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Ultra-precise test confirms photons are bosons（图）

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Physicists in the US have carried out an extremely precise test of the one of the cornerstones of modern physics – the idea that the two types of fundamental particle, bosons and fermions, follow two distinct kinds of statistical behaviour. The laser-based experiment confirmed that photons behave according to Bose–Einstein statistics, narrowing the odds that photons could in fact be fermions by about a factor of 1000 compared with previous tests.

Physics tells us that fundamental particles come in two basic varieties: bosons, which have integer values of intrinsic angular momentum or "spin", and fermions, which have half-integer spin. Bosons include force-carrying particles such as the photon, W and Z and follow Bose–Einstein statistics. An important consequence of this is that many identical bosons are free to occupy the same quantum state, leading to phenomena such as Bose–Einstein condensates and lasing.

Fermions include the fundamental matter particles such as quarks and electrons and obey Fermi–Dirac behaviour. Identical fermions can never exist in the same quantum state, giving us the shell structure of atoms and, with it, chemistry.

No simple explanation

The principle that integer spin particles are governed by Bose–Einstein statistics while half-integer spin particles display Fermi–Dirac behaviour has been proved using the mathematics of quantum field theory. But some physicists, including the late Richard Feynman, have been troubled by the fact that there is no simple explanation for this connection and that it rests on many assumptions, some stated and others implicit. Indeed, it has been speculated that these assumptions may not hold in more general physical theories, such as string theory.

Dmitry Budker and Damon English of the University of California at Berkeley decided they would test this principle, known as the spin-statistics theorem, as precisely as they could. They knew that the chances of disproving the theory were tiny, but reckoned it was important to carry out the experiment anyway. As Budker points out, the discovery of CP violation in particle physics was not anticipated and "didn't have any immediate theoretical appeal" but is now one of the main ingredients in explaining why the universe appears to contain vastly more matter than antimatter. "Our experiment is very high risk but very high pay-off," he says, "in that we are extremely unlikely to disprove the theory but if we did it would be a revolutionary discovery."

Budker and English, together with Valeriy Yashchuk of the Lawrence Berkeley National Laboratory, investigated a particular kind of two-photon absorption by barium atoms in which the total angular momentum of the atoms shifts from zero to one. Quantum mechanics tells us that it is impossible to construct a two-particle wavefunction with a total angular momentum of one if the wavefunction is symmetrical (with respect to particle interchange) as is the case for identical bosons. In other words, if photons are bosons it should be impossible to carry out this particular absorption process for pairs of photons having the same frequency.

No such absorption

The researchers fired two green laser beams from opposite directions into a beam of barium atoms contained within an optical cavity, with the combined energy of a photon pair (made up of one photon from each of the beams) equal to the barium absorption energy. They found that when the frequencies of the two beams were very slightly different to one another this absorption took place, which they observed by measuring the photons given off by the barium's subsequent de-excitation. But they observed no such absorption when the frequencies were identical – demonstrating that photons really are bosons.

Budker and David DeMille, now at Yale University, published results from a similar experiment carried out in 1999, which also showed that photons behave as bosons. However, the latest test is much more precise, thanks to improvements in the experimental set up, and reduces the uncertainty in the result by over three orders of magnitude – proving the result to better than four parts in 1011 at a confidence level of 90%. According to Budker, the precision could be improved 100–1000 times by improving the stability of the lasers and enhancing the efficiency and reducing the noise of the photon detector.

Practical benefits

Budker adds that the experiment could even have practical benefits. He says that they have been able to measure a previously unobserved and extremely weak kind of two-photon transition enabled by hyperfine splitting, and that this transition could potentially be used in new kinds of atomic clocks.

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