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Are virtual particles really constantly popping in and out of existence? Or are they merely a mathematical bookkeeping device for quantum mechanics?

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Gordon Kane, director of the Michigan Center for Theoretical Physics at the University of Michigan at Ann Arbor, provides this answer.

Virtual particles are indeed real particles. Quantum theory predicts that every particle spends some time as a combination of other particles in all possible ways. These predictions are very well understood and tested.

Quantum mechanics allows, and indeed requires, temporary violations of conservation of energy, so one particle can become a pair of heavier particles (the so-called virtual particles), which quickly rejoin into the original particle as if they had never been there. If that were all that occurred we would still be confident that it was a real effect because it is an intrinsic part of quantum mechanics, which is extremely well tested, and is a complete and tightly woven theory--if any part of it were wrong the whole structure would collapse.

But while the virtual particles are briefly part of our world they can interact with other particles, and that leads to a number of tests of the quantummechanical predictions about virtual particles. The first test was understood in the late 1940s. In a hydrogen atom an electron and a proton are bound together by photons (the quanta of the electromagnetic field). Every photon will spend some time as a virtual electron plus its antiparticle, the virtual positron, since this is allowed by quantum mechanics as described above. The hydrogen atom has two energy levels that coincidentally seem to have the same energy. But when the atom is in one of those levels it interacts differently with the virtual electron and positron than when it is in the other, so their energies are shifted a tiny bit because of those interactions. That shift was measured by Willis Lamb and the Lamb shift was born, for which a Nobel Prize was eventually awarded.

Quarks are particles much like electrons, but different in that they also interact via the strong force. Two of the lighter quarks, the so-called "up" and "down" quarks, bind together to make up protons and neutrons. The "top" quark is the heaviest of the six types of quarks. In the early 1990s it had been predicted to exist but had not been directly seen in any experiment. At the LEP collider at the European particle physics laboratory CERN, millions of Z bosons--the particles that mediate neutral weak interactions--were produced and their mass was very accurately measured. The Standard Model of particle physics predicts the mass of the Z boson, but the measured value differed a little. This small difference could be explained in terms of the time the Z spent as a virtual top quark if such a top quark had a certain mass. When the top quark mass was directly measured a few years later at the Tevatron collider at Fermi National Accelerator Laboratory near Chicago, the value agreed with that obtained from the virtual particle analysis, providing a dramatic test of our understanding of virtual particles.

Another very good test some readers may want to look up, which we do not have space to describe here, is the Casimir effect, where forces between metal plates in empty space are modified by the presence of virtual particles.

Thus virtual particles are indeed real and have observable effects that physicists have devised ways of measuring. Their properties and consequences are well established and well understood consequences of quantum mechanics.

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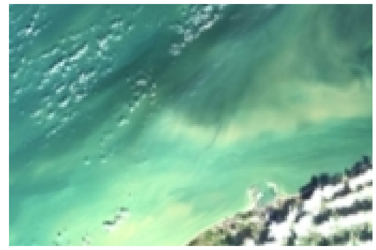

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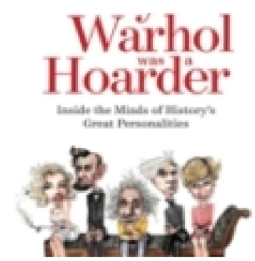

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