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Abstract

One of the most favourable properties of Lambshift sources is to deliver intense beams with small emittance. Up to now they are used to produce negatively charged proton or deuteron beams only. Extended studies of selective ionization of metastable atoms by charge exchange processes demonstrated the Lambshift source to be able to produce positively charged polarized beams also. The source described in detail is able to produce 500 nA transverse polarized deuteron beams within an emittance of less than 1 cm rad $eV^{1/2}$. The tensorpolarization measured by neutron asymmetry of the $T(d,n)^4He$ reaction is $P_{33} = -0.73$.

Zusammenfassung

Mit der Lambshiftquelle lassen sich intensive Ionenstrahlen mit kleiner Emittanz erzeugen. Bisher wurden sie nur für die Erzeugung negativ geladener polarisierter Wasserstoffionen eingesetzt. Eingehende Untersuchungen der Ladungsaustauschprozesse für die selektive Ionisation zeigten, daß sich mit der Lambshiftquelle auch positiv geladene, polarisierte Ionenstrahlen erzeugen lassen. Die hier beschriebene Ionenquelle liefert einen transversal polarisierten Strahl von 500 nA Intensität bei einer Emittanz, die kleiner 1 cm rad $eV^{1/2}$ ist. Die über die Asymmetrie der Neutronenverteilung der $T(d,n)^4He$ Reaktion gemessene Tensorpolarisation betrug $P_{33} = -0,73$.

The Lambshift type polarized ion source takes advantage of the different lifetimes of the metastable $2S\frac{1}{2}$ hydrogen states, in combined magnetic and electrical fields. This special property of the metastable $2S\frac{1}{2}$ state is a consequence of the Lambshift, leading to a level crossing of the $2S\frac{1}{2}$ and $2P\frac{1}{2}$ states at a magnetic field of 575 Oe |1|. The first figure shows a metastable beam running through two special magnetic fields, both of 575 Oe but of opposite field directions. Thereafter only two of the 6 metastable 2 S states of the deuterium are occupied. In a weak magnetic field the atoms in these two states are polarized with a nuclear polarization of $P_{33} = -1$ |2,9|.

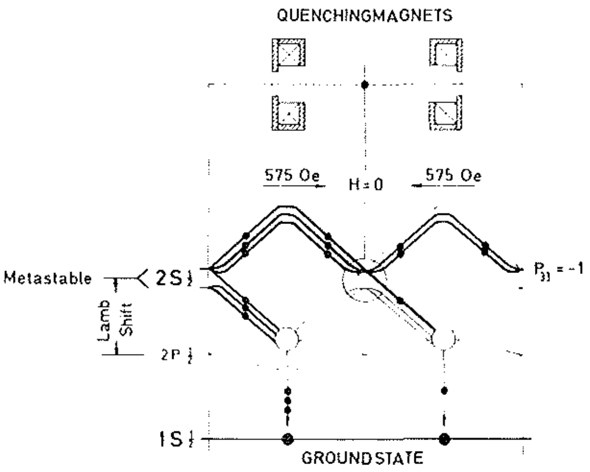

fig. 1

Designing a Lambshift source the first problem is to produce an intense beam of metastable atoms.

These atoms can be produced by charge exchange of low

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energetic deuterons with cesium |3|.

$$D^{+} + Cs \rightarrow D(2S) + Cs^{+}$$

The source of metastable atoms used at present is shown in figure 2. The primary ions are extracted at an energy of 7 keV from a rf ion source and decellerated in a gridded electrostatic tube lens to 1 keV. The distance towards the following Cs-cell is 14 cm. This Cs-cell is made from stainless steel. The system at the top contains an ampoule filled with cesium. This glass ampoule can be opened when the cell is evacuated. The liquid cesium flows to the bottom, where it is heated to 160° C. Very thin walls minimize the heat transfer from the bottom to the other parts of the cell. These other parts are heated to 60° C by a second system. In this way only the temperature of the cesium at the bottom determines the cesium vapor density, because cesium condenses at the other parts with a small vapor pressure of less than 10^{-4} torr. The special geometry prevents the cesium atoms, evaporated at the bottom, from escaping the cell without colliding with the 60° C heated walls or other cesium particles in the vapor. Therefore the loss of cesium is small: 50 mg/h.

