Research Paper Illuminates How Light Pushes Atoms

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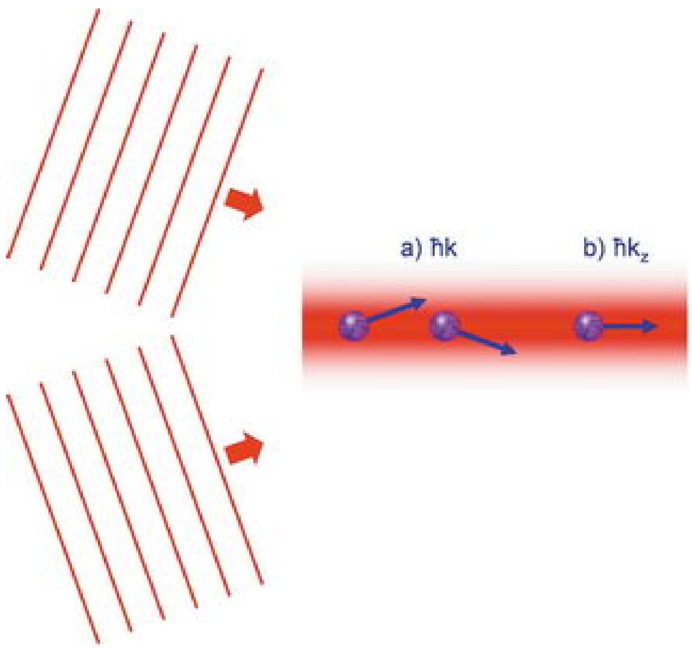

A pencil-like laser beam can be made by intersecting two infinitely wide light waves at a small angle. "You might think that an atom would absorb a photon randomly from only one of the beams," as depicted in the section labeled a), "but this paper shows that the atom recoils with a speed that is less than it would get from the momentum of either of the infinitely wide photons, with no sideways recoil," as depicted in b).

A research paper to be published in the 18 August edition of the journal *Physical Review Letters* reveals a new effect in the fundamental way that laser light interacts with atoms.

"Unlike water, which speeds up as it passes through a small nozzle, photons of light have less momentum at the center of a focused laser beam," says Kurt Gibble, an associate professor of physics at Penn State University and the author of the research paper. Gibble's theoretical paper analyzes the speed of an atom after it absorbs a photon of light and reveals the surprising effect that a photon in a narrow laser beam delivers less momentum to an atom than does a photon in a wide beam of light.

Einstein proposed that a light wave is made of photons that carry discrete packets of energy. "When a photon hits an atom, the atom recoils with a speed that is determined by the photon's momentum, similar to two balls colliding on a billiard table," Gibble explains. Physicists often think of a focused laser beam as the intense intersection of two or more infinitely wide light waves, and Gibble's discovery provides an important new understanding of what happens to an atom that is pummeled by photons coming from the different directions of these multiple intersecting light waves. "You might think that an atom would absorb a photon randomly from only one of the beams, but this paper shows that the atom feels the effect of the photons from all of the beams simultaneously and, surprisingly, that it recoils with a speed that is less than it would get from the momentum of any one of the infinitely wide photons."

Gibble's discovery has implications for the accuracy of atomic clocks, which are based on microwaves. "For a laser beam that is 1 centimeter in diameter, the sideways components of the photons act as microwave photons, which have a smaller energy and momentum than visible photons," Gibble explains. The world's most accurate atomic clocks use microwaves. "These microwaves produce sideways forces on the atoms in exactly the same way as a narrow laser beam," Gibble says. "With the traditional approach of treating the microwaves as being infinitely wide, you expect an error in the clock that is comparable to the current accuracy of the best atomic clocks, so this effect needed to be better understood." Gibble's new work demonstrates that the recoil from the microwave photons produces a smaller frequency shift than previously thought, meaning that the clocks actually can be more accurate.

Gibble's research also reveals an important correction for the next generation of more precise tests of fundamental physics. Some of these tests use atom interferometers to measure precisely the recoil speed of an atom, which is used to determine the fine-structure constant--a fundamental description of how matter and electromagnetic energy interact. "The important thing is that we now understand much better some of the physics that is behind atomic clocks and atom interferometers," Gibble comments.

Source: Eberly College of Science

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