Physicists describe method to observe timelike entanglement

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(PhysOrg.com) -- In "ordinary" quantum entanglement, two particles possess properties that are inherently linked with each other, even though the particles may be spatially separated by a large distance. Now, physicists S. Jay Olson and Timothy C. Ralph from the University of Queensland have shown that it's possible to create entanglement between regions of spacetime that are separated in time but not in space, and then to convert the timelike entanglement into normal spacelike entanglement. They also discuss the possibility of using this timelike entanglement from the quantum vacuum for a process they call "teleportation in time."

"To me, the exciting aspect of this result (that entanglement exists between the future and past) is that it is quite a general property of nature and opens the door to new creativity, since we know that entanglement can be viewed as a resource for quantum technology," Olson told *PhysOrg.com*. "The greatest significance of our result is almost certainly in some application that is yet to be imagined."

Olson and Ralph's paper, which is posted at arXiv.org, describes how timelike entanglement can be converted into spacelike entanglement using two detectors.

"Essentially, a detector in the past is able to 'capture' some information on the state of the quantum field in the past, and carry it forward in time to the future -- this is information that would ordinarily escape to a distant region of spacetime at the speed of light," Olson said. "When another detector then captures information on the state of the field in the future at the same spatial location, the two detectors can then be compared side-by-side to see if their state has become entangled in the usual sense that people are familiar with -- and we find that indeed they should be entangled. This process thus takes a seemingly exotic, new concept (timelike entanglement in the field) and converts it into a familiar one (standard entanglement of two detectors at a given time in the future)."

In their study, the scientists also proposed a thought experiment in which they move a quantum state into the future using timelike entanglement as the resource. They call the process "teleportation in time."

In the thought experiment, the physicists described two qubit detectors, one of which is coupled to the field in the past and one to the field in the future. First, the detector coupled to the past operates on a qubit and generates information about how the qubit can be detected. The qubit is then teleported into the future, essentially skipping over a middle period of time. Then the first detector is removed and the second, future-coupled detector is placed in the first detector's spatial location, so that the detectors are separated in time but not in space. After a certain amount of time, the second detector receives the information from the first detector, which it uses to reconstruct the teleported qubit.

The physicists emphasized that there is an important symmetric time correlation that must be followed in order for the procedure to work. If the qubit is teleported at t=0, then the first detector must have operated the same amount of time before t=0 as the second detector operated after t=0. For example, if t=0 is 12:00, and the first detector operated at 11:45, then the second detector must wait to operate at exactly 12:15 in order to achieve entanglement. The scientists also noted that between 12:00 and 12:15, it's impossible to recover the teleported qubit.

According to the physicists' previous work, such timelike entanglement should generate a new thermal effect arising from the quantum vacuum (the quantum vacuum is thought to exhibit several thermal effects, including Hawking radiation from black holes, though none of these thermal effects have been observed). The physicists predict that the new thermal effect may be easier to observe than other thermal effects using current technology. If such a procedure for extracting and converting timelike entanglement can be realized, then it could provide a way for scientists to directly observe the quantum entanglement inherent in the space-time vacuum for the first time.

"Entanglement is observed every day," Olson said. "However, direct observation of entanglement in the vacuum state would be new, and being able to observe it would potentially enable us to use this entanglement as a resource for quantum technology. Since the vacuum state is the closest thing we have to 'nothing' in physics (it is the state with zero ordinary particles around), observing and using the entanglement inherent in the vacuum as a technological resource would potentially give us a way to build quantum devices with just empty space as the most fundamental ingredient."

More information: S. Jay Olson and Timothy C. Ralph. "Extraction of timelike entanglement from the quantum vacuum." arXiv:1101.2565v1 [quant-ph]