1 Introduction - Understanding "understanding".

"I don't understand Quantum Physics" the interested layman often asserts when (s)he meets a theoretical physicist. The honest reply from the physicist is "Nor do I."

This seemingly facetious reply is indeed appropriate if the word "understand" is used in its usual context. What we usually mean is the ability to visualize something. If you were to explain what a "waterfall" (for example) was to a person who had never seen one, then provided your explanation is sufficiently articulate, that person should be able to picture in his(her) mind what a waterfall actually looks like. When we think of sub-microscopic systems (such as atoms), the temptation is to attempt to visualize them based on our visual experience of the macroscopic world. Thus, since we can visualize the solar system in terms of the sun at the centre and a set of planets moving in elliptic orbits with the sun at one focus, it is tempting to think of an atom which consists of a **nucleus** and **electrons** in the same way, namely the nucleus at the centre and the electrons forming elliptical orbits around the nucleus. Unfortunately this is erroneous and atoms do not lend themselves to such clear pictures in which the paths of the electrons can be precisely determined. We simply have to get used to the idea that if we consider systems which are too small to be clearly seen (directly or indirectly) we need to abandon the luxury of being able to visualize such systems in terms of our experience of macroscopic systems. Visualization is the usual but not the unique way in which we can conceptualize. For example, by playing with two magnets we can develop the concept of a force even though we cannot actually see what is pushing the magnets apart or pulling them together. In this sense, we have an understanding of a **magnetic field**. Similar effects can be observed with electrodes connected to the poles of a battery so that we can understand **electric fields**. However, there exists a type of force called **"degeneracy pressure"** which is of purely quantum origin and has no classical analogue. This "degeneracy pressure" is the reason that a **neutron star** does not collapse under its own gravity (unless the density of the neutron star exceeds a critical value known as the **Tolman-Oppenheimer-Volkov limit** [2]). Nevertheless, it cannot be understood within the framework of our everyday experiences.

Traditionally, it was believed that the objective of Science was to be able to fully understand everything in Nature, by which we mean to be able to relate everything our everyday experiences, in a way which is intelligible. This is regrettably not the case for modern physics, i.e. for the Quantum Physics. The objective of Theoretical Physics is reduced from this ambitious objective, to the development of a set of rules which enable us to calculate quantities which can be experimentally measured. Quantum Theory generates an equation, whose solution yields (directly or indirectly) such physically measurable quantities. In (non-relativistic) Quantum Theory, this equation is was first written down by Erwin Schrödinger [3] in 1925 (**Schrödinbger's equation**) and its solution can be used to calculate the optical **spectrum** of various atoms.[1]

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[1] Only for the simple case of the **hydrogen atom**, can the Schrödinger equation be solved exactly. For more complicated atoms, various approximate methods exist which generate these spectra up to a certain accuracy.

Such optical spectra can be observed in the laboratory and the successful comparison of the observed spectra with those predicted from the solution to the Schrödinger equation tells us that Quantum Physics is consistent with Nature. We cannot, however, use this to determine the exact (i.e. localized) positions of the electrons relative to the nucleus at any given time, simply because these exact positions *do not* exist in Quantum Physics. An electron does not possess the property of being located at a given precise point, rather it has to be thought of as existing "everywhere", with a high **probability** of being found at a certain location and a very small probability of being found far away from that location. It may be really strange to assert that an electron does not actually possess a single (localized) position, but we have to live with this strange idea if we accept that Quantum Physics describes Nature correctly. The absence of predictions of the positions of the electrons does not indicate a failing of the theory, because it allows physicists to calculate quantities which can be experimentally measured - and so far these calculations have always agreed with the experimental measurements. It is this agreement that promotes Quantum Theory to the status of a correct theory despite its failure to allow us to understand what is going on inside an atom. Thus we theoretical physicists are not simply being awkward when we say that we "don't understand Quantum Physics". We mean that whereas it gives us a set of working rules that enable us to calculate measurable quantities, it does not help us to understand what is going on inside an atom. We have to accept the rather uncomfortable idea that objects which are too small to be seen, cannot be described in terms of the usual concepts, with which we are familiar.