Proposed experiment offers new way to generate macroscopic entanglement

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(PhysOrg.com) -- In the development of quantum information processing, one of the key requirements is achieving quantum entanglement. But recently, physicists have been investigating other forms of quantum correlations besides entanglement, and wondering if they may be useful and if they may play a role in future quantum communication and computation. In a new study, scientists have found that other forms of quantum correlations can be used to obtain useful entanglement of macroscopic systems, providing new insight and potentially leading to novel quantum technologies.

Physicists Laura Mazzola and Mauro Paternostro from Queen's University Belfast have published their study on activating entanglement through non-entangled quantum correlations in a recent issue of *Nature Scientific Reports*. Such non-entangled quantum correlations, which are sometimes referred to as being "beyond entanglement," can be measured using quantum discord.

In a seminal work in this area, Marco Piani of the University of Waterloos and co-workers previously demonstrated that quantum discord can produce entangled states, which is not possible when only classical correlations are available. Building on this work, Mazzola and Paternostro have shown that, by starting with a system of massive harmonic oscillators that have quantum discord, they can generate entanglement in an optomechanical setting involving light fields and mechanical oscillators.

“By running this protocol, one is able to get entanglement, which is a well-known resource for quantum technology and, allegedly, the key to the advantages of quantum information processing, from systems that shared correlations of a nonclassical nature (discord) but are not entangled at all,” Paternostro told *PhysOrg.com*.

This new way of generating entanglement is significantly different from the way that entanglement is normally produced.

“Usually, one starts from systems that do not share quantum correlations at all, in order to prove that the ‘mechanism’ that one sets up is able to produce entanglement,” Paternostro explained. “In the protocol by Piani, et al., and modified so as to adapt to the optomechanical scenario of our work, the key is that if one considers initially discorded states, entanglement is produced!”

So far, this form of entanglement activation has recently been discussed for certain domains, and here Mazzola and Paternostro show that the scheme can be extended, at least in one instance, to systems that have an infinite variety of physically allowed energy configurations.

As Paternostro explained, the scheme is not only intriguing in the way in which it works, but the entanglement it produces is also intriguing in itself due to its potential availability in the macroscopic realm.

“Optomechanical entanglement is the entanglement between an optical light field and a massive, quasi-macroscopic mechanical oscillator,” he said. “By shining light onto an optical cavity endowed with a movable mirror, which embodies the mechanical oscillator, one can get entanglement between the cavity light field and the movable mirror. Therefore, optomechanical entanglement can be seen as ‘normal’ entanglement but, importantly, involving a massive object that verges to macroscopic dimensions (you can really see these guys with your naked eye!)."

By producing optomechanical entanglement, the proposed scheme also provides indirect evidence of mechanical nonclassicality. That is, it shows that two massive mechanical objects, such as oscillators, can be in a state that cannot be described by means of classical theory alone.

"This is what we would define as mechanical nonclassicality: a quantum mechanical state involving massive mechanical systems, with no classical counterpart," Paternostro said. "Such states are in general rather demanding to be prepared due to the fact that massive objects tend to feel the effects of the surrounding environment rather strongly. Likewise, accessing their properties is indeed difficult: any measurement performed on such systems would severely affect the nonclassical features if not destroy them altogether. The 'Holy Grail' in this context is to generate certified nonclassical mechanical states and be able to reveal their nonclassicality."

From a practical perspective, optomechanical entanglement could have applications in quantum communications.

"Beside the fundamental implication of having entanglement between macroscopic objects, therefore pushing quantum mechanics to the realm of the observable-by-naked-eye, one could exploit optomechanical entanglement to 'distribute' entanglement in a network of mechanical nodes, connected by light field," Paternostro said. "Our goal is to show that one can use this sort of architecture to set up an efficient quantum communication network."

Since the proposed experiment uses technology similar to that used in recent optomechanics experiments, the researchers predict that demonstrating the new scheme should be feasible in the near future.

"One of the core activities in my group at Queen's University Belfast is the demonstration that nonclassicality can be enforced in macroscopic systems," Paternostro said. "This experiment is indeed a nice way to do it."

More information: Laura Mazzola and Mauro Paternostro. "Activating optomechanical entanglement." *Nature Scientific Reports*. DOI:10.1038/srep00199