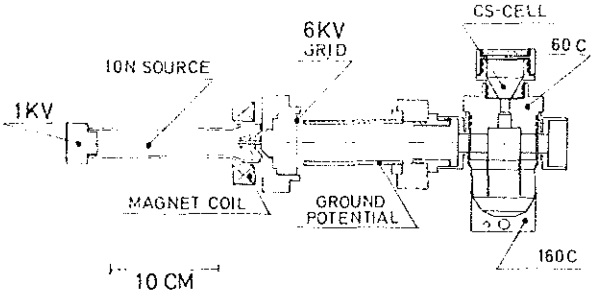


fig. 2

The effusing cesium is of no disadvantage at all because it is necessary to get an intense beam of metastable atoms. The emerging cesium condenses at the walls of the water cooled focusing system. This arising layer is able to deliver secondary electrons for compensating the beam loading of the positively charged ion beam. To shorten the time until there is a sufficient layer on the surface of the focusing electrodes, the newly filled cesium is overheated for some minutes.

However, the production of neutral atoms by charge exchange with the cesium leads to atoms in the 1S ground state as well. The cross section for this process is much higher. In the neutral beam leaving the cesium cell is about 15 % of the deuterium atoms in the metastable 2S state. These metastables are polarized by two selective quenching processes and this reduces the intensity to a third of the original. This remaining small part has to be ionized to get polarized ions. Because the overwhelming part of the atoms are in the ground state and nearly unpolarized, this ionization process must select only the metastable atoms. Up to now only charge exchange processes of the following type could be shown to deliver satisfactory gain.

$$D(2S) + X \xrightarrow{P\pm} D^{\pm} + X^{\mp}$$

$$D(1S) + X \xrightarrow{\gamma\pm} D^{\pm} + X^{\mp}$$

If the cross section p is higher than the cross section γ the charge exchange process is selective. Until now Lambshift ion sources used the charge exchange with argon for selective ionization. This process delivers negatively charged polarized ion beams |4|.

The production and selective ionization of the metastables take place in charge exchange cells typically with inner diameters of 1,8 cm, at an energy of 1 keV. The distance from the beginning of the cesium cell to the end of the argon cell is about 90 cm. This leads to a small emittance of less than 1 cm rad $eV^{1/2}$ for the polarized metastable beam. The selective ionization does not appreciably effect this emittance.

Because of the beam quality of the Lambshift source for negative ions, it was intended to make it useful as a polarized source for cyclotrons. For this application positively charged polarized ions are needed and therefore charge exchange reactions were studied. All investigated reactions (with one exception |5|) could be shown to be selective for the production of positively charged ions |6|. Iodine turned out to be the best charge exchange partner |7,8|.

Figure 3 shows the cross sections p and γ for iodine as function of energy in comparison with the equivalent ones of argon.

The cross sections p of argon and iodine are nearly equivalent whereas the selectivity of iodine is still higher than the selectivity of argon. Therefore the Lambshift ion source is suitable for production of polarized positively charged ions too.

