CONSTRUCTION OF POLARIZED HEAVY ION SOURCE AT RCNP

T. Ohshima* and K. Katori*
and
M. Tanaka**
and
M. Fujiwara, T. Itahashi, H. Ogata, and M. Kondo

Research Center for Nuclear Physics, Osaka University
Mihogaoka 10-1 Ibaragi Osaka 567, Japan
*Laboratory of Nuclear Study, Osaka University
Machikaneyama-cho 1-1 Toyonaka Osaka 560, Japan
**Kobe Tokiwa Jr. College
Ohtani-cho 2-6-2 Nagata Kobe 653, Japan

Abstract

We report the present status of the construction of a polarized heavy ion source at the Research Center for Nuclear Physics (RCNP), Osaka University. Production of the polarization is based on spin and charge exchange collisions between highly stripped heavy ions and polarized sodium atoms. Our project aims at the production of the polarized ^{3}He beam at intermediate energy nuclear physics by injecting it into a new ring cyclotron now being under construction at the RCNP.

1 Introduction

Polarization phenomena in nuclear physics give us information about the spin dependent reaction mechanism. So far, the polarization studies at the intermediate energy region have been carried out mainly with polarized protons and deuterons, whereas the studies with polarized heavy ions have been scarcely carried out at these energy region. It is quite timely that we start constructing a polarized heavy ion source so as to offer it to a new ring cyclotron (K=400MeV) being now under construction at the RCNP for the development of nuclear physics at the intermediate energy region.

Basic principle of our polarized heavy ion source is as follows; highly stripped ion extracted from an ion source collides with a polarized sodium atom, a polarized electron of sodium atom is transferred to the ion, and the certain amount of the electron polarization is then transferred to the nucleus by hyperfine interactions. This principle has been successfully applied for polarized proton ion sources[1]. Using this principle, it is expected that any heavy ions with a nuclear spin can be polarized. As a first step of our project, we try to produce a polarized ^{3}He beam, because ^{3}He beam will be of importance as a composite particle in the intermediate energy region.

At present, the construction of an ECR ion source has been almost finished. The performance of the ECR ion source has been measured with ^{3}He gas. The atomic polarization of sodium vapor has also been measured with various wall materials of the sodium cell. It is noted that a part of our work has been published in refs. 2, 3, and 4.

2 Experimental Procedure

A top view of the polarized heavy ion source is shown in Fig.1. The ion source is composed of two sections; an ECR ion source, a spin charge exchange part. In addition, the instrument for detection of ^{3}He nuclear polarization is equipped at the end of the ion source. Some focusing elements; an einzel lens and three

