CONSTRUCTION OF THE RCNP POLARIZED HEAVY ION SOURCE, "HISPANIOLA"

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ABSTRACT

Construction of the RCNP polarized heavy ion source is presented. Principle of the polarization production is based on charge and spin exchange collisions between highly stripped heavy ions and polarized Na vapor. A 2.45 GHz ECR ion source produces highly stripped heavy ions. A single mode ring dye- laser serves in producing Na polarization by means of an optical pumping. As a first step of our project, the production of polarized ^{3}He is primarily scheduled.

1. Introduction

Polarization phenomena in heavy ion nuclear physics have attracted much interest in terms of not only the elucidation of the reaction mechanism but also a probe of nuclear spectroscopy or solid state physics (surface physics). However, only a limited number of institutes can provide polarized heavy ion beams. Moreover, their attainable energies are restricted almost to $\leq$ 10 MeV/A. On the other hand, polarized heavy ion beams at intermediate and high energy regions ($\geq$ 100 MeV/A) have not been available hitherto. Recently, RCNP has started, so called, "Cyclotron cascade project," in which a ring cyclotron (SSC) with k=400 MeV will be constructed and the K= 120 MeV isochronous cyclotron already in operation will be employed as an injector accelerator.

Guided by the expectation that heavy ion beams with intermediate energies ($\sim$100 MeV/A) can be obtained with above accelerator coupling, construction of a polarized heavy ion source has also been started. As one of the most promising types, a polarized ion source based on spin and charge exchange collisions [1] was chosen because in principle this type of ion source allows to polarize any kinds of heavy ions irrespectively of ion species. It is noticeable that above principle has been successfully applied to the production of polarized proton beams by the KEK group [2] and vigorously extended also in Moscow [3] and TRIUMF [4]. Our polarized heavy ion source is basically composed of; (1) production of highly stripped heavy ions by an ECR (Electron cyclotron resonance) ion source, (2) production of polarized alkali metal vapor through which an incident ion picks up a polarized electron, (3) production of nuclear polarization through the hyperfine interactions between the polarized electron picked-up and the nucleus, (4) stripping of the electron picked-up. As a first step of our project†, the production of polarized ^{3}He is intended because of hands-down as compared with other heavier ions.

2. Outline of the instrument

A top view of the ion source is illustrated in Fig. 1. An ECR ion source is a single stage type driven with a 2.45 GHz micro-wave. A micro-wave from a 5kW power supply is radially injected into the ECR cavity through a wave guide after passing through an isolator and EH tuner. A window of a feed- through is a pyrex glass covered with a teflon sheet which protects a direct hit of plasma on the glass window. A high voltage insulation of the ECR cavity from the wave guide is accomplished by a chalk frange which can endure up to 20kV. An axial magnetic field excited by a couple of solenoidal coils serves as production of a mirror field and the coil distance is varied in order to change the mirror ratio. A hexapole magnetic field is generated by an array of pieces of ferrite core magnets. The ECR cavity and hexapole magnet are cooled by circulating water. Two sets of 1200 l/s oil diffusion pumps respectively evacuate the ECR cavity and the ECR extraction section down to $\sim$2 x 10^{-6} Torr. During the ignition of the ion source with a gas flow rate of $\sim$7 cc/min, the vacuum of the ECR cavity is kept at $\sim$4 x 10^{-5} Torr. A diameter of an extraction hole is 4mmϕ. The distance between the extraction hole and the extraction electrode is varied from 2 mm to $\sim$20 mm. Through an Einzel lens and an electric quadrupole doublet lens (Q_1) an ion is analyzed by a D_1 magnet with which only an aiming ion is selected.

† We name this project "HISPANIOLA", which is an abbreviation of "Heavy Ion Source for Polarizing Atomic Nuclei by Intense Optical pumping LAser. HISPANIOLA is a name of a ship in the famous novel, Treasure Island, written by R.L. Stevenson. She could successfully carry back with many jewels after perilous adventure.

