THE POLARIZED ION-SOURCE FOR COSY

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The polarized ion-source for COSY-Jülich has been set in operation. The source produces polarized H^- and D^- ion beams by means of a charge exchange reaction. For the first time beam acceleration in the injector cyclotron and a first measurement of the beam polarization has been performed. The working scheme of this colliding beam source and the latest results are discussed.

1 Introduction

Because of Liouville's theorem stripping of H^- or D^- during injection into the Cooler-Synchrotron COSY is about an order of magnitude more efficient than stacking injection of H^+ or D^+. Therefore, a polarized ion-source for negatively charged $\vec{H}^-$ or $\vec{D}^-$ has been built and set in operation by a collaboration of three groups from the universities Bonn (atomic beam production), Erlangen (charge exchange, extraction, and spin handling), and Cologne (cesium-beam production). Since the charge exchange reaction of the colliding beam source (CBS) [1,2] works selectively for atoms, a very high degree of nuclear polarization can be expected.

2 The colliding beam source

The negatively charged ions are produced in a direct charge exchange process of colliding beams. The scheme of the source is shown in figure 1. A neutral nuclear polarized $\vec{H}^0$- or $\vec{D}^0$-beam meets a fast neutral Cs^0-beam [1] according to:

$$\vec{H}^0 + Cs^0 \longrightarrow \vec{H}^- + Cs^+ \qquad (1)$$

The neutral, nuclear polarized $\vec{H}^0$- or $\vec{D}^0$- beam is produced in the atomic-beam source figure 2 consisting of a water cooled rf dissociator and a sextupole separation magnet.

At first, gas molecules are dissociated in an $300-400W$ rf-discharge. The atoms are cooled to about $30K$, while passing an aluminum nozzle of $20mm$ length and $3mm$ diameter. Therefore, the atoms are slowed down with some beneficial consequences that:

i) the first tapered sextupole magnet has an increased solid angle of acceptance in inverse proportion to the beam temperature;

ii) shorter sextupole magnets can be used;

iii) the dwell time of atoms in the charge exchange region increases in inverse proportion to the decreasing beam velocity.

It is evident that the reduced atomic beam velocity leads to an increased $\vec{H}^-$ intensity. The first sextupole magnet produces the electron state polarization of the atoms. Atoms with $m_J = -1/2$ are defocused and only atoms with $m_J = +1/2$ are remaining in the beam. A second sextupole magnet downstream the atomic beam acts as an achromatic lens and the atoms are focused into the ionizer region. The nuclear polarization is provided by two rf transitions (one for each nuclear spin state in the case of hydrogen) switching between the hyperfine substates of the hydrogen atoms. After passing the rf transition units, the atomic beam enters the ionization region where the H^0 atoms collide with a collinear Cs^0 beam traveling in the opposite direction.

At the position of the charge exchange region a hydrogen intensity of $I_{H^0} \geq 4 \cdot 10^{16} atoms/s$ has been verified. The rf transitions have been tested in the Bonn and Jülich polarized ion-sources, where efficiencies of up to 90% have been observed [3].

The fast neutral Cs^0-beam [4] needed for the charge exchange reaction in the solenoid is produced in two steps. First, Cs-vapour is thermally ionized on a hot ($1200°C$) porous tungsten surface at an appropriate beam potential of about $40-60kV$, where the cross section for the charge exchange reaction has its maximum. Since it is difficult to transport this Cs^+-beam further than about $45cm$ [5], this beam has to be focused into the charge exchange

