POLARIZED DEUTERONS OF A LAMBSHIFT ION SOURCE ACCELERATED BY THE KARLSRUHE ISOCHRONOUS CYCLOTRON

V. Bechtold, L. Friedrich,
Kernforschungszentrum Karlsruhe, Germany

D. Finken, G. Strassner, P. Ziegler,
Universität Karlsruhe, Germany

Abstract

At the Karlsruhe isochronous cyclotron a Lambshift source has been installed delivering a vector polarized deuteron beam of 0.8 μA within an emittance of 100 mm-mrad at an energy of 10 keV. The distance between the injection system of the cyclotron and the Lambshift source is 11 m. The small emittance of this Lambshift source makes it possible to design a horizontal beam line using only two acceleration and three electrostatic einzel lenses. For beam adjustment small stators of three-phase current motors are used. The whole set-up is completely inserted into a 22 cm diameter tube of iron for shielding from the stray field of the cyclotron. A beam of 100 nA polarized deuterons has been accelerated to an energy of 52 MeV and 40 nA have been extracted.

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Introduction

Lambshift sources are commonly used for production of polarized negative hydrogen or deuterium ions for tandem accelerators[1]). It was shown that they are also able to deliver positive ions if iodine is used for charge exchange with the polarized metastable atoms[2,3]). Comparing the Lambshift source and the atomic beam source, the emittance of the Lambshift source is smaller by a factor of 5 and the brightness is twice as big[4]). The Lambshift source C-LASKA designed for the isochronous cyclotron at Karlsruhe delivers a vector polarized deuteron beam of 0.8 μA within an emittance of 100 mm-mrad at an energy of 10 keV[5]). In order to get transverse polarized ions the charge exchange process of the metastable atoms with iodine takes place in a transverse magnetic field[5]). This metastable atoms are produced by charge exchange of 1 keV deuterons with Cs in the cesium cell. The maximum possible emittance of the neutral metastable beam is determined by the geometrical set-up of the two charge exchange cells (fig. 1) and can be calculated from the diameter and the distance of the two cells. This emittance and the measured emittance of the polarized ions are shown in fig. 2.

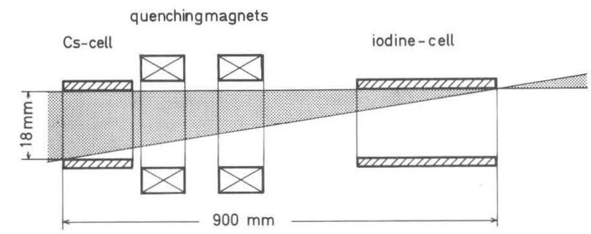

Fig. 1 The geometrical set-up of the charge exchange cells and two peripheral rays of the metastable beam. The two quenching magnets are needed to polarize the metastable atoms[6]).

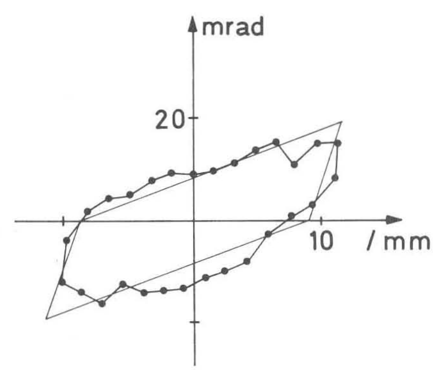

Fig. 2 The measured emittance of the polarized 1 keV ions (-•-•-) and the calculated emittance of the metastable beam.

The horizontal beam line described below has to transmit a beam with this emittance to the injection system of the cyclotron.

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The horizontal beam line

It was originally planned to place the polarized ion source directly below the cyclotron. Since the space was limited and the magnetic stray fields of the cyclotron of up to 40 G were extremely disturbing, it was decided to erect the source in the basement of the experimental hall and to connect it with the injection system by an 11 m long beam transport system. Thus, a

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remote control system was avoided and the source is accessible when the cyclotron is operated with the internal beam only.

The injection energy of the beam is 10 keV. For this reason good shielding against magnetic fields is needed. Therefore, an iron tube from the source to the injection system was provided, forming a channel with a magnetic field smaller than 100 mOe.

Another requirement for transport systems with low beam energies is a vacuum of at least 10^{-6} Torr. A simple mechanical structure makes it possible to use only a small number of pumps. This calls for large suction apertures which are most convenient obtained by use of electrostatic tube lenses as focusing elements. Such tube lenses offer the additional advantage that they can be easily fabricated. Fig. 3 shows a section of the beam line and an einzel lens inside.

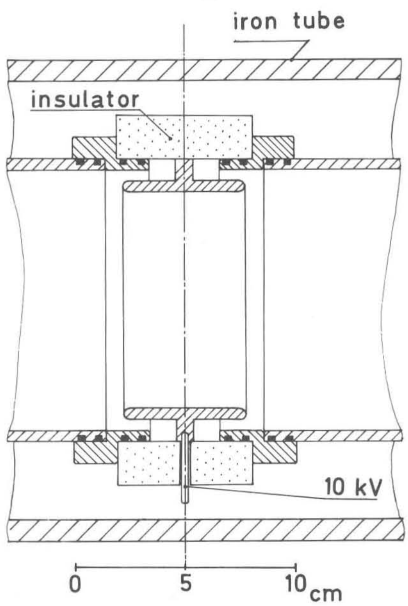

Fig. 3 Section of the beam line with an electrostatic einzel lens drawn to scale.

