Localization

In the case of light, a single photon that has a wave packet that propagates in a vacuum retains the shape of the wave packet or can be said to propagate in a dispersion-free medium. This is because the energy and momentum of a photon are directly proportional and hence the momentum wave function change that occurs in unitary evolution of time proportional to t_0 is multiplication by e^{ikt_0}. Since the momentum and position wave functions are Fourier transforms of each other, the effect of the Schrödinger unitary propagation of a photon wave function is simply that the entire wave function translates or propagates with a phase proportional to t_0, as can be seen by applying the shifting property of the Fourier transform.

A property of unitary evolution found by de Broglie is that not only light but also matter can be associated with a wave function. However, unlike light, the relationship between the energy and the momentum of matter is generally not linear. Hence the wave function of isolated matter particles generally disperses or spreads over potentially wide areas of space when one computes the wave function at later times via Schrödinger's equation.

A characteristic of Einstein relativity, in classical physics, and generally if you simply look around your surroundings, is that objects appear to have very well-defined positions. If unitary evolution were strictly correct, then matter wave functions will generally disperse under unitary evolution. For example, consider the well-known experiment that demonstrated the diffraction of fullerene molecules [26]. This has now been extended to rather large molecules in [26]. Suppose that it is found that larger systems could be diffracted as well, or even a single cell. If such cells always had wave functions that were spread across miles of space, the world might be appear rather chaotic. On the other hand, if one has a microscope and sees a cell, then there is no doubt that the cell is localized. Hence it seems very reasonable to consider whether or not system localization is a necessary and/or sufficient condition for measurement.

Discerning Localization

It has not been proven, at least to the authors' knowledge, that the condition of localization is a necessary and sufficient condition for measurement. While it does appear that macroscopic objects are localized, this does not logically imply that a macroscopic object could not be produced in a laboratory that is not localized.

Consider an atom that interacts unitarily with a photon in a cavity. Suppose the initial state of photon-atom is $|1\rangle|0\rangle$. After waiting for a time related to a π pulse, one will find that the atom has absorbed the photon and the photon is not found in the cavity but is localized in the atom. Hence localization of a photon that was previously external to the atom has occurred and has been demonstrated by only unitary evolution. However, one could include such unitary mechanisms in the Chapter 3 UMDT for each device, and entanglement of the two devices, or a CHSH sum of $2\sqrt{2}$, would be predicted under such unitary devices. One might argue that it cannot be established which particular device unitarily absorbed the photon in the UMDT due to the predicted entanglement, but nonetheless the wave that existed outside the two devices does cease to exist after time even in unitary evolution (time given by π pulse, on-resonance).

Suppose that a measurement has occurred, and we know which of the two devices has absorbed the photon. Now we also know which device absorbed the photon, but is the photon localized within that detector any better than it was during unitary evolution in time π? Perhaps or perhaps not. If not, then the major difference between unitary evolution and measurement would seem to be that in measurement the entanglement is removed and we know which atom absorbed the photon, but unitarily after time π, we also know that the wave of the photon has ceased to exist in all space outside the matter. Localization of a photon therefore does not appear to be a sufficient condition for measurement.

Let us now consider whether or not localization is a necessary condition for measurement. In the case of interaction-free measurement or negative measurement, the wave-function is projected outside a device that does not detect the particle. If the wave-function is spread outside the detector, it will remain spread and hence full localization cannot be said to have occurred in IFM. If a positive detection occurs, it is generally the case that the particle is then found localized to the detector area. Hence for positive detection, it does appear to be a reasonable hypothesis that localization is a necessary condition for measurement.