Propagation of Cold Atoms along a Miniature Magnetic Guide

M. Key, W. Rooijakkers, E.A. Hinds

Sussex Centre for Optical and Atomic Physics, University of Sussex
Brighton, BN1 9QH, United Kingdom
Tel +44-1273-877100, Fax +44-1273-678097
E-mail: e.a.hinds@sussex.ac.uk
Website: http://pburton.maps.sussex.ac.uk/scoap/index.html

There is widespread interest in guiding cold atoms [1]. Waveguides for cold atoms may become important elements for atom optics and atom lasers.The waveguide can be a 'hosepipe', delivering large quantities of atoms to an inaccessible region or a 'single-mode' fibre permitting coherent propagation of de Broglie waves for applications such as interferometry or integrated atom optics. In several previous experiments, cold atoms have been guided inside hollow core optical fibres where the optical dipole force is used to provide a repulsive force at the fibre wall. With this approach it is difficult to avoid heating of atoms through intensity fluctuations and spontaneous emission. Confinement using static magnetic fields provides an attractive alternative.

We present a miniature magnetic waveguide using a fibre manufactured by the Optoelectronics Research Centre at Southampton [2]. Five holes of radius $263\mu m$ run through the length of the fibre parallel to the vertical z-axis. Four of them intersect in the $(x,\ y)$ plane on the corners of a square at $(\pm a,\ \pm a)$, with a=522μm. Wires, carrying current alternately up and down the fibre, are threaded through these holes to create a magnetic guiding potential. The fifth hole is on the fibre axis where the atoms are guided. To a good approximation, the magnetic potential is purely quadrupole. At the top of the guide the wires spread out to form a magnetic funnel of apex angle 90 degrees. A miniature 'pinch coil' is wound around the base of guide allowing the end of the guide to be closed off.

We release atoms from a MOT, letting them evolve in the magnetic guide. The fluorescence images in figure 1 show atoms falling into the guide. There is a period of darkness while they travel downwards, reflect from the pinch coil and propagate back up. Images taken after 110msec measure the difference in fluorescence between the pinch coil being on and off. This ensures that only those atoms which travel down and up the waveguide are detected. We find an optimum coupling efficiency of ~11% with 4.68amps in the guide. The reason for the optimum coupling efficiency can be understood by the following simple model. When an atom falls 1cm to the mouth of the fibre, the gravitational potential energy released is equivalent to the atom interacting with a magnetic field of 15G. The optimum magnetic field at the wall of our fibre is 17.9G. Higher magnetic fields make the magnetic aperture of the funnel smaller, which constricts the entrance to the guide. Weaker magnetic fields result in poor overlap of the cloud with the physical aperture of the guide. An additional constraint is imposed by the atoms angular momentum because the guiding force must be large enough to overcome the centrifugal force of the atoms at the guide wall.

In one experiment we measure the threshold current needed to reflect atoms at the pinch coil. When the atoms are not optically pumped, we observe several steps in the reflected signal corresponding to the thresholds for the various m_f values. For atoms optically pumped into the state of maximum m_f, the gravitational potential energy released is equivalent to an interaction with a field of 35.8G. We find that these atoms are reflected at a lower field because some of their energy is in the transverse motion. We measure the mean energy in the transverse motion by adding a horizontal bias field while the atoms are inside the guide. This displaces the magnetic centre of the guide, causing the outermost atoms to bang into the waveguide wall. We find the mean energy in the transverse motion (divided by μ_B) to be 9.9G, which is in excellent agreement with a full Monte Carlo simulation of the experiment. Expressed as a temperature this is $670\mu K$, considerably greater than the $25\mu K$ temperature of the atom cloud because atoms have been adiabatically compressed by gravity in the magnetic funnel. The corresponding mean radius for atoms within the guide is $98\mu m$.

By adding a second pinch coil to the top of the fibre and turning it on after the atoms have entered the guide, we have held atoms inside the guide for ~2 seconds, which is equivalent to guiding atoms over distances of ~50cm. We will also present recent work on inelastic bouncing of atoms from the pinch coil and on progress towards propagation in a single transverse mode of the waveguide [3].

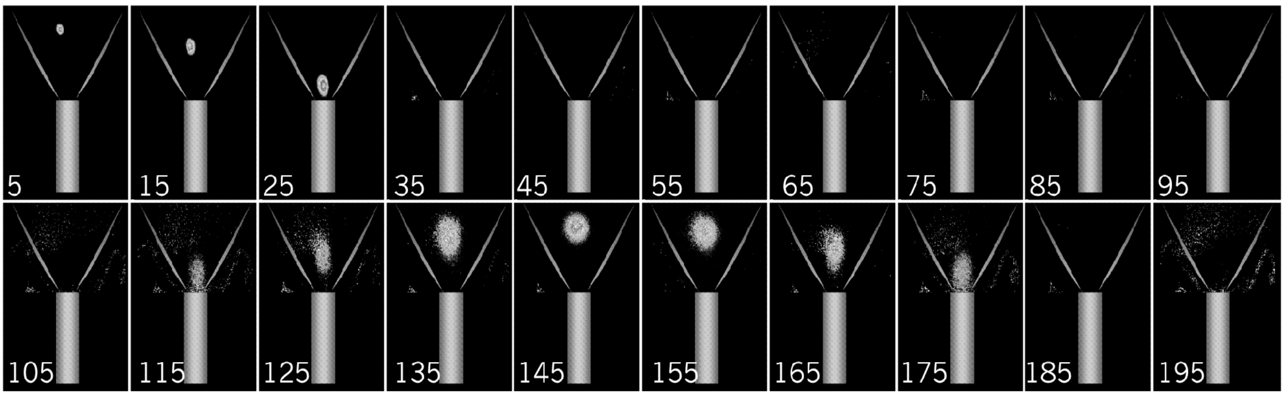

Figure 1: Fluorescence images of cold atoms falling from the MOT towards the waveguide. Numbers indicate the time in milliseconds from release of atoms from the MOT. Atoms disappear from view as they propagate inside the guide. Outline of waveguide has been added to aid the viewer.

[1] E. A. Hinds *et al.*, *J. Phys. D* **32** R119 (1999).
[2] M. Key *et al.*, *Phys. Rev. Lett.* **84** 1371 (2000).
[3] E. A. Hinds and Claudia Eberlein, *Phys. Rev. A* **61** 033614 (2000).