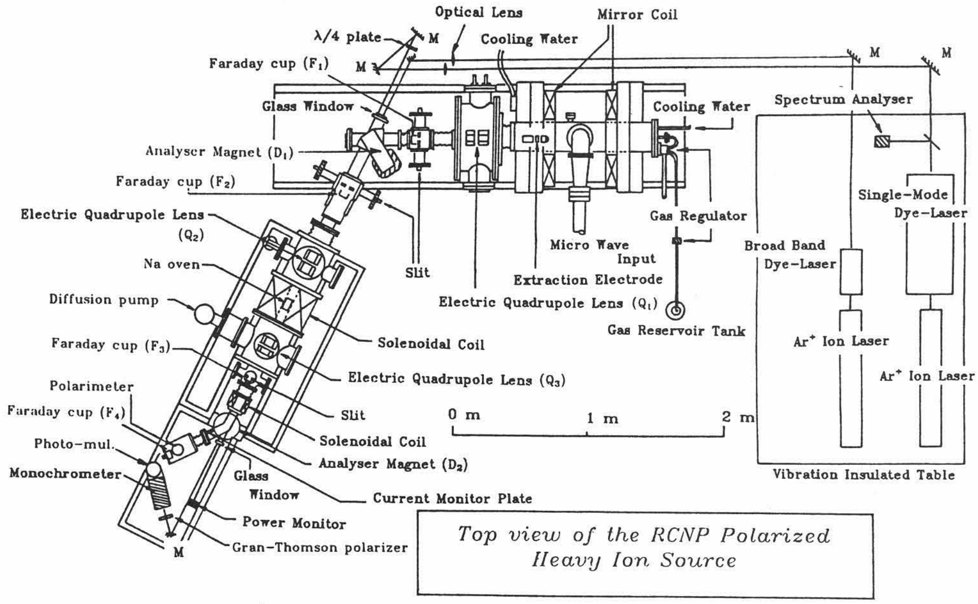

Fig. 1 A layout of the RCNP polarized heavy ion source

An aiming ion is, through a quadrupole doublet lens (Q_2), introduced into a Na cell located in a solenoidal coil which can produce a magnetic field of ∿3 kG. The outermost electron ($3^2S_{1/2}$) of Na atom is polarized along the magnetic field direction by a circularly polarized laser light tuned at the D_1 line of Na atom. A ring dye laser pumped by a 5 W Ar^+ ion laser is used for this purpose. The polarization degree of the Na vapor is monitored by measuring a Faraday rotation angle [5] of a linearly polarized laser light whose frequency is tuned midway between the D_1 and D_2 lines of Na atom (i.e., λ=589.3 nm). All the laser system is located in a dust free atmosphere surrounded with a transparent plastic sheet. After spin and charge exchange collisions between an incident $^3He^{++}$ and polarized Na atom;

$$\vec{Na} + He^{++} \longrightarrow Na^+ + \vec{He}^+$$

the nuclear spin of emerging $^3He^+$ ion from the cell is then polarized through the hyperfine interaction when they feel a non-adiabatic change of the magnetic field [6].

The resulting $^3He^+$ ion is then analyzed by a D_2 magnet and its intensity is measured by a Faraday cup. The polarization degree of the ^3He nucleus is measured by the beam foil spectroscopy: $^3He^+$ ion psssing through a thin carbon foil located at the focus point of the D_2 magnet will be neutralized and thereafter emit photons. The photons (λ=388.9 nm) corresponding to the transition from the 3^3P_J to 2^3S_1 states in helium atom are expected to be circularly polarized [7] through the hyperfine interaction. The measurement of the photon circular polarization is now prepared.

3. Experimental results

3.1 ECR ION SOURCE

Since the first ignition of the ion source in September 1987, its performance has been measured for ^4He gas instead of ^3He for the sake of economy and convenience. As shown in Fig. 2, the charge state distribution was observed for ^4He gas by using the D_1 analyzer magnet. Fig. 3 shows extracted ion current of He^{++} plotted as an extraction voltage. Fig. 4 shows ion currents measured by varying helium gas flow. From these results, it is found that more than 170 μA $^4He^+$ and 3 μA $^4He^{++}$ were successfully extracted. It is also estimated that the ratio of the double charged He to single charged one is at most 1%. However, it is expected that the amount of $^4He^{++}$ is enough large for our ion source because about 300 nA polarized $^3He^+$ can be obtained if the efficiency of spin and charge exchange rate is assumed to be about 10%*.

