature of the analysis of quantum phenomena is, however, the introduction of *a fundamental distinction between the measuring apparatus and the objects under investigation*. This is a direct consequence of the necessity of accounting for the functions of the measuring instruments in purely classical terms, excluding in principle any regard to the quantum of action' (Bohr 1959).**

N Bohr in 1916

# COPENHAGEN Interpretation (II)

**The relationship between the measurement system & the quantum object of observation is clearly one of entanglement:**

**'Now, the quantum postulate implies that any observation of atomic phenomena will involve an interaction with the agency of observation not to be neglected. Accordingly, an independent reality in the ordinary physical sense can neither be ascribed to the phenomena nor to the agencies of observation. . . ..' (Bohr, 1928)**

**What his means is that even though we have to describe physical phenomena using classical concepts like position & momentum, these concepts cannot be applied in the usual way:**

**'We are here faced with an epistemological problem quite new in natural philosophy, where all description of experience has so far been based on the assumption, *already inherent in ordinary conventions of language*, that it is possible to distinguish sharply between the behavior of objects and the means of observation. This assumption is not only fully justified by all everyday experience *but even constitutes the whole basis of classical physics*. . . . As soon as we are dealing, however, with phenomena like individual atomic processes which, due to their very nature, are essentially determined by the interaction between the objects in question and the measuring instruments necessary for the definition of the experimental arrangement, we are, therefore, forced to examine more closely the question of what kind of knowledge can be obtained concerning the objects' (Bohr, 1938).**

**This leads to the idea of COMPLEMENTARITY: that different classical quantities are describing complementary properties of physical systems, and 2 complementary properties cannot be simultaneously defined. Examples of complementary quantities are (i) position r and momentum p (ii) two perpendicular components of spin.**

**Notice that if we take the QM wave-function to represent 'physical reality', rather than just our information about the system, then we must conclude that these complementary properties of the system cannot simultaneously EXIST.**

# The MEASUREMENT PARADOX (I)

It is now easy to see that entanglement leads to a very severe paradox in Quantum Mechanics, once we include the measurement operation itself in the quantum description. By definition a measurement must correlate the state of a measuring system (call it 'system 1') AFTER the measurement with the state of the observed system (call it system 2) BEFORE the measurement. Now IF THE MEASURING SYSTEM ITSELF IS TREATED AS A QUANTUM SYSTEM, we also have to describe it by a wave-function- call it $\Phi(1)$. Then the measurement operation must work as follows:

$$\Phi_o(1)\ \phi_-(2) \rightarrow \Psi_{--}(1,2) = \Phi_-(1)\ \phi_-(2)$$

INITIAL STATES FINAL STATES

$$\Phi_o(1)\ \phi_+(2) \rightarrow \Psi_{++}(1,2) = \Phi_+(1)\ \phi_+(2)$$

One should not be intimidated by the algebra here. On the left we see the initial state- the 'apparatus' (system 1) is in some initial 'zeroth' state, and we imagine the atomic system (system 2) in either a state -- or a state + . The final state of the apparatus must then be uniquely correlated with these initial states, as shown. So far so good. But now suppose the atomic system is in a SUPERPOSITION of + and -- states. Then there is no way we can avoid the following conclusion:

$$\Phi_o(1)\ [\ \phi_+(2) + \phi_-(2)\ ] \rightarrow (\Psi_{++} + \Psi_{--})$$

$$= [\ \Phi_+(1)\,\phi_+(2) + \Phi_-(1)\,\phi_-(2)\ ]$$

The final state is neither + nor -- but a superposition of the two. But this is incredible- the apparatus is a macroscopic system, & the 2 apparatus states might be quite different (involving, eg., 2 different pointer positions). This consequence of QM is called the "measurement paradox".

