13 Interpretations of Quantum Physics

13.1 Copenhagen Interpretation

The Copenhagen interpretation of Quantum Physics was developed by Niels Bohr and his assistant, Werner Heisenberg, between 1925 and 1927 [29]. It is based on the proposition that Physics is the Science of measurement and that a measurable quantity has no reality until it is measured. In the Copenhagen interpretation, one applies the rules of Quantum Mechanics to sub-microscopic systems but not to the measuring device, which is a macroscopic object that has the property (for reasons which are not understood) of effecting wavefunction collapse from a quantum superposition to a classical probabilistic state.

It is for this reason that a system can be in a superposition of several (or even an infinite number of) states in which a given measurable quantity takes on different values. Once a measurement is performed the wavefunction collapses to what Bohr described as a classical state i.e. one can apply classical physics to the system after measurement.

Importantly, this means that questions that we are aching to ask, such as "which slit did the electron go through in Young's (electron) double slit experiment?" may not be asked by a physicist, since in the interference experiment we do not observe which slit the electron passed through. A philosopher is, of course, at liberty to ask any question (s)he likes, but a physicist may only ask questions to which the answer has (at least in principle) been determined by a measurement.

Until the late 1950s this was accepted as the standard interpretation of Quantum Physics, although as we shall see below, when taken to extremes it can lead to absurdities.

13.2 Many Worlds Interpretation.

An alternative to the Copenhagen interpretation of Quantum Physics is the Many Worlds Interpretation, first proposed by Hugh Everett [30] in 1957 and further developed by Bryce de Wit in the 1960's and 1970's [31].

This interpretation dispenses with the arbitrary distinction between the sub-microscopic and macroscopic (measuring apparatus), insisting that everything including the measuring apparatus and the observer must be treated as a Quantum system and that wavefunctions should be a wavefunction for the entire Universe. There is therefore no such concept of wavefunction collapse, although the Many Worlds Interpretation makes use of the idea of decoherence, which is explained in terms of quantum interaction between sub-microscopic systems and their environment.

Instead of arguing that the wavefunction collapses when a measurement is made the Many Worlds interpretation argues that each time an observation is made, the entire Universe splits into many Universes in which each possible outcome for the result of the observation occur. The probability of a particular outcome is reflected in the number of Universes in which that particular outcome occurs. We return to the example used in section 10, in which particle confined in a box is in the superposition state

$$\Psi \ = \ \frac{1}{2}\Psi_1 \ + \ \frac{\sqrt{3}}{2}\Psi_2$$

representing a particle which does not have well-defined energy but could be in either the first or second allowed energy levels with respective probabilities $\frac{1}{4}$ and $\frac{3}{4}$. When the energy of the particle is observed the Universe splits into many Universes. The probability that a system in the above superposition state has probabilities $\frac{1}{4}$ and $\frac{3}{4}$ to be the in state described by Ψ_1 and Ψ_2 respectively, which means that in $\frac{1}{4}$ of those many Universes the energy of the particle is

$$\frac{h^2}{8mL^2}, \quad \text{(the } n = 1 \text{ energy level - see. eq.(8.4))}$$

and in $\frac{3}{4}$ of the Universes the energy of the particle is

$$\frac{h^2}{2mL^2}, \quad \text{(the } n = 2 \text{ energy level - see. eq.(8.4))}$$

This rather fanciful interpretation of Quantum Physics has now become accepted by many theoretical physicists as being more satisfactory than the Copenhagen interpretation, despite the fact that the mechanism which causes the splitting of the Universe is not explained in any more detail than wavefunction collapse. As you can probably tell, I am in the minority of physicists who finds the Many Worlds interpretation difficult to accept, and not particularly illuminating.