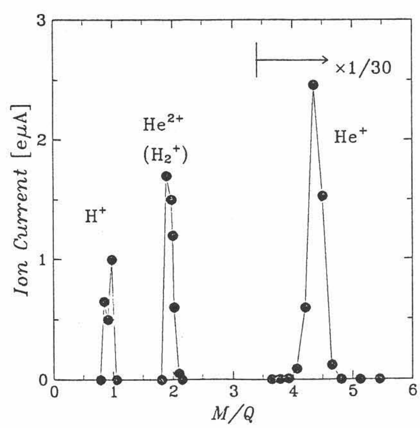

Fig. 2 Charge state distribution extracted from the 2.45 GHz ECR ion source observed at the position of F_2 for ^4He gas, where extraction voltage = 10 kV, micro-wave input power ∿300W and gas flow rate ∿7 cc/s

* This value is estimated by using cross section of 10^{-15} cm^{-2} and Na vapor thickness of 10^{14} $1/cm^2$.

3.2 OPTICAL PUMPING OF VAPOR

Na vapor was produced in a temperature controlled cell with 6 cm in length. Both sides of the cell have a hole with 6 mmϕ, through which an ion beam, a circularly polarized pumping laser (turned at λ=589.6 nm) and linearly polarized monitor laser (turned at λ=589.3 nm) pass. The intensity of the pumping laser was varied up to ∿150mW. The measurement of the Na polarization was obtained by observing the intensity change of the linearly polarized probe laser through a Gran-Thomson polarizer set at θ=45 deg. Here the frequency of the pumping laser was scanned with a range of 30 GHz including the resonance frequency.

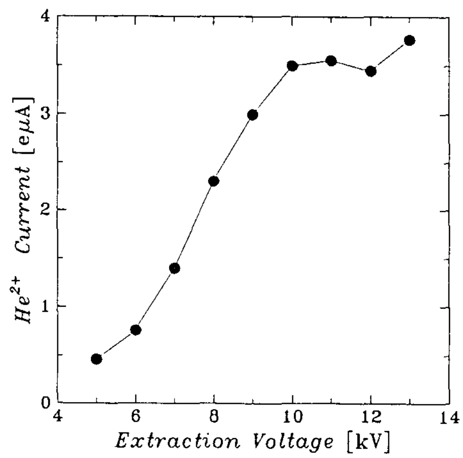

Fig. 3 Ion current of He^{++} is plotted as a function of an extraction voltage.

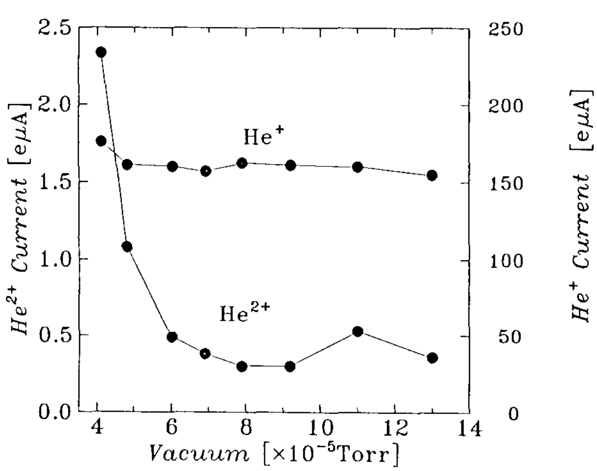

Fig. 4 Ion currents measured by varying helium gas flow. 4 x 10^{-5} Torr. corresponds to ∿7cc/min

Various coating materials were examined for suitable wall surfaces of the Na cell so as to obtain the large Na atomic polarization with a relatively weak laser power. In Fig. 5, observed polarization of Na is shown as a function of the intensity of the pumping laser for a pyrex glass wall coated with and without a dry-film ($(CH_3)_2SiCl_2$)[8]. Here about 3kG magnetic field is a applied in order to make wall relaxation time as long as possible. In Fig. 6 the Na polarization is plotted as a function the external magnetic field. The solid curves in Figs. 5, 6 are the results of the theoretical calculations [9]. In Fig. 7, observed Na polarization was plotted as a function of Na thickness. It is found that the polarization decreases as an increase of Na thickness. The observed trend is supposed to be caused by so called, "radiation trapping" [10], in which a photon emitted from a certain Na atom that absorbs a pumping photon is absorbed by a Na atom nearby, eventually decreasing the overall polarization.