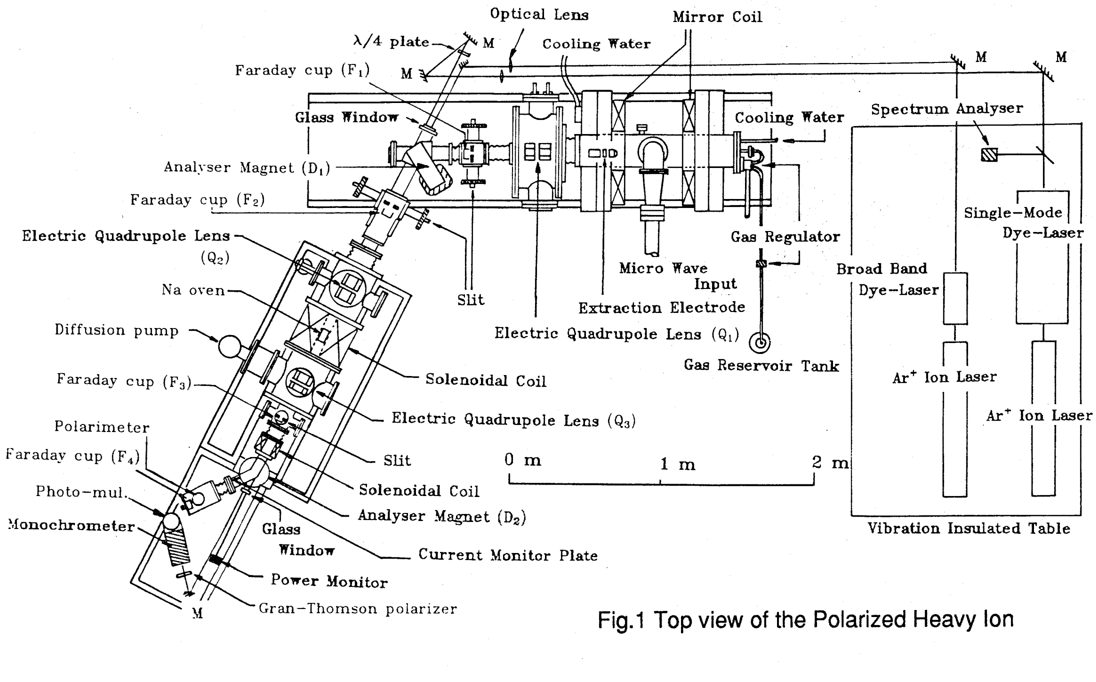

Fig.1 Top view of the Polarized Heavy Ion

electric quadrupole lenses are used for the beam transportation. Ions extracted from the ECR ion source are analyzed by the D1 magnet. Analyzed $^3He^{2+}$ ions are transported to the spin charge exchange part, where some of them pick up a polarized electron of sodium atom by a spin and charge exchange collision. Then the polarized $^3He^+$ ions are analyzed by the D2 magnet and transported to the polarization detection part.

2.1 ECR ion source

The ECR ion source is a single stage ion source using 2.45 GHz microwave. The maximum microwave power is 5kW. For plasma confinement, a mirror magnetic field is generated by a couple of solenoidal coils, and a hexapole magnetic field by ferrite core magnets. The maximum DC voltage of 20kV can be applied to the ECR chamber. Two 1200 l/s diffusion pumps are set at the ECR chamber and at the ion extraction region, respectively.

2.2 Spin and charge exchange part

Sodium vapor is produced by a temperature controlled oven in a solenoidal coil. The magnetic field in the solenoidal coil (up to 3kGauss) keeps the polarization of sodium atoms, and reduces the electron depolarization of $^3He^+$ ions caused by the L-S coupling. A single mode cw dye laser is used for optical pumping by tuning the frequency to the D_1 line of sodium. A broadband dye laser offers probe light to measure the polarization of sodium atoms by means of the Faraday rotation; the direction of the linear polarization rotates an angle defined by both the polarization and the thickness of sodium vapor [5], where the frequency of the probe light is tuned just midway between D_1 and D_2 lines of sodium atom.

2.3 Detection of ^3He polarization

We try to detect the nuclear polarization of ^3He by using the beam foil spectroscopy so as to examine the performance of the ion source. This method was successfully applied to the detection of the polarization for proton [6]. Principle of this method is as below: Polarized $^3He^+$ ion passes through a thin carbon foil, picks up an unpolarized electron of carbon atom and becomes a neutral atom in the excited levels. Since the period that ^3He traverses the foil is enough short compared to hyperfine periods, the nuclear spin is not affected during the passage through the foil. As the exited atom moves away from the foil, an angular momentum transfer occurs via the hyperfine interaction from the ^3He nucleus to the electron,which will eventually make photons circularly polarized in the transitions to the lower levels. Hopefully, the $3^3P_J - 2^3S_1$ transition of helium atom (wavelength is 388.86nm) will be a good candidate for the polarization detection.

3 Experimental Results

3.1 Performance of ECR ion source

Fig.2 shows an example of a mass spectrum of extracted ions using ^3He gas. About 50 eμA He^+ and 1 eμA He^{2+} were successfully extracted under the following conditions; the extraction voltage of 10kV, gas flow of about 0.1cc/min, and the power of microwave about 500W. The ratio of $^3He^{2+}/^3He^+$ was about 1%, which is not change drastically by tuning ECR parameters.

Besides ^3He ions, hydrogen, carbon, nitrogen, and oxygen ions were observed. They may be originated from the oil of the diffusion pump or the gas leakage of the system.

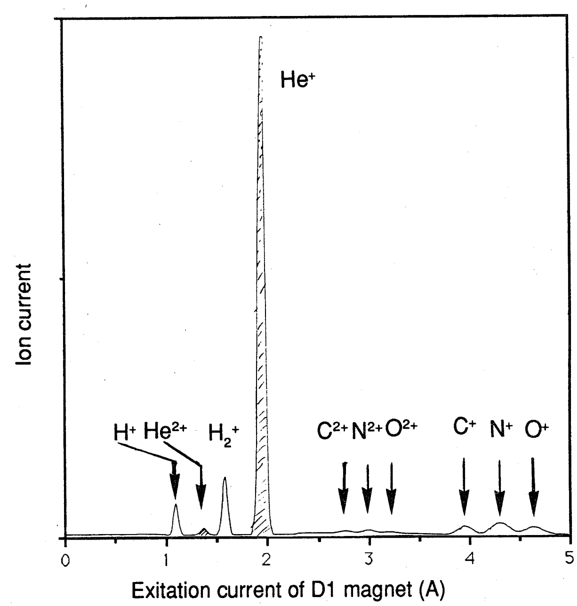

Fig.2. Ion currents measured by varying the strength of the analyzing magnet.

3.2 Polarization of sodium atoms

In the production of the nuclear polarization by spin and charge exchange collisions, the large atomic polarization of sodium is required to obtain the large nuclear polarization. From a simple consideration of optical pumping, the magnitude of the polarization is determined from the competition between pumping