Physicists investigate the role of quantum entanglement in the magnetic compasses of animals

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Physicists have found that quantum entanglement may play a role in some types of magnetoreception with certain molecules, but more work is needed to determine the exact molecules involved in the magnetoreception of animals such as cows and others that seem to have a chemical compass. Image credit: Daniel Schwen.

(PhysOrg.com) -- Many animals possess some kind of magnetic sense, allowing them to navigate by using a magnetic field. The ability to detect a magnetic field, called magnetoreception, has been observed in a variety of animals, including birds, turtles, sharks, lobsters, cows, fungi, and bacteria. However, scientists do not fully understand the mechanisms responsible for this ability. In a new study, physicists have investigated the role of quantum interactions in magnetoreception, and have shown that quantum technologies could be used to enhance or reduce the performance of an animal's chemical compass, and potentially control other biological functions.

"I think our study has made clear that entanglement, as a genuine quantum effect, may not only be observed in isolated and highly-controlled laboratory systems," Hans Briegel, a professor of theoretical physics at the University of Innsbruck, told *PhysOrg.com*. "It can also exist and play a role in biologically relevant systems, specifically the chemical compass, and we have described a route how this could in principle be investigated experimentally."

In their study published in a recent issue of *Physical Review Letters*, Briegel and coauthors Jianming Cai and Gian Giacomo Guerreschi explain that there are two main hypotheses of magnetoreception. One of these is called the radical-pair mechanism, in which magnetic receptors in an animal's eye are activated by photons to produce a pair of free radicals. Each free radical has an unpaired electron, and the spins of the electrons are correlated. The interaction between the free radicals and a surrounding weak magnetic field can cause different kinds of spin correlations to occur, allowing an animal to "see" the magnetic field.

One of the things that the Innsbruck researchers wanted to know was whether the electrons from the radical pairs needed to be quantum mechanically entangled, or whether classical correlations were sufficient to account for the sensitivity of the compass. In their calculations, they found that the answer largely depends on the radical-pair lifetime: for short lifetimes, such as in the case of a molecule used in recent spin-chemistry experiments, entanglement is a prominent feature; on the other hand, for long lifetimes, such as in the case of the molecule thought to be responsible for magnetoreception in European robins, entanglement does not seem to play a significant role.

Since scientists are not entirely certain which molecules are involved in the radical-pair mechanisms in different animals' chemical compasses, the question of whether animals use entanglement to detect magnetic fields remains an open question. However, the physicists suggest that certain experiments could be performed to help narrow down the possible molecular candidates in animal magnetoreception. For instance, by applying pi pulses that are parallel, perpendicular, or a variation of both to an animal's surrounding magnetic field, researchers may be able to observe how the quantum control protocol affects the animal's orientation ability. The physicists stressed that much more work would be needed to study the effect of quantum control pulses on biological tissue before such experiments could be carried out safely.

More information: Jianming Cai, Gian Giacomo Guerreschi, and Hans J. Briegel. "Quantum Control and Entanglement in a Chemical Compass." *Physical Review Letters* 104, 220502 (2010).
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