Entanglement without Classical Correlations

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Quantum mechanics is full of counterintuitive concepts. The idea of entanglement – when two or more particles instantaneously exhibit dependent characteristics when measured, no matter how far apart they are – is one of them. Now, physicists have discovered another counterintuitive result that deals with the line between the quantum and classical worlds.

Normally, when two or more particles are entangled (and seem to communicate with each other instantaneously), they not only share quantum correlations, but also classical correlations. Although physicists don't have an exact definition for classical correlations, the term generally refers to local correlations, where information does not have to travel faster than the speed of light.

So if entangled particles demonstrate correlations across large distances, you might assume that they will also have correlations across shorter distances. After all, if entangled particles can communicate at faster-than-light speeds, they should be able to communicate at slower-than-light speeds.

But a team of physicists from the National University of Singapore, Mediterranean Technology Park in Barcelona, the University of Leeds, and the University of Bristol has demonstrated something different. They've theoretically shown that any odd number (greater than one) of entangled particles can exist without classical correlations. They explain this paradox in a recent issue of *Physical Review Letters.*

“One way of seeing this is as follows,” Vlatko Vedral, Professor of Quantum Information Science at the University of Leeds, told *PhysOrg.com*. “Entanglement means being correlated as far as many different measurements are concerned. Classical correlations mean being correlated as far as one particular measurement is concerned. That is why researchers usually think that when there is entanglement, there are also classical correlations. However, our paper shows that you have to be careful about making this inference.”

As Vedral explained, generally when physicists measure entanglement, their measurements destroy the quantum correlations first, and then the classical correlations.

“Entanglement represents excess of correlations, over and above classical ones. In other words, whatever cannot be accounted for locally is due to quantum entanglement. When you make local measurements on entangled particles, then you will invariably be destroying their correlations (both classical and quantum). Since quantum is in excess of classical, it is possible that you can first get rid of entanglement, but are still left with some classical correlations.”

But to do the opposite of this – to get rid of the classical correlations and have only quantum correlations – is more difficult to comprehend.

“Imagine that I tell you that I am a billionaire,” Vedral said as an example. “You would then infer that I certainly have 100 million somewhere in my assets. You would be very surprised, indeed, if I told you that this was not true and that I am actually not also a millionaire. You can't have more, without have less as well (by definition).”

This is not the first time that physicists have demonstrated entanglement without classical correlations. In 2006, Toth and Acin found an example of a three-qubit system that also shows this phenomenon. This three-qubit example has already been observed in the laboratory, and the physicists hope that their new example with any odd number of qubits can also be observed. They also expect that even numbers of qubits should exhibit the same effect, but do not yet have an example.

“The key is that we are using one particular definition of classical correlations, which is in fact the main one used in the solid state physics (and is used to mark phase transitions among other things),” Vedral said. “This is based on average values of a set of observables and the key is that this set is not complete. However, when it comes to two particles (and two point correlations is what all solid state experiments are about) then you cannot have the situation that we found with three and more particles. Namely, if classical correlations vanish for two qubits, then so do the quantum ones.”

The paradox that quantum correlations can exist without accompanying classical correlations could have some thought-provoking consequences. For instance, physicists often use a test of Bell inequalities to determine if local realism has been violated and that quantum correlations have occurred. But since Bell inequalities are based on classical correlations, the test doesn’t work for this example. This leads to the need for a new way to detect quantum correlations, based on different concepts.

The study may also affect how physicists view the boundary between the classical and quantum worlds – a question at the foundation of physics. With this demonstration of the existence of a state that has quantum correlations without classical correlations, the physicists suggest that local realism might be used as the criteria to characterize the classical world.

The result could also have practical applications – for instance, as a possible method for detecting phase transitions. Using quantum correlations only (instead of both quantum and classical) for detecting phase transitions could provide a more universal measurement than conventional methods.

More information: Kaszlikowski, Dagomir; Sen(De), Aditi; Sen, Ujjwal; Vedral, Vlatko; and Winter, Andreas. "Quantum Correlations without Classical Correlations. *Physical Review Letters* 101, 070502 (2008).