18 Is Quantum Theory Correct and Complete?

Almost certainly and almost certainly not *(respectively)*!!

Quantum Theory provides us with a methodology (Quantum Mechanics) for calculating the probability of obtaining a given result of a given experiment. These probabilities can be tested experimentally by performing the measurement a large number of times, N. If the probability of obtaining a certain result, x, is $P(x)$, then we would expect this result to occur in $P(x)N$ of the measurements (up to statistical fluctuations which are well-understood). Such experiments yield results which are totally in agreement with the (probabilistic) predictions of Quantum Mechanics.

Furthermore, in the cases where Schrödinger's equation can be solved (at least to a very good approximation) to obtain the allowed energy levels of atoms, these have been in extremely good agreement with the results obtained from observation of atomic spectra. Ions at lattice sites in a crystal perform harmonic oscillation and the quantum behaviour of these oscillations leads to predictions of various thermodynamic properties of solids, such as their specific heat, which are also in good agreement with experimental measurements.

The most spectacular application of Quantum Physics is the working of a **transistor** which is the key component of all modern electronic devices. Transistors exploit the fact that an electron in a **semiconductor** can undergo the quantum tunnelling described earlier through a barrier of a different type of semiconductor - despite the fact that this cannot happen classically because the barrier repels the electrons. However, viewed as a wave, the wave can extend over both sides of the barrier so that there is some probability to find the electron on the other side. The tunnelling probability is very sensitive to the repulsive potential of the barrier, so a small variation in such a potential leads to a very large change in the rate of flow of electrons (electric current) through the barrier. This is the principle of a transistor amplifier.

All of this indicates that Quantum Theory is consistent with the laws of Nature. One can never be sure that there will not, in the future, be experimental measurements that yield results which are in conflict with the predictions of Quantum Physics - indeed the subject was born because experiments were conducted whose results were inconsistent with the thitherto accepted theory of Classical (Newtonian) Mechanics. Classical Mechanics is not wrong. It is just incomplete. It can be successfully applied to any macroscopic system providing results which agree with experiment to any reasonable degree of accuracy. However, when applied to the sub-microscopic world this agreement breaks down. It is quite possible that in the future, we will perform measurements of certain systems, which yield results that are not compatible with the predictions of Quantum Physics, so that Quantum Physics will also have to be amended or even replaced by a new theoretical framework appropriate to the analysis of such systems.

Even before this happens, it is clear that Quantum Theory as it currently stands, does not explain the process of measurement in a satisfactory matter. We do not understand how it can be that a sub-microscopic system which is in a superposition of states and therefore does not possess a well-defined value for certain measurable quantities, can nevertheless be confronted with an appropriate measuring apparatus, from which a definitive value for such quantities emerges. If we accept the Copenhagen interpretation, then we are unable to explain wavefunction collapse. The Many Worlds interpretation dispenses with the idea of wavefunction collapse, but one needs to understand how the Universe can be continually splitting in to many parallel Universes. Both interpretations rely on the idea of decoherence, in which quantum information of a sub-microscopic system is lost and the system which is described by quantum superposition of states is converted into a classical (and understandable) probability distribution. Decoherence is understood to arise from quantum interactions between a microsystem and its environment. So far this has only been simulated using somewhat ad hoc models. It has not been derived using Quantum Mechanics, which is the mathematical framework of Quantum Physics. In the meantime, we have to accept either the phenomenon of wavefunction collapse, or the idea of the Universe continually splitting into multiple Universes, in the same way that we have to accept all the other features of Quantum Physics, notwithstanding the fact that they are not compatible with our everyday experiences of the macroscopic world and defy human attempts to understand it in terms of visualization.