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Capturing Atoms: First You Have to Slow Them Down

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Slowing and capturing atoms by bombarding them with photons of laser light is easier said than done. One elegant solution to the problem took scientists years to devise, and both the problem and the solution concern a phenomenon called the Doppler effect.

In everyday life, the Doppler effect can be heard when a car passes by blowing its horn. The pitch, or frequency, of the horn slides noticeably downward as the car goes by because the horn's sound waves are distorted by the car's motion.

As the car approaches, the sound waves are squeezed closer together like the bow waves of a boat, so the horn's pitch sounds higher than it really is.

Motion also distorts the frequency, or color, of light waves and photons. Therefore, to a sodium atom hurtling head-on through a barrage of yellow laser photons, the color of each photon appears slightly shifted toward the higher-frequency blue part of the spectrum.

This Doppler shift complicates atom trapping because free atoms absorb photons only at select frequencies called resonant frequencies. Like tiny radios programmed for several key stations, the atoms absorb laser photons only when the laser is "broadcasting" at one or more of those predetermined frequencies.

Since the motion of the atoms shifts the laser's apparent frequency out of tune with their resonant frequencies, scientists must compensate for the difference.

One solution is to apply a strong magnetic field to the atoms. This alters their structure and fine-tunes the atomic "radios" until the laser "station" locks in.

But that creates another problem. When the atoms are tuned in, they absorb laser photons and quickly decelerate. And as the atoms continue to slow down, the apparent frequency of the oncoming photons shifts out of tune again. Photon absorption falls off and so does deceleration.

Happily, this problem is solved by tapering the magnet that surrounds the atoms. As the atoms absorb photons and decelerate down the barrel of the magnet, the steadily changing magnetic field keeps their resonant frequency correctly tuned to the laser frequency.

Once the atoms have absorbed enough photons to bring them to a virtual stop (about 30,000 for a sodium atom), they can be confined by a force field called "optical molasses," which is created by six opposing laser beams pointing east-west, north-south and up-down.

Since the six identical beams are deliberately detuned just below the resonant frequency, atoms traveling in any direction with enough velocity to escape will encounter Doppler-shifted photons near or at their resonant frequency. The resulting increase in photon absorption slows down the atoms and usually frustrates their escape. A difficult problem becomes a clever solution.