# The MEASUREMENT PARADOX (II)

**The reason why the result just discussed is so bizarre, is that we have succeeded in entangling a microscopic and a Macroscopic system, such that they in a superposition involving 2 macroscopically different apparatus states (eg., 2 different pointer positions). But these are surely CLASSICAL states- how can they be superposed? In the philosophical approach of Bohr, such Macroscopic superpositions Are disallowed. However- if this superposition is impossible, then we have to explain WHEN the usual QM picture breaks down, ie., WHEN the QM superposition undergoes "WAVE-FUNCTION COLLAPSE" to one or other classical state.**

**The whole idea of basing Quantum Mechanics on measurements, & the results of measurements, has struck many as very bizarre. Bell has summarized this well:**

**"The concept of 'measurement' becomes so fuzzy on reflection that it is quite surprising to have it appearing in physical theory *at the most fundamental level.* Less surprising perhaps is that mathematicians, who need only simple axioms about otherwise undefined objects, have been able to write extensive works on quantum measurement theory- which experimental physicists do not find it necessary to read" (JS Bell, 1981)**

**"It would seem the theory is exclusively concerned with 'results of measurments', and has nothing to say about anything else. When the system in quesation is the whole world, where is the measurer to be found? Inside, rather than outside, presumably. And what exactly qualifies some subsystems to play this role? Was the world wave-function waiting for billions of years until a single-celled living creature appeared? Or did it have to wait a little longer for some more highly qualified measurer- with a PhD?" (JS Bell, 1982)**

**The basic problem here is of course that a measuring system is just a physical system like any other. Thus a proper theory has to either treat it along with rest of the world, in a unified way- or else if measuring systems really are different, the theory has to explain how, & explain when & how wave-packet reduction occurs. We return to this later**

# QUANTUM ONTOLOGY

The most disorienting aspect of QM is the apparent lack of any notion of an underlying **PHYSICAL REALITY**, objective and independent of any observer or observation. Curiously, it would be hard to find any physicist who really behaves in accordance with the idea that the states of objects in the physical world are contingent on observers or measuring systems. However the writings of some of the early theorists in Quantum Mechanics were at variance with this common sense attitude. We have already seen what Bohr had to say- here is another:

> "… in the experiments about atomic events we have to do with things & facts, with phenomena that are just as real as any phenomena in daily life. But the atoms or the elementary particles are not as real; they form a world of potentialities or possibilities rather than one of things or facts" (W. Heisenberg, 1933)

What is common to these early writers is the idea that 'quantum reality' has to be understood quite differently from classical- that the properties of an atomic system do not 'belong' to the atom but to the atom plus whatever it is entangled with (in particular, the 'experimental arrangement'). The 'real' properties of the atom are somewhat like a rainbow- objectively verifiable, but essentially an illusion coming from raindrops, light, and an observer in a particular relationship to each other.

In more recent years many have rebelled against this idea. A typical example from a philosopher is the following:

> The opposite view, usually called the *Copenhagen interpretation*, is almost universally accepted. In brief it says that *"objective reality has evaporated", and that quantum mechanics does not represent particles, but rather our knowledge, our observations, or our consciousness of particles."* (K Popper, 1967)

However, so far no more acceptable way to understand QM has been found- at least, not one that has been widely accepted. Thus the question of what kind of physical reality we are dealing with has yet to find a satisfactory resolution.

On the other hand, one can also try to find a different interpretation of QM- many have tried this….

# Quantum Philosophy - Other Interpretations (I)

**We see that whether we adopt the ideas of Bohr (in which macroscopic systems are classical) or instead assign a quantum state to macroscopic systems, we get bizarre conclusions. Are any other 'interpretations' of QM possible? Here are a few others (none of which is widely accepted):**

