A SPIN FLIPPER FOR THERMAL ATOMIC BEAMS

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ABSTRACT

The spin flipper presented here is based on the method of diabatic passage. It allows for a rapid reversal of electronic as well as nuclear polarization of a thermal atomic beam without affecting beam intensity, beam profile, or magnetic fields in the interaction region. The flipper will be useful in spin dependent measurements where instrumental asymmetries and systematic errors have to be kept small. The spin flipper was tested with a polarized lithium beam in an atomic physics experiment and the reversal efficiency was found to be 0.98. The flipper can easily be adapted for other spin-polarizable atoms, e.g. for a polarized atomic hydrogen beam target.

INTRODUCTION

Usually diabatic transitions (Majorana transitions) are to be avoided in transporting polarized beams. With suitably shaped fields however, these transitions can be exploited for efficient spin reversal. The diabatic reversal method has frequently been used in nuclear or elementary particle physics experiments. In those sources however, either the velocity of the polarized particle was high (about 100 times thermal as in the case of Lamb-shift sources[1,2]) or the magnetic moment of the particle was small (as in the case of neutron beams[3]). In both cases the diabatic conditions, outlined below, can be met much more easily than for thermal beams of paramagnetic atoms. Hight et al.[4] studied diabatic transition probabilities in a thermal atomic hydrogen beam, theoretically as well as to some extent experimentally, whereas our work[5] emphasizes the development of a useful spin-flipping device.

PRINCIPLE OF OPERATION

A spin flip occurs if the change of field direction seen by the atoms is fast compared to the Larmor precession frequency. This diabatic condition can be met in a spin flipper with weak and opposing longitudinal magnetic fields and a rapid crossing of zero in between. In such a field configuration (see Fig.1) the atomic spins do reverse their orientation with respect to the local magnetic field but do not change their direction in space. For setting the spin flipper to the adiabatic mode a relatively strong transverse magnetic field (about 0.1 mT) is applied at the field reversal region. In the combined fields the atomic spins now precess rapidly and follow the local magnetic field direction adiabatically, turning through 180^0 in space. The spin orientations are illustrated in the lower part of Fig.1.

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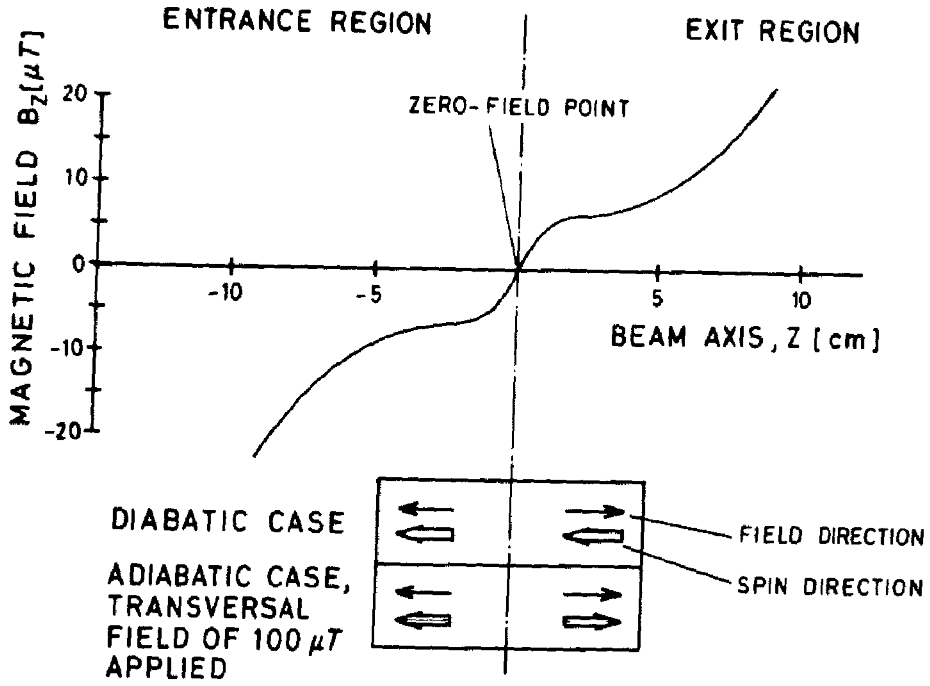

Fig. 1 Magnetic field strength B_z on the axis of the spin flipper. The arrows indicate the relative orientation of magnetic field and spin for the two operational modes.

