Physics News Update
The AIP Bulletin of Physics News

Number 732 #1, May 24, 2005 by Phil Schewe and Ben Stein

The First Direct Measurement of Recoil Momentum

The first direct measurement of recoil momentum for single atoms struck by light in an absorptive medium has been made by Gretchen Campbell, Dave Pritchard, Wolfgang Ketterle and their colleagues at MIT. Parcels of light, photons, do not possess mass, but a beam of light does carry momentum. In general, when light strikes a mirror, the mirror will recoil ever so slightly, and this recoil has previously been measured. But what about a single photon striking a single atom in a dilute gas?

The momentum of a photon equals h/lambda, where h is Planck's constant and lambda is the wavelength of the light in vacuum. In a dispersive medium, a medium which can scatter or absorb light, the index of refraction for the medium, n, comes into play: an object absorbing the photon will recoil with a momentum equal to nh/lambda. This is what has been measured for the first time on an atomic basis.

The MIT team used laser beams sent into a dilute gas; a beat note between recoiling atoms and atoms at rest provided the momentum measurement of selected atoms. The fact that the recoil momentum should actually be proportional to the index of refraction came as something of a surprise to the experimenters. You might expect that in isolated encounters, when an individual atom absorbs a single photon, that the recoil of the atom should not depend on n. That's because the atoms in the sample---in this case a Bose-Einstein condensate of Rb atoms---is extremely dilute, so dilute that each atom essentially resides in a vacuum.

Nevertheless, the interaction of the light with all the atoms has to be taken into account, even if the specific interaction being measured, in effect, is that of single atoms. The atoms "sense" the presence of the others and act collectively, and the extra factor, the index of refraction, is applicable after all. At several colloquia before audiences of physicists, Ketterle has put the question: will the recoil be h/lambda or nh/lambda? Generally the opinion among these experts divides about 50/50. So, on this basic question of light traveling a medium, a physicist's intuition can be wrong, at least in half the cases. Ketterle believes that this new insight about what happens when light penetrates a dispersive medium provides an important correction for high-precision measurements using cold atoms. (Campbell *et al.*, Physical Review Letters, 6 May 2005)

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