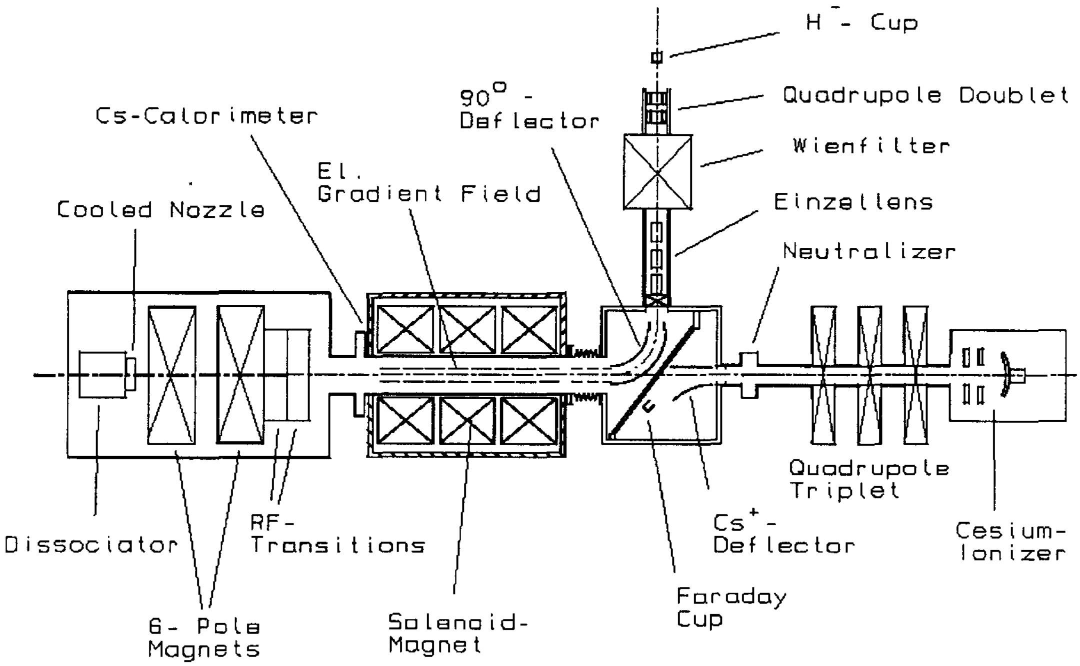

Figure 1: The polarized ion-source for COSY.

region by a magnetic quadrupole triplet system. After passing the charge exchange solenoid, the Cs intensity can be measured by a calorimeter. The Cs^+ emittance ϵ was measured to be less than 65 π *mm mrad*. Second, the fast Cs^+-beam is neutralized by a passage through Cs-vapour according to:

$$Cs^+(40keV) + Cs^0 \longrightarrow Cs^0(40keV) + Cs^+ \qquad (2)$$

The neutralizer figure 3, placed between the magnetic quadrupoles and the solenoid, is filled with Cs-vapour only during the injection period of COSY. It consists of a Cs-oven, a cell covered inside with a fine mesh and filled with Cs-vapour, and a magnetically driven flapper valve between oven and cell. The charged, fast Cs^+-beam becomes neutralized with an efficiency $\eta \geq 90\%$ and enters the charge exchange region. The remaining charged Cs^+-beam is electrically deflected into a water cooled Faraday-cup behind the neutralizer.

In the charge exchange region of $L = 40cm$ length the neutral polarized hydrogen beam with velocity v and intensity I_{H^0} meets the fast neutral Cs-beam with the intensity I_{Cs^0} in a mean cross sectional area F. With a given cross section σ for the charge exchange reaction, the intensity I_{H^-} of the extracted H^--beam can be calculated:

$$I_{H^-} = \frac{L \cdot \sigma}{F \cdot v} \cdot I_{H^0} \cdot I_{Cs^0}. \qquad (3)$$

Table 1: Calculated maximum polarization[2] .