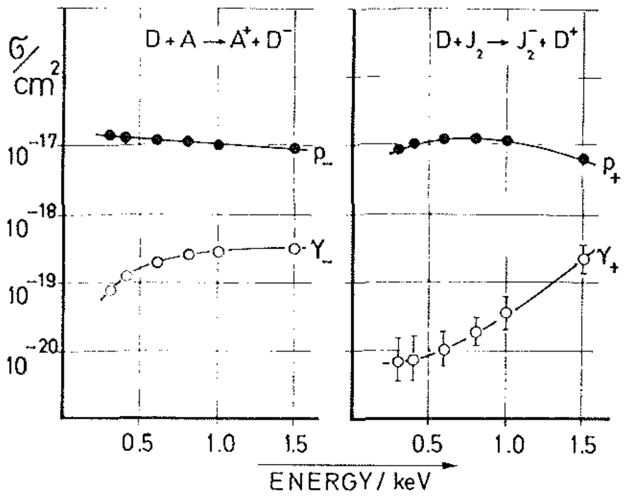


fig. 3

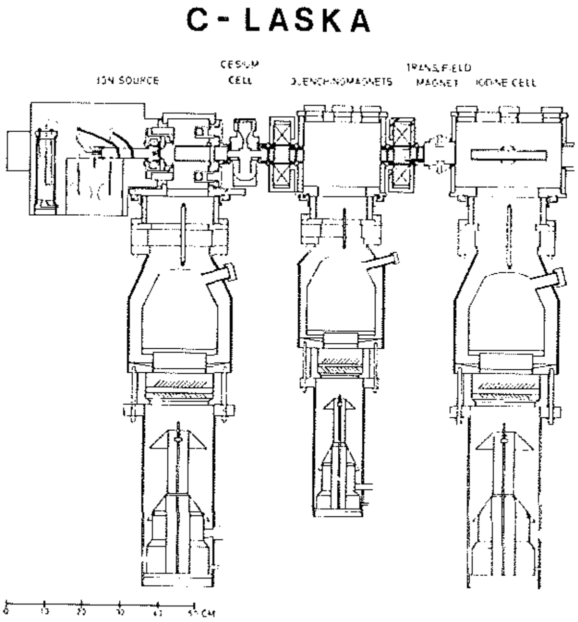
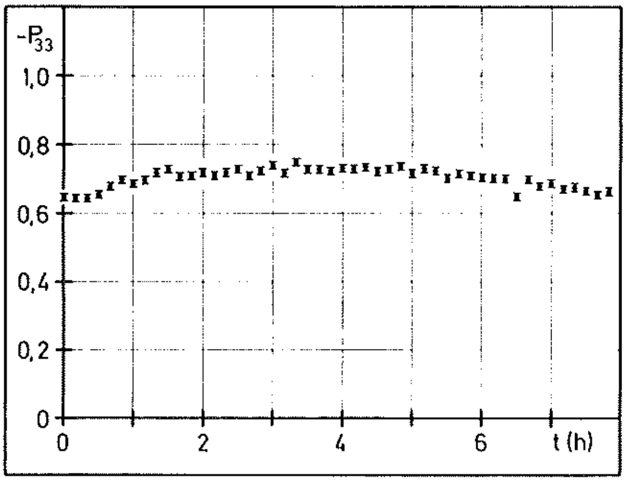


fig. 4

In figure 4 the source designed for the isochronous cyclotron in Karlsruhe is drawn to scale. Between the metastable source and the iodine cell the two iron-shielded quenching magnets are shown. By the iron-shielding of the two solenoids it was possible to reach a minimum length of only 37 cm for this set-up. Electrical fields rotate with 50 Hz in the range of maximum field strength of the quenching magnets. These electrical fields separate charged particles from the neutral beam with minimum loss of metastable atoms by quenching. After the second quenching magnet the longitudinal polarization of the metastables is rotated to transverse direction by a small magnetic field of 30 Oe. Within the following iodine cell the metastables are ionized in a transverse magnetic field compensated by an electrical field. The tube of the iodine cell is sliced into 12 segments, which are held at different potentials. The dimensions of the iodine cell are 1,8 cm diameter and 25 cm long. The optimum pressure in the middle of the cell is $1{,}1 \times 10^{-3}$ torr. The cell is fed with 20 mg of iodine per hour to achieve this pressure. The source is pumped by oil diffusion pumps with nitrogen vapor traps to a pressure of about 10^{-6} torr away from the cell.

In figure 5 the transverse polarization as function of the time is shown. At the beginning the polarization increases because the intensity increases and there is a nearly constant background of unpolarized ions. After 7 hours the nitrogen traps warm up partially and the background increases.

fig. 5



During these measurements a typical transverse polarization was $P_{33} = -0.73$ at an intensity of 100 nA.
At present a new 'metastable source' is being investigated (fig. 6).

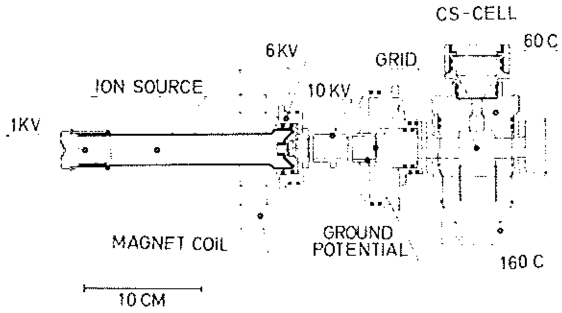


fig. 6

The drift length for the 1 keV D^+-Ions and the diameter of the electrodes have been reduced. A second focusing electrode has been added. The grid is now at ground potential. In the first test run intensities of about 500 nA were measured.

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