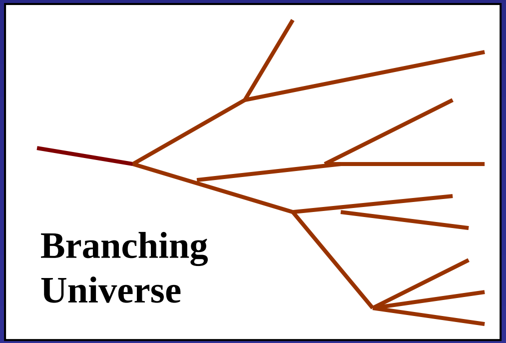
**(1) Statistical Interpretation: In which the results of measurements, and the wave-function, only give the statistical properties of ensembles of similarly prepared systems. Sometimes taken to imply that the wave-function only encodes our "information" about the quantum system., or about statistical correlations between measurements.**

**Problems: Gives up the attempt to describe individual systems (which we are in reality concerned with). Tries to make QM solely about information and measurements- what has happened to the physical systems themselves, and what defines a measurement in the real world?**

**(2) 'Many Worlds' interpretation: In which the universe branches into all the components of the wave-function every time a measurement takes place- giving a multi-branched universe.**

**Problems: The 'branching' process corresponds in no way to the underlying 'multi-path' structure of QM, or to any known spacetime structure (for quantum gravity); worst of all, there is no prescription for WHEN the branching (ie., measurement) takes place- this is just the measurement problem again. As Bell writes:**

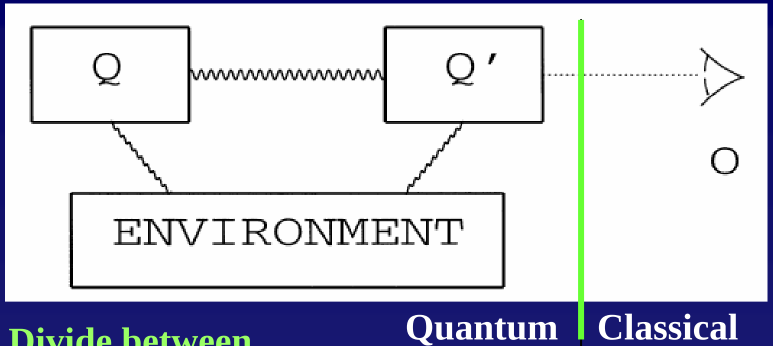
*'The* 'Many worlds interpretation' *seems to me an extravagant- and above all an extravagantly vague- hypothesis' (JS Bell (1986))*




**(3) 'Consciousness': That the dividing line between the quantum and classical world can be found, and lies in the divide between mind and matter- that somehow the conscious mind causes the collapse of the quantum wave-function, leading to classical physics once one reaches the level of conscious systems…(some are willing to substitute 'biological' for 'conscious')...see next page →**

# Other Interpretations (II)






Divide between classical & quantum regimes; the conscious observer **O** is classical, but the atomic system **Q**, apparatus **Q'**, & environment are quantum

**Problems: why 'consciousness' (whatever it is)? Does this mean 'self-consciousness', or just 'consciousness'? Of what, and by whom? Does this include only humans, or dogs, cats, or bacteria? Or robots/computers? Looks anthropomorphic, & hopelessly vague, with no trace of a theory at all. Even if one supposes some 'wave-function collapse' at the biological level, this still smacks of vitalism, & looks mediaeval- there is no evidence from biology for such an *ex cathedra* hypothesis.**

**(4) Quantum Gravitational Effects: The speculation is that in some theory of quantum gravity or string theory, gravitational effects might cause wave-function collapse at the macroscopic scale.**

**Problems: No theory (only dimensional arguments). No reason why gravity should play any role in typical quantum measurements, where gravitational effects are typically v small & unrelated to the physics taking place.**

**(5) 'Non-Linear' Theories: These introduce non-linear terms into the Schrodinger equation to cause wave-function collapse when the number of particles is large.**

**Problems: These theories are very *'ad hoc'*; there is no real theoretical justification for the non-linear terms beyond the desire to solve the measurement problem. They are usually vague- where more specific & testable they have been wrong.**

**It seems most likely that any theory which supplants Quantum Mechanics is likely to be much less artificial than these remedies- and probably much stranger, but even more general, than QM now seems!**