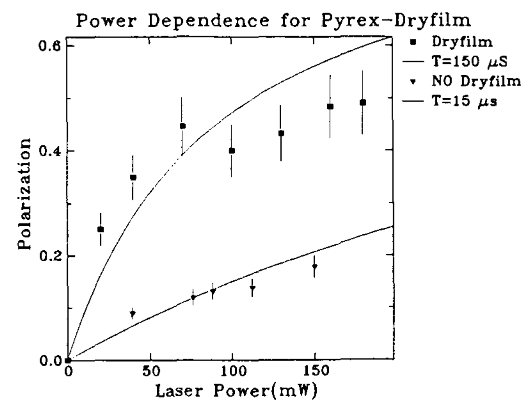

Fig. 5 Observed Na polarization as a function of applied laser intensity for a pyrex glass wall with and without a dry-film with B_{ex} ∿3KG. The curves denoted are the results of the theoretical calculations.

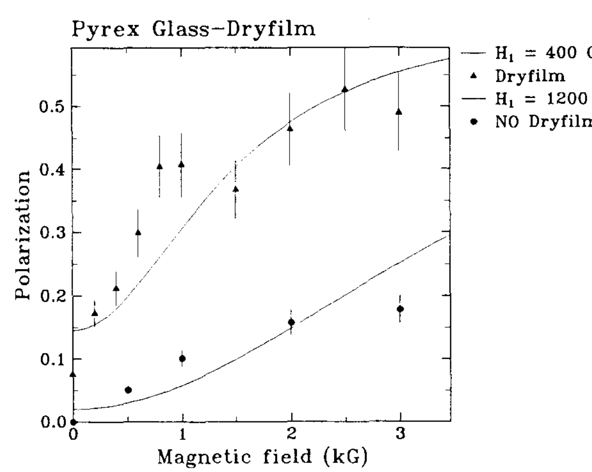

Fig. 6 Observed Na polarization as a function of external magnetic field for a pyrex glass with an without a dry-film coating

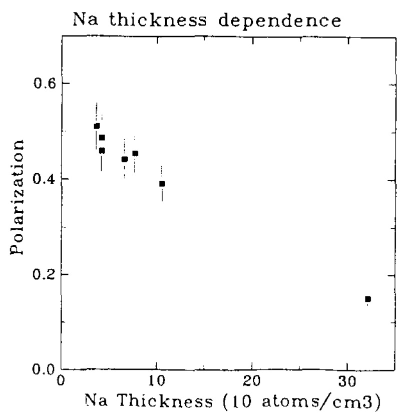

Fig. 7 Observed Na polarization as a function of Na thickness for a pyrex glass wall coated with a dry-film in the presence of the external magnetic field of 3kG

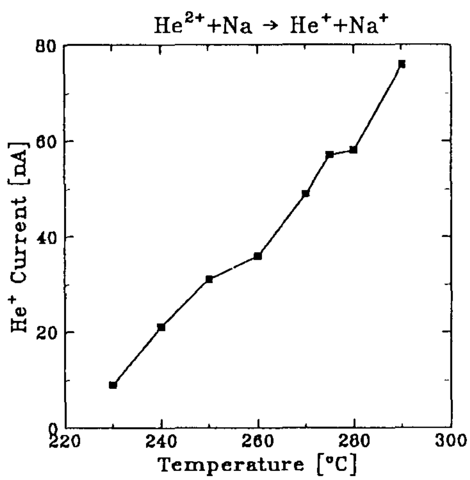

Fig. 8 Observed yield of charge-exchanged He^+ as a function of the Na cell temperature

3.3 CHARGE EXCHANGE COLLISIONS

In Fig. 8, a preliminary result on the observed yield for charge-exchanged He^+ is shown as a function of the Na cell temperature. Here incident He^{++} energy is 20 keV. From this result, $\leq$ 100 enA charge-exchanged He^+ is extracted from the Na cell, whose value corresponds to a charge exchange rate of a few %. However it was found that there was a similar amount of He^+ component even when Na vapor is absent. This component seems to be induced by collisions of incident He^{++} at somewhere around the Na cell. It is indispensable to reduce this background component in order to keep the polarization large.

4. Conclusion

We could successfully extract more than 3eμA He^{++} from the 2.45 GHz ECR ion source. With this beam, more than 50 enA charge-exchanged He^+ was obtained. A laser power with 150 mW enabled to produce the Na polarization of ∿60% with a dry-film coated wall in the presence of a 3kG magnetic field.

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