The number and configuration of the acceleration and einzel lenses was derived from the following consideration:

To be able to connect several external ion sources simultaneously to the cyclotron the injection system was supplemented in the cyclotron laboratory by a vertical deflector pivoted on the injection axis and made up of three quadrupole lenses with a 45° deflector on each side[7]). This system transforms the original cylindrically symmetric acceptance into an acceptance no longer symmetric with a vertical waist 5 cm in front of the deflector and which is convergent in the horizontal direction (see fig. 4).

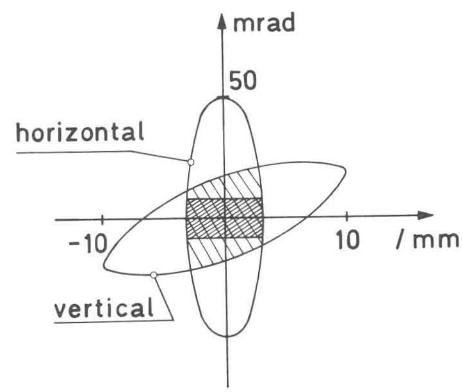

Fig. 4 The calculated acceptance[8]) at the transmission point B.

The area of intersection of both ellipses (shaded rectangle) corresponds to the maximum cylindrically symmetric emittance for a beam which can still be completely accepted. The entered rectangle has a surface area of 100 mm-mrad. It corresponds exactly to the emittance of the ion source beam accelerated to 10 keV. This shows the advantage of the low and

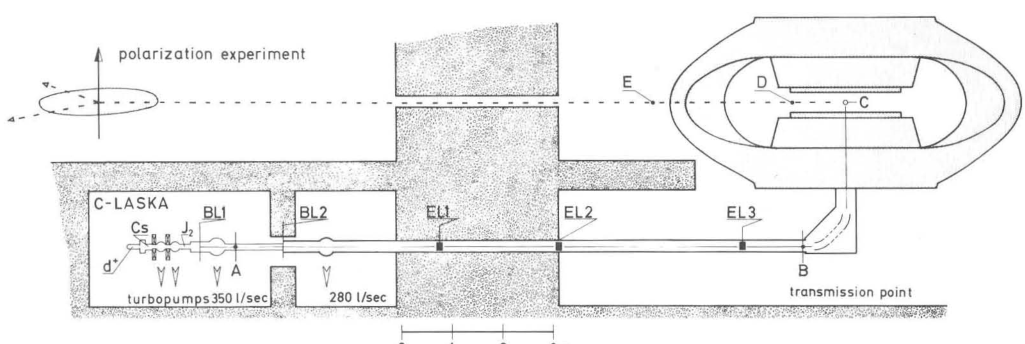

Fig. 5 The whole set-up shows the Lambshift source C-LASKA and the beam line in the basement. The cyclotron and the polarization experiment are in the upper part. BL1 and BL2 are acceleration lenses, EL1 through EL3 are electrostatic einzel lenses.

rotationally symmetric emittance of the Lambshift source. It should therefore be possible to match the emittance by tube lenses only, i.e. without quadrupole lenses. The beam transport system so equipped consists of two acceleration and three einzel lenses and is shown in fig. 5.

The basic operation of the two acceleration lenses BL1 and BL2 is explained by the following fig. 6.

On the left hand side two peripheral rays as generated by the cell geometry of the Lambshift source has been represented.

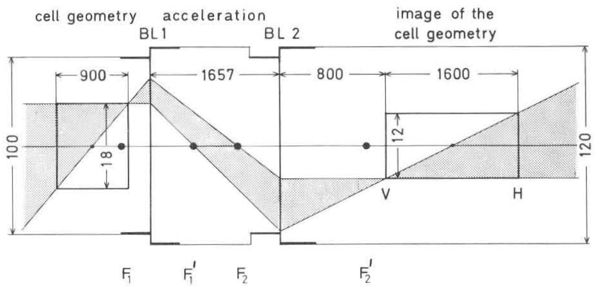

Fig. 6 The two acceleration lenses BL1 and BL2 with peripheral rays.

The shaded peripheral rays make clear how the two acceleration lenses transform the initial cell geometry into a corresponding 'cell geometry' of 12 mm diameter and 1600 mm length (image of the initial cell geometry). For this purpose, the first lens must be so positioned that the center of the cell geometry coincides with the double focal length. The lens diameters and distances calculated for this purpose by means of Timm[9]) have been entered in fig. 6. For experimental vertification a simple arrangement was set up which allows to measure with two probes the beam diameter at the points V and H. For a voltage of 6.5 kV applied to acceleration lens BL2, i.e. when the beam is accelerated from 1 keV via 3.5 keV to 10 keV, the beam diameters are actually the same at both points, namely 12 mm as required.

