Atomic Beam Targets

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Abstract

New techniques for laser manipulation of atomic beams offer new possibilities for polarized internal atomic beam targets in storage rings. The advantages and applications of these techniques for polarization and density increase of an atomic beam are discussed.

Effusive Atomic Beams

Basic limitations concerning target-thickness and luminosities for an effusive beam as an internal target arise from the relation between the maximum vapour pressure and the corresponding dia- phragm in the atomic beam source [1]. For a realistic atomic beam apparatus with a length of 50 cm, an oven orifice of 3 mm diameter and an apperture of 3 mm diameter at the target-zone, a target-thickness of about 10^9 atoms/cm^2 could be reached, resulting in a luminisity of $5*10^{26}$ cm-^{2}s^{-1} with parameters given for the COSY-ring ($N=3*10^{11}$ particles in the ring, a revolution frequency of $f=1.5*10^6$ s^{-1}) . Even using supersonic beams (density increase by a factor of about 10) or taking unrealistic large values for the oven-orifice combined with a very short apparatus will result in a low target-density. In addition problems may arise by the fast consumption of the evaporated target material and vacuum-con-ditions.

Manipulation of the Atomic Beam with Laser Light

1.Polarization

On the other hand the possibility of strong atomic orientation via optical pumping (electronic and nuclear polarization) seems to make the atomic beam nevertheless attractive for target use. Franzen and Emslie [2] showed that nearly 100% of atomic orientation in a Na atomic vapour could be reached, using a single Na D-line.

The level-scheme and pumping-diagram of ^{23}Na in an external weak magnetic field shows that a two level system, necessary for sufficient pumping cycles, can be prepared using the D_2-line as a pumping-transition: the illumination of the atoms with circularly polarized laser light, tuned to the transition $^2S_{1/2}$,F=2 -> $^2P_{3/2}$, F'=3 will pump all the atoms into the hyperfine-substate $^2S_{1/2}$ (F=2,m_F=2) which is composed by the combination of m_J=+1/2 and m_I=+3/2. So the optical pumping ends up in a nuclear polarization of nearly 100% . The nuclear orientation can be chosen being longitudinal or transverse by the orientation of the external magnetic field and the polarization of the laser beam and can be switched rapidly by changing the polarization of the laser beam.

But as the pumping transition F=2 -> F'=3 is only seperated by 60 MHz from the transition (F=2 -> F'=2) this second transition will be induced by the laser with a propability of about 1% . Thus the upper level $^2S_{1/2}$,F=2 will be depleted to the non-resonant (æª¸1.7 GHz) F=1 groundstate. So as a counter measure both groundstate hyperfine levels have to be pumped simultaneously by laser-transitions (seperated by 1.712 GHz) to avoid losses in polarization. Generation of the second laser-frequency can be achieved by electrooptic modulation techniques [3].

Complete polarization of the Na-atoms can be reached with a few mW of laser power allready on a short interaction zone of typical-ly 1 cm. So the interaction-zone can be placed anywhere in the apparatus. The orientation can be transferred from the interaction zone to the target zone with the help of a weak external magnetic guiding field. Probing of the polarization can be done by probing the population in the different hyperfine sublevels by laser induced resonance fluorescence in a weak external magnetic field.

Examples for different operating polarized atom and ion sources are given in refs. [4] - [7].

A problem concerning the degree of the polarization at the target zone might arise by interaction of protons (or ions) from the storage ring with inner shell electrons of the target atoms in the target beam changing the nuclear orientation of the polarized atoms.

2.Collimation

For target use the density of the atomic beam has to be increased. A first gain in intensity (density) can be achieved by the collimation of the diverging atomic beam at the crucible with the help of transverse, resonant laser beams (transverse cooling of the atomic beam) [8]. This laserfield reduces the initial radial velocity of the emerging atoms considerably by photon momentum transfer, thus increasing the initial angle of divergence which will contribute in the target zone. This is achieved -with respect to the unshifted resonance frequency- by a slightly red shifted laser frequency. Thus the light will be tuned into resonance with radially counterpropagating atoms, decelerating them towards the beam axis, if the atomic beam is irradiated perpendicularly by the laser light. This lightfield can be created by a cone-shaped mirror [8].

The maximum gain in density that can be achieved by this method is mainly given by the radiation forces, the interaction length and the diameter of the atomic beam defining diaphragm.

The collimation of the atomic beam ends up in an increase in target-thickness by a factor of about 400, compared with the example above for the non-manipulated atomic beam. Taking the same values for the length of the apparatus, the oven orifice and the apperture, this leads to a target-thickness of $n_F=4.6*10^{11}$ atoms/cm^2 of fully polarized atoms.

3.Contraction

A further increase in target thickness can be reached by an increase in density of the atomic beam by contraction in phase space. Again this can be achieved by laser manipulation [9].

Focussing the laser light onto the atomic beam axis by a spherical mirror produces an extremely strong and inhomogeneous light field on the axis. As result the atoms are accelerated towards the high intensity region, the atomic beam axis, by the dipole force [9], when the laser frequency is tuned properly to the red side of the absorption frequency. The resulting oszillating motion is damped by additional transverse cooling, as explained above. Thus a contraction of the atomic beam depending on the length of the interaction zone, the velocity of the atoms, the laser power and the beam waist can be reached. The principle limit of contraction in atomic beam diameter is given by Heisenbergs uncertainty principle between momentum and location resolution.

The contraction of the atomic beam may result in a further increase of target thickness by a factor of 3 to 10, depending on the experimental situation. So a target-thickness of $1.5*10^{11}$ and $5*10^{12}$ atoms/cm^2 respectively could be reached, taking the polarized atomic beam with collimation gain from the example above.

4.Cooling

If the resulting target density is still too low, there is the possibility of decelerating the atomic beam with the help of resonant, counterpropagating laser light [10]. As the density is proportional to Þ/v, where Þ is the total (constant) flux produced by the oven and v is the mean velocity of the atoms in the beam, the target thickness inreases with 1/v.

The deceleration is achieved by photon momentum transfer from a counterpropagating, resonant laser field to the atoms. In the case of sodium the deceleration may become $0.9*10^8$ cm/s^2 or nearly 10^5 times the acceleration of gravity.

For this purpose two major experimental problems have to be solved: optical pumping and keeping the resonance condition for the fast changing Dopplershift of the fast downslowing atoms (e.g. 1GHz in 1ms for sodium atoms). Two new successful experimental methods have been developed which overcome these [3,11,12] problems.

A density increase by a factor of 10 can be reached, if the atomic beam is decelerated by a factor of 10. As by-product a complete polarization of the atomic beam is directly achieved by using a circularly polarized laser beam.

Suitable Elements for these Schemes

The atomic level schemes, suitable for laser manipulation of atomic beams, and the wavelength region that is easily reached by dye lasers today fa-vourate the alkalines. In these cases laser manipulation can be done with the help of dye-lasers (^{6,7}Li,^{23}Na,^{39}K,^{85,87}Rb,^{113}Cs) or even diode-lasers (^{85,87}Rb,^{113}Cs). In addition it is no longer necessary that the laser is placed next to the apparatus. Optical fibers which are available today allow the laser light being transported over a distance of some ten meters without major losses. So the lasers can be placed in another room or even another building.

Conclusions

A target thickness for laser manipulated atomic beams between 10^{12} and 10^{14} atoms/cm^2 seams to be feasable. A comparison of the values above with the values given for other possible internal targets (cluster beams, fiber,...) shows that the laser-manipulated atomic beam may be quite attractive as an internal target for COSY, especially as it is fully polarized.

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