DESCRIPTION OF FLIPPER

The layout of the spin flipper is shown in Fig.2. The field shape can be set by adjusting the currents in six pairs of coils mounted inside a magnetic shield (1 mm thick Hyperm 760). In order to ensure that the zero-field point lies exactly on axis two transverse coils, orthogonal to each other, are used for fine adjustment. These coils are also used for applying transverse magnetic field when switching to the adiabatic mode. The field strength in the region between the external guiding fields ($\approx$ 1 mT) and the low-field reversal region was chosen to decline (rise) approximately proportional to $1/|z|$, thereby ensuring good adiabatic transport into (out of) the flip region while keeping the length of the flipper reasonably short.

PERFORMANCE

In the diabatic representation depolarizing transitions, which reduce the flipping efficiency, can occur only between adjacent hyperfine states with different populations. We computed the transition probability, η, from initially populated states into adjacent empty states, where η depends on $1/v$ and on r^2. For comparison with measurements η was averaged over starting phases, velocity distribution, and radial atomic beam extension (beam diameter $r = 3$ mm). As described in detail elsewhere[5] $\bar{\eta}$ was measured in a lithium - 6 atomic beam arrangement with polarizing and analyzing sextupoles, combined with an additional spin flip region. The result of $\bar{\eta} = 0.03$ is in good agreement

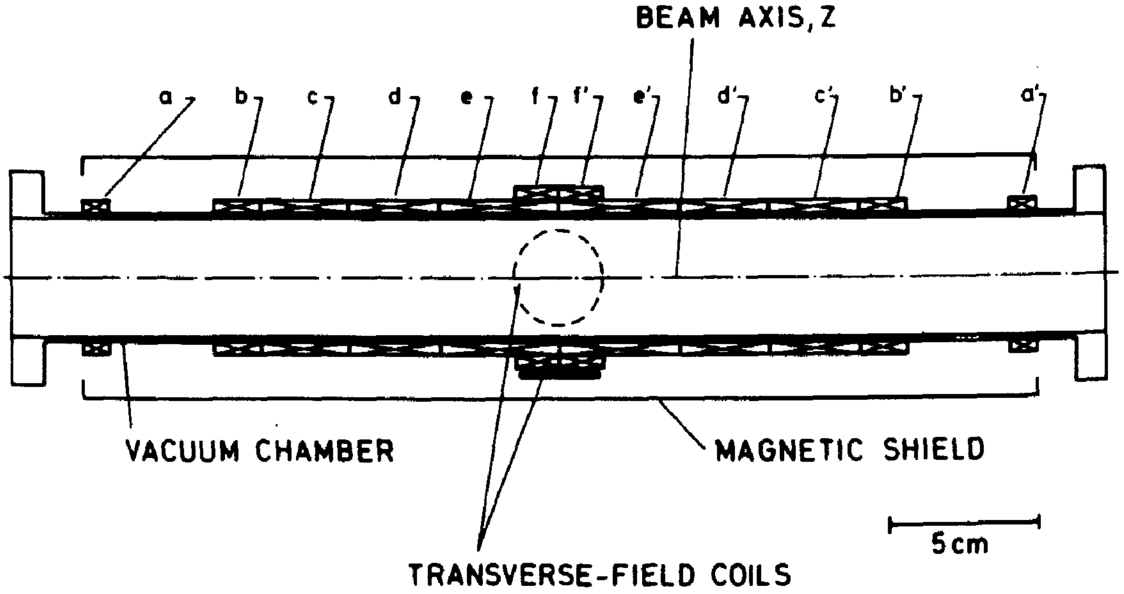

Fig. 2 Cross section of the spin flipper.

with the calculations, leading to a reversal efficiency of $\varepsilon = 0.98$ for the electron polarization in the lithium beam. The experimental studies showed that ε does not critically depend on the currents in the longitudinal field coils. The application of the small transverse field at the flip region inside the magnetically shielded region has a negligible effect on atomic beam intensity, atomic trajectories, and magnetic field in the interaction. This was tested in a polarized electron - polarized atom crossed beam scattering experiment where null - asymmetries could be obtained. They were found to be consistent with zero within the statistical error (± 0.001), showing that the spin flipper is free of systematic errors on at least that level. Considering the reversal of nuclear polarization of a polarized hydrogen ground state source the atoms should be prepared in the hyperfine substate with $m_S = m_I = 1/2$, otherwise the spin flipper will switch only from full to zero polarization.

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