The beam is further transported by three einzel lenses EL1, EL2 and EL3 of the design given in fig. 3. The first einzel lens has a focal length of 800 mm and is placed 800 mm behind the cell

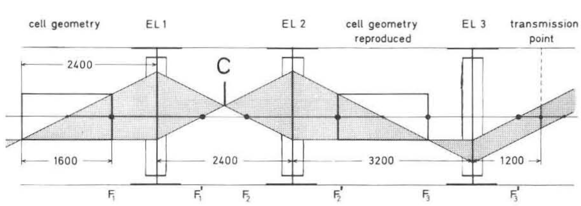

Fig. 7 The three einzel lenses EL1, EL2 and EL3 with peripheral rays.

geometry. It appears from the peripheral rays drawn in fig. 7 that this einzel lens generates a double waist of 6 mm diameter (1/2 Ø of the cell geometry) at point C, i.e. at 1.5 times the focal length. This behaviour was also verified experimentally and is represented in fig. 8.

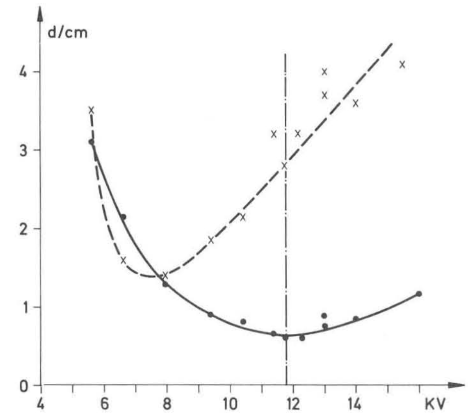

Fig. 8 The beam diameter measured as a function of the lens voltage 1.60 m behind the double waist (dotted line) and at the double waist (point C, fig. 7).

In fig. 8 a minimum of the beam diameter of 6 mm is observed at 11.8 kV. The distance between the two measuring points as well as the diameter of almost 3 cm found at the second measuring point yield a beam divergence of roughly 15 mrad, which exactly corresponds to the rectangular emittance required by the beam transmission condition (fig. 4).

The following einzel lens EL2 (fig. 7) reproduces the 10 keV cell geometry and EL3 generates again the 6 mm waist, however, this time exactly at the point of beam transmission in front of the injection system.

Since the position and direction of the beam at the point of injection are extremely critical, steering magnets were applied to the beam tube, which have a design similar to the stators of AC electric motors (fig. 9). The coils were excited by three direct currents coupled in such a way that they correspond to the instantaneous value of a three-phase alternating current. Thus a magnetic field can be produced vertical to the beam axis. Its direction can be turned around the axis and its intensity can be varied. With the help of two such fields the ion beam can be brought always to the optical axis.

In case the pre-acceleration and beam transport system are operated at the focusing voltage determined by the laboratory test, more than 90% of the source current could be transmitted to the injection system. To get maximum intensity of the accelerated polarized beam, however, lower focusing voltages must be set (table 1).

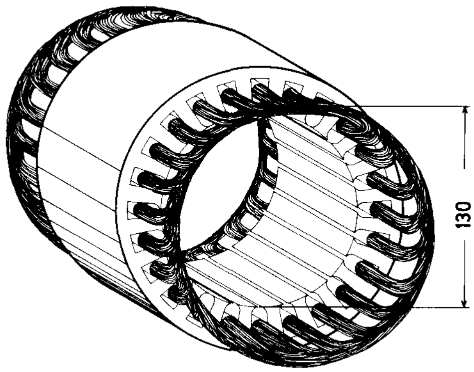

Fig. 9 Stator of AC electric motor used as steering magnet.

Table 1

	Energy	BL2	EL1/2	EL3
Laboratory test:	10 keV	6.5	11.8	11.8
Maximum accelerated beam:	10 keV	5.6	9.3	9.5

This results in a considerable increase of the beam diameter inside the lenses. Therefore beam intensity is lost at the diaphragms, which have been provided for monitoring the beam position.

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Performances

Since the end of 1973 the Lambshift source was 500 h in operation for polarization experiments in nuclear physics. From each period of 80 h about 15 h were used to set the source in operation and to optimize the injection system and the cyclotron. Thereafter we got a steady polarized beam and no further tuning of the source was needed. Averaged over this periods the following transmission rates were achieved ((A) through (E) shown in fig. 5.):
From source (A) to

- beamstop before injection system (B) 70%
- hyperboloid inflector (C) 55%
- internal beam of end energy (52 MeV) (D) 13% (3,8)
- extracted beam (E) 4% (1,1)

(Figures in brackets were achieved without buncher).

At maximum 100 nA polarized deuterons have been accelerated to 52 MeV and 40 nA were extracted. The vector polarization P_y of the 52 MeV deuteron beam was calibrated by elastic scattering on ^{12}C. $P_y = 0.45$ was achieved. This is the maximum value expected from the source parameters. It can be concluded that no depolarization is observed while the beam is accelerated in the cyclotron.

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