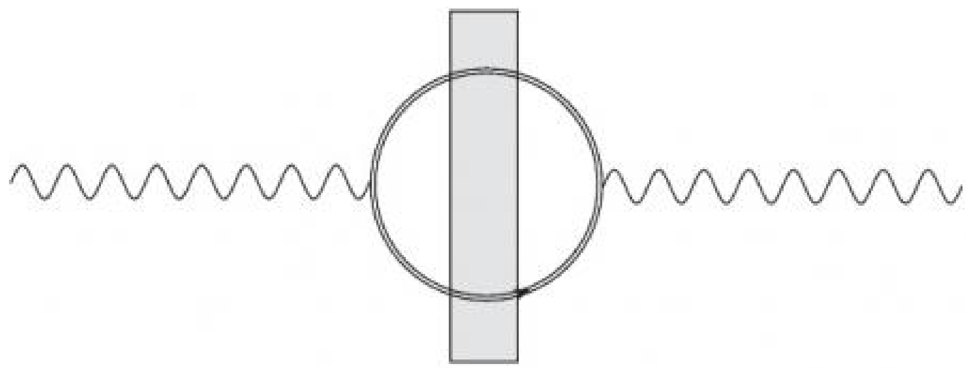
'Tunneling of the third kind' experiment could search for new physics

October 3 2012, by Lisa Zyga



This diagram shows a photon (wavy line) tunneling through a barrier mediated by a minicharged particle-antiparticle loop. The possibility of tunneling is enhanced by an applied magnetic field. Image credit: Döbrich, et al. ©2012 American Physical Society

(Phys.org)—In an attempt to solve some of the observational puzzles in physics, theorists have proposed a number of new physics models. Several of these models suggest the existence of extremely weakly interacting lightweight particles with tiny fractional electric charges called minicharged particles (MCPs). Constraining the masses of MCPs could help theorists refine their models, but so far it has been very difficult to detect MCPs. Now in a new study, physicists in Germany have proposed a new search for MCPs based on a new tunneling mechanism called "tunneling of the third kind," which could prove very useful in the search for new physics.

The physicists, Babette Döbrich (currently at DESY in Hamburg, Germany), Holger Gies, and Felix Karbstein, working at the Friedrich Schiller University of Jena and the Helmholtz-Institut Jena, both in Jena, Germany, along with Norman Neitz working at the Friedrich Schiller University of Jena (currently at the Max Planck Institute for Nuclear Physics), have published their paper on a new search for MCPs in a recent issue of Physical Review Letters.

"The general idea behind MCPs, as well as other light and weakly interacting particles, is the following: New particles are mostly assumed to 'hide' at high masses/energies, but they could also have very well eluded our searches if they are light, but weakly coupled," Döbrich told *Phys.org*. "Particularly, many theories beyond the Standard Model predict a spectrum of new particles at low masses and weak coupling. In some parameter regions they could explain phenomena such as dark matter and some astrophysical puzzles. In a nutshell, finding minicharged particles could help us very much in constraining theories proposed beyond the Standard Model."

Although MCPs are very difficult to detect due to their weak coupling, several experiments are currently searching for them. Here, the scientists propose using "tunneling of the third kind," which is so named because it was the third kind of tunneling to be discovered. In all three known types of tunneling, a quantum particle passes through a barrier that a classical particle cannot pass through. In the first kind of tunneling, known simply as standard quantum mechanical tunneling, this phenomenon occurs due to the uncertainty principle, which gives a finite probability that a quantum particle can pass through a barrier.

In the second kind of tunneling, a quantum particle that interacts strongly with the barrier and cannot pass through, such as a photon, is converted to a particle that does not interact with the barrier and can easily pass through. This kind of tunneling is sometimes called "light shining through a wall," and is the basis for some of the current experiments searching for MCPs.

In tunneling of the third kind, a quantum particle that cannot pass through a barrier changes into a pair of virtual particles that pass through the barrier before changing back into the first particle. Gies, along with coauthor Joerg Jaeckel, discovered this kind of tunneling in 2009. They suggested that this tunneling could take the form of photons changing into MCPs, which can tunnel through certain barriers and then change back into photons. Like the second kind of tunneling, this kind would also appear as light shining through a wall.

The physicists in the current study have theoretically shown that experiments involving tunneling of the third kind can potentially detect MCPs with very small masses, including those in the regime suggested by new physics models. The key to such experiments is to apply a strong magnetic field, which can significantly amplify the MCPs' tunneling probability.

In the proposed experimental set-up, a photon travels toward a perfectly opaque wall up to 1.8 cm thick, and behind the wall is a photon detector. The wall is installed in the 0.28-meter-diameter bore of a 1.2-meter-diameter solenoid magnet that provides a very large field strength of 5 Tesla. The large field strength enhances the potential for detecting very low-mass particles such as MCPs as photons appear to pass through the wall.

"The experiment suggested by us is of the light-shining-through-a-wall type," Döbrich said. "Several of these experiments have already been performed, and at the moment two upgrades that push these studies to their limits are proposed (ALPS-II at DESY and REAPR at Fermilab).

The experiment suggested by us differs from these setups in the magnetic field configuration, which is optimized in our setup for minicharged particles. This is a consequence of the 'tunneling of the third kind' scenario in contrast to 'tunneling of the second kind,' which previous experiments are based on."

The physicists calculate that this experiment should be sensitive to detecting MCP masses down to 7 x 10^{-7} eV, which is in the parameter regime of new physics. This sensitivity significantly improves upon the capabilities of other experiments, such as the polarizzazione del Vuoto con laser (PVLAS) experiments and CMB-based cosmological experiments, both of which have been previously used to search for MCPs. As Döbrich explained, detecting photons on the opposite side of the wall would be a clear indication of physics beyond the Standard Model.

"The nice thing about the light-shining-through-a-wall effect is that known (i.e., Standard Model) particles cannot produce such an effect within current sensitivities," Döbrich said. "Thus, if light shining through a wall were observed, it would be a clear hint of new physics! As a second step, one would have to determine the nature of this new particle precisely (as ongoing, for example, for the new particle at the LHC, a.k.a. the Higgs boson, whose spin, for example, still has to be determined). In our experiment, changing, for example, the angle of the incident light or changing its polarization would be a way to discriminate minicharged particles from other weakly interacting new particles."

More information: Babette Döbrich, Holger Gies, Norman Neitz, and Felix Karbstein. "Magnetically Amplified Tunneling of the Third Kind as a Probe of Minicharged Particles." *PRL* 109, 131802 (2012) DOI: 10.1103/PhysRevLett.109.131802