Atom bouncers have it taped

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EXPERIMENTERS now have a new set of tricks for manipulating and storing cold atoms — and the key ingredients are familiar high-street commodities. Edward Hinds and co-workers at Yale University have repeatedly bounced rubidium atoms from magnetic tape of the kind used to record audio signals[1]. In later experiments, they obtained better results with floppy disks.

A particle that has a magnetic moment is attracted to or repelled from a region of high magnetic field, depending on which way the magnetic moment is pointing. So a localized region of high magnetic field reflects slow particles, provided that their magnetic moments are first oriented in the proper direction. As far back as the 1920s, Stern and Gerlach used spatially non-uniform magnetic fields to deflect the trajectories of silver atoms, each of which has a magnetic moment due to an unpaired electron. But the deflection produced was slight. Normal-incidence reflection, as observed by the Yale group, required methods for creating a strongly varying magnetic field as well as methods for slowing the atoms before attempting to reflect them.

The arrangement of magnetic fields used in the recent reflection experiments was discussed in 1961 by Vladimirskii[2]. The application he had in mind was the production of focused beams of polarized neutrons (that is, neutrons that have their spins and hence their magnetic moments oriented in the same direction). He pointed out that a surface on which the magnetic field reverses direction periodically as one moves parallel to the surface along one direction (say the x direction) and which is constant as one moves parallel to the surface along the perpendicular (y) direction would form a magnetic field suitable for a plane magnetic mirror. Away from the surface, the magnitude of the field decreases exponentially, as $|B| = B_0 \exp(-kz)$. Here B_0 is the magnitude of the field at the surface, k is 2π divided by the spatial period of the surface magnetization, and z is the distance from the surface.

The direction of the field changes rapidly, but the orientation of the magnetic moment with respect to the field direction will be preserved if the particle moves slowly enough. The magnetic force will then depend only on the magnitude of the field, not its direction. As the particle approaches the surface, it will be subjected to an exponentially increasing magnetic force. If it is going slowly enough and if its magnetic moment is pointing in the right direction to begin with, it will be reflected.

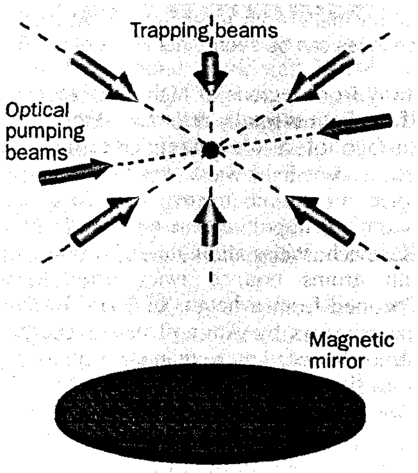

FIG. 1 A magneto-optic trap, made from a combination of laser beams and magnetic fields, collects and cools a sample of rubidium atoms, which are released and allowed to fall. The optical pumping beams orient the magnetic moments of the atoms so that they will be repelled from the magnetic mirror, which is made from audio cassette tape or a floppy disk. After Fig. 1 of ref. 1.

Vladimirskii originally proposed creating such a plane of alternating magnetic field by laying down an array of parallel conductors in which the direction of the electrical current alternated from one to the next. More recently, Opat, Wark and Cimmino[3] pointed out that a better method was to record a suitable magnetization pattern on a ferromagnetic substrate, such as audio recording tape.

Atoms have previously been reflected at normal incidence from evanescent light fields. An optical electric field, tuned above an atomic resonance, causes the charge distribution within the atom to oscillate at the same frequency, but with a phase lag. This generates a positive interaction energy, so that an atom is pushed away from regions of high light intensity. If the light is totally reflected at the inside surface of a transparent medium, the evanescent light wave that leaks out can form an atomic mirror. The first such 'atomic trampoline' was made in 1990 by Kasevich, Weiss and Chu[4], who saw sodium atoms bounce twice after being dropped from a height of 2 cm. In later experiments by Aminoff *et al.*, caesium atoms bounced more than eight times[5].

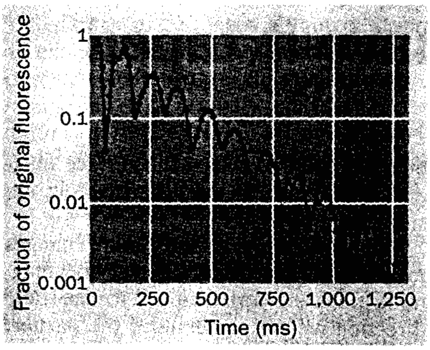

FIG. 2 Fraction of atoms recaptured in the magneto-optic trap as a function of the time after being dropped onto a concave magnetic mirror made from a floppy disk. At least 8 bounces can be seen. After Fig. 2 of ref. 6.

In the new experiment reported by the Yale group, a magnetic mirror was created by recording a 5-kHz audio tone on cassette tape with an ordinary tape recorder. The spatial period of the magnetization was 9.5 μm. Three strips of tape were cut out and glued to a 2.5-cm flat glass substrate to form the mirror. The field just outside the tape is 0.11 tesla, which would be strong enough to reflect rubidium atoms dropped from 0.8 m, although the atoms were actually dropped only a few centimetres.

The experimental arrangement is sketched in Fig. 1. Rubidium atoms are collected in a magneto-optic trap, consisting of a non-uniform magnetic field and three pairs of mutually perpendicular laser beams, detuned below resonance. After enough atoms have accumulated, the frequencies of the lasers are further detuned from resonance, which cools the atoms to about 20 microkelvins. The laser beams and magnetic fields that make up the trap are then shut off, allowing the atoms to drop onto the magnetized tape. Before the atoms fall out of the trap region, they are optically pumped by two of the laser beams so that their magnetic moments have the proper orientation to be reflected. The optical pumping has the side-effect of heating the atoms to 30 microkelvins. After a variable time, the magneto-optic trap is switched back on, and the number of atoms retrapped is recorded.

Multiple bounces were observed with this apparatus, for a duration of 600 milliseconds. Only 63 per cent of the atoms fell on a magnetized region of the tape, but, of those that did, about 94 per cent were reflected. The reflection was specular. The reflectivity of demagnetized tape was also high, but was diffuse, presumably because the random orientations of the magnetic domains create a magnetic mirror that has a rough surface.

An improved version of this experiment uses a pattern with a 10-μm period recorded on the surface of a floppy disk. A sine-wave audio signal was sent directly to the recording head, bypassing the ordinary recording electronics. The stepper motor of the drive mechanism was modified so that successive tracks overlapped, and the pattern was recorded over the entire available surface. A 2.5-cm diameter circular piece was cut out and stretched into a concave shape, which focused the reflected atoms and allowed more bounces to be seen. Figure 2 shows the fraction of the atoms recaptured as a function of the time after they are released — bounces can be clearly seen out to about 1 second.

These magnetic methods for reflecting atoms are certainly simpler to implement than optical methods, but will they prove as useful? One remaining question is whether coherence can be preserved in the reflection. If so, magnetic mirrors could be used as retroreflectors in atom interferometers. If not, there might still be applications that do not require coherence, such as storing atoms, free from laser radiation, for use in some other experiment. We could imagine creating a magnetic 'bucket of atoms', perhaps containing some rare isotope. This would give a double meaning to the term 'magnetic storage medium'. ☐

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