

Panel Discussions: Quantum Entanglement

Prof. Chandrasekhar Roychoudhuri

University of Connecticut and Femto Macro Continuum, Storrs, CT, USA

My position is based upon two observations that are accepted by quantum mechanics at a fundamental level, but usually ignored during implementation for convenience of staying within the strong influence of the Copenhagen Interpretation. (i) First, let me quote Dirac's famous statement, "Interference between different photons never occurs", which correctly captured the general reality that light beams do not interfere by themselves to create energy re-distribution (fringes) in the absence of light-matter interaction. Photons are Bosons and they can occupy the same space at the same moment while passing through each other completely unperturbed. This obvious reality was also missed by classical physics. Perhaps, Dirac failed to over-ride the classical cultural belief system that "light interferes with light" and hence wrote another sentence, "Each photon then interferes only with itself", preceding the previous quotation given above. Of course, self-interference and appearance and dis-appearance of any stable elementary particle from certain space and temporal position to create fringes, without undergoing any interaction, is a gross violation of the very conceptual and mathematical foundation of physics. All registered superposition phenomenon between light beams become manifests through some measurable transformation experienced by a detector. This brings us to our second point. (ii) We cannot measure anything that is interaction-free and force-free. In physical experiments, we measure some transformations between the interactants. All such transformations require some energy exchange, which must be guided by one of the allowed four forces. Since, all forces have finite ranges, all measurable transformations experienced by the interactants are bound to be *local* in the sense that they must be within the sphere of influence of each other [1]. In this world there is no force-free, interaction-free, or energy-exchange-free transformation that we can measure using our real physical instruments. Otherwise, our mathematical equations, which represent strict causal and logical relationship between different interactants or different fields, could not have been so successful in predicting our measurement results.

Let us now "jump into" the following conclusion that will be clarified further in later paragraphs. Those engineering designs, meant for quantum communication, computing and encryption, which literally require generation, modulation, complex-system-propagation and detection of the same indivisible single photon, will be impossible to realize in practice. This is especially true for photons in the visible and infrared range due to diffractive spreading of light beams. Since diffractive spreading is inversely proportional to the frequency, high energy individual gamma photons can be tracked. But we do not have such flexibility with visible photons, especially, considering all the current technologies related to generation, diffractive-propagation and detection of visible photons.

Let us quickly assess the indivisibility of photons. This is a myth even in quantum optics. Light propagates through the cosmic medium, following universal diffraction phenomenon for EM waves. This is well validated through the use of the diffraction theory (i) to design and analyze image formation by macro domain like Hubble telescope,

and (ii) to design practical complex nano-photonic integrated optoelectronics in the nano domain. So photons are all prone to energy divisibility as they interact with other material particles or are obstructed by some apertures. While inverse proportionality of diffractive divergence to frequency allows gamma photons to preserve their strong particle-like nature, their divisibility is obvious from their tracks in volume-scintillation detectors as they keep on losing their energy in a series of discrete interactions. The divisibility of X-ray photons is obvious from the classic Compton scattering where every scattering from an electron, the original photon gives up a part of its energy and comes out as a lower frequency photon. The divisibility of visible photons is obvious from nonlinear optical processes like parametric down conversion. Summability of visible photons is obvious from nonlinear frequency summing and two-photon fluorescence processes. Of course, QED also claims that the original photon in all interaction processes is first absorbed completely and then a new indivisible photon is emitted. Physicists must accept a common conceptual premise so debates can produce productive and logical outcomes.

The next important criterion used in quantum optics for quantum computing like applications, which use interferometers, is *entanglement* of different photons produced by a beam-splitter, or by a parametric down-converter. We believe that the *entanglement* characteristic should be reserved for those states that are literally *entangled* through an operating quantum mechanical force. Consider the example of quantum states of atoms A and B bound inside a large molecule. Clearly, the rotational and vibrational states of A can be influenced by tinkering with those of B. These quantum states are truly *entangled*, because they influence each other through the complex electromagnetic binding force that holds the molecule together. If A and B are released by delivering a force greater than their binding energies, they will be released. After release, A and B. will carry on complementary properties based on all the conservation laws. However, they are no longer *entangled* to each other provided they are far from each others direct influence of electromagnetic forces.

This logic is even more dramatic for a photon pair production in the visible range, whether one uses the cascade-emission or the down-conversion process. The photon pair will carry on complimentary physical properties like polarization, frequency etc., enforced by conservation laws during the quantum mechanical process of emission (light-matter interaction). However, they will not be *entangled* to each other in any physical sense, because there is no influencing photon-photon interaction force between them when they are freely flying away with velocity c or c/n .

Let us split a collimated laser beam into two new spatially independent beams of well defined beam-waist, either with the original frequency using a beam-splitter, or with a new frequency using a frequency down-conversion system. Let these two beams be used in two independent interferometers on the same table, say, a Michelson and a Mach-Zehnder, to quantitatively measure the length of a meter-block and the refractive index of a material, respectively, using superposition fringe counts. We will derive accurate reproducible results from each interferometer, independent of the *parallel* existence of the other. Now, let us insert a tandem of laser energy absorbers in the original laser beam to reduce the photoelectric “click” counts from many billions to a few thousands per second. Will the results of the two interferometers become *entangled*? There is nothing magical about reducing the photoelectric “click” counts from very large to very low rates, unless the superposition phenomenon at very low light flux follows different physical law

that we have not quantitatively articulated yet. Of, course, keeping track of the statistics of the counts become more difficult. [Note that the “click” counts are not single electrons. They constitute amplified current pulses carrying probably billions of electrons per pulse!]

The physical states of the *Schrodinger's Cat* as *dead* or *alive* do not become *entangled* simply by forcing the cat inside a closed chamber with radioactive trigger to release deadly poison inside. Radioactive particle emission from an excited nucleus is certainly a quantum mechanical statistical process; the pre-emission and the post-emission states of the radioactive nucleus are certainly related to each other or are *entangled* by the nuclear force. But, once released and far from the influence of the nuclear force of the parent nucleus, the emitted particle is no longer *entangled* with the parent. It is now a “classical” particle until it interacts with a new quantum entity to create new *entanglement* independent of the parent nucleus. The radioactive poison triggering device is totally a classical device although the timing of the trigger-event is statistically determined by the quantum mechanical nucleus. The *dead* or *alive* states of the Schrodinger's Cat are never entangled; they are classical states and are doubly removed from the quantum mechanical excited state of the original nucleus. It appears that Schrödinger's sarcasm was converted by the Copenhagen group into real physics, followed by the introduction of mysticisms, like *interaction-free transformations*, *teleportation*, *production of multiple universes during every quantum transition*, etc., into serious physics.

In summary, force-free interaction-free *entangled* photon-states do not exist in the real world. Besides, there is no photon-photon interaction that can *entangle* them! The continuously evolving universe, from macro to micro levels, is causal. This is the crucial reason why human constructed logical and causal mathematical equations are able to guide us to understand so much of this still-unknown but a magnificent cosmic system.