Entanglement made tangible

September 30 2014

EPFL scientists have designed a first-ever experiment for demonstrating quantum entanglement in the macroscopic realm. Unlike other such proposals, the experiment is relatively easy to set up and run with existing semiconductor devices.

Quantum entanglement refers to the "pairing" of two subatomic particles in such a way that they form a whole quantum system. Interest in entanglement is increasing today, as it challenges the foundations of quantum mechanics itself, and is also key for achieving quantum information processing and communication. Entanglement is thought to exist up to the everyday, or "macroscopic" realm – according to the predictions of quantum physics – but experimental proposals to show this often involve conditions that are difficult to achieve in today's labs. Publishing in *Physical Review Letters*, scientists at EPFL have put forward an experimental protocol for demonstrating QE at the macroscopic scale by using a device that can be controlled by light. Unlike others, the protocol can be carried out with relative ease, using state-of-the-art nanostructures that are already available in several laboratories worldwide. This perspective can propel our understanding of the quantum world towards unexpected directions.

"Spooky action at a distance"

Quantum entanglement is an intriguing phenomenon that occurs when elementary particles become inextricably linked in such a way that, when the a change is induced on one particle, a corresponding change happens to the other regardless of how far apart they are. The two particles behave as a whole, and this "correlation" is different from any one that classical physics can explain. Entanglement is such a bizarre phenomenon, and has such strange implications for physics, that Einstein himself called it "spooky action at a distance."

Nonetheless, entanglement between particles has been shown repeatedly in the lab today, with a Canadian firm even claiming to have built a quantum computer in 2011. But the critical question, with both fundamental and practical implications, is whether quantum entanglement can be achieved beyond the microscopic realm of elementary particles and into the everyday or "macroscopic" world. Several experiments have been proposed to run this test. Most of them however cannot be carried out as they rely on prohibitive parameters and conditions that cannot be realistically implemented in today's labs.

A feasible experiment

Vincenzo Savona and his postdoc, Hugo Flayac have now proposed a feasible, real-world experiment to demonstrate entanglement in the "macroscopic" realm. The experimental design draws from his recent research in the field of optomechanics, which Savona describes as "the art of conceiving systems in which light interacts, in highly controlled and highly tailored way, with a mechanical vibration of some sort." This mechanical vibration can be thought of as a musical note from a tuning fork, but in optomechanics it involves tiny devices specifically designed for this purpose.

"The experiment begins with a single photon, which is in a quantum superposition of two states", says Savona. "This is not entangled yet, because entanglement per definition must imply at least two objects, and here we have only one photon. An optomechanical system acts in such a way that, whatever the state of the photon, it is transferred to the state of a mechanical vibration." In the case when the photon is in a quantum superposition then, its state is converted into a pair of entangled mechanical vibrations ("notes") at different frequencies.

"This represents entanglement," says Savona, "because each 'note' is made up of the collective vibration of billions of atoms, hence there is not one particle, but rather billions of them. This is ultimately what I call 'macroscopic entanglement'."

The protocol is designed in such a way that, once vibrations are converted back into light, the latter shows a peculiar interference pattern that reflects the presence of entanglement. "Under specific conditions, interference, together with the fact that the system contained no more than one quantum (e.g. a photon) show that entanglement actually took place. In our protocol, the readout phase does exactly this: it checks that only one quantum was present inside the system. This check, plus the occurrence of the interference, is the evidence that entanglement was present."

The optomechanical device used in this experiment is called a "photonic crystal nanocavity" (PCN). It is basically a nano-device designed in such a way that it can trap and hold incoming light for a certain amount of time, while vibrating at two different resonant frequencies. Savona's quantum entanglement experiment uses a PCN that his team developed and tested earlier this year. This particular kind of PCN has been shown, by another EPFL scientist, Tobias Kippenberg, to produce mechanical vibrations of different frequencies when it interacts with light. "This was the ideal playground for an entanglement experiment," says Savona. "Combined with the ability of this PCN to hold light for a particularly long time, it formed the basis of our experimental proposal."

The experiment requires an extremely low temperature (0.004 K or -273.146oC), which is nonetheless commonly feasible– once again thanks to lasers – in optomechanical devices. But the experimental design is unique because it proposes light as a means for connecting quantum entanglement to the macroscopic realm.

It is also special because of its focus on what can practically be done in labs today. "Our approach was essentially the opposite of other experimental proposals," says Savona. "We said, 'let's see what physical systems we have available, which have already been fabricated and tested; let's start with the physical properties of those systems and see if we can devise a way to produce an entangled state of mechanical modes'." Savona's team is now looking forward to carrying out the experiment in collaboration with other groups.

More information: Flayac H, Savona V. Heralded Preparation and Readout of Entangled Phonons in a Photonic Crystal Cavity. *Physical Review Letters* 30 September 2014. On Arxiv: arxiv.org/abs/1407.5275

Provided by Ecole Polytechnique Federale de Lausanne

Citation: Entanglement made tangible (2014, September 30) retrieved 20 April 2024 from https://phys.org/news/2014-09-entanglement-tangible.html