Solenoid field [G]	Maximum polarization [%]
0	50
500	85
1000	94.5

In the charge exchange solenoid the polarization is preserved by the longitudinal magnetic field B with its vector potential $\vec{A}$. Table 1 shows how much polarization can be expected for a given solenoidal field provided that the $\vec{H}^0$-beam has a nuclear polarization of 100%. In addition, the solenoid field defines the emittance of

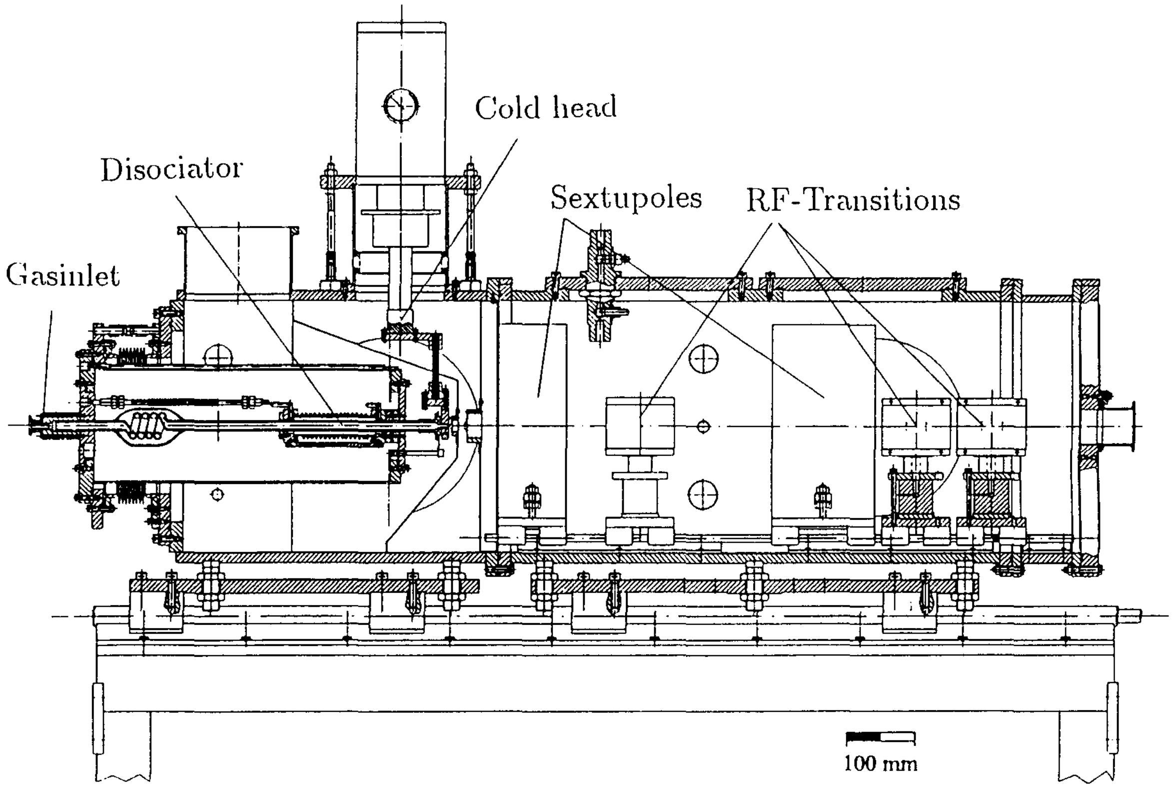

Figure 2: The atomic beam source.

the beam. As a consequence of the conservation of total angular momentum $\vec{M}$

$$\vec{M} = e\vec{A}r + \vec{L} \tag{4}$$

the 'spatial part' $\vec{L}$ of the total angular momentum will grow to the extent that the ion leaves the solenoid field and the vector potential becomes zero. At this point the 'magnetic part' of the total angular momentum has been converted to a macroscopic spatial angular momentum of the beam which results in a transversal emittance for the H^- beam [6]:

$$\epsilon = 34.6\,\pi B r^2 \frac{1}{\sqrt{U}} \tag{5}$$

B $[G], r$ $[cm], U$ $[V], \epsilon$ $[mm\ mrad]$.
For the nominal geometric acceptance $\epsilon = 500$ $mm\ mrad$ of the injector cyclotron, an $\vec{H}^-$-beam potential of $U = 4kV$ and a radius $r = 0.5cm$ where the ionization takes place B must not exceed $1000\,G$. The longitudinal phase space corresponding to the energy spread of the beam is adjusted by the electric drift field inside the solenoid which is provided by eight individually adjustable electrodes. In this way a small electric field gradient guides the very slow H^--ions to the extraction orifice of the ionizer. Passing an extraction and a focusing lens the H^--ions are deflected by a 90° electrostatic, toroidal deflector into the injection beam line of the cyclotron. Subsequently the ions are then focused by an einzellens and an electrostatic quadrupole doublet into a Faraday cup. Between the einzellens and the quadrupole doublet a Wienfilter separates the H^--ions from electrons and other background. The Wienfilter is rotatable around the beam axis which enables an orientation of the polarization vector in any direction. In particular, the spin of the polarized $\vec{H}^-$- or $\vec{D}^-$-ions can be orientated to be parallel to the cyclotron magnetic field, thus no polarization is lost during acceleration.

3 Status and results

The polarized ion source for COSY has been set in operation. The $\vec{H}^-$-beam has been extracted and measured with the Faraday cup behind the Wienfilter. Recently

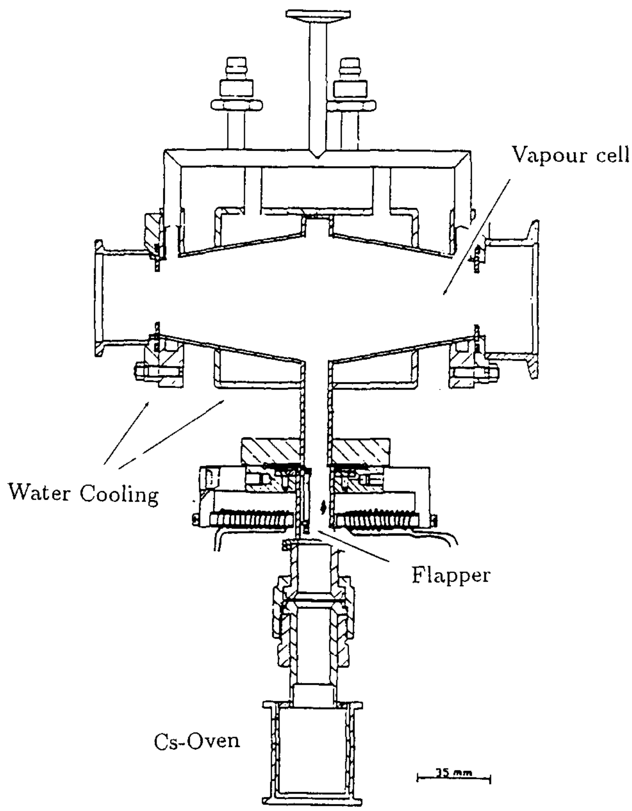

Figure 3: The neutralizer.

the $\vec{H}^-$-beam has been accelerated by the injector cyclotron to $45MeV$. Downstream of the cyclotron the polarization has been measured with a ^{12}C-polarimeter. All components of the source work together very well. The measured polarization of $p_y \geq 0.85$ meets the design expectations. A maximum $\vec{H}^-$-beam intensity of $5\mu A$(DC) has been observed at the H^--cup, corresponding to a Cs^0 intensity of $I_{Cs^0} = 4mA$ at the calorimeter. In a more conservative operation mode a Cs^0 intensity of $I_{Cs^0} = 1.7mA$ yields a $\vec{H}^-$-beam intensity of $3.5\mu A$(DC). The Cs^0 transmission from the Cs-gun to the calorimeter has been measured to exceed 65%. The typical unpolarized background of the source was very low ($45nA$) which is expected due to the high selectivity of the charge exchange process to atoms. In the near future it is planned to pulse the atomic hydrogen or deuterium beam and the Cesium gun from which both, a gain in $\vec{H}^-$ intensity and long term stability of the source can be expected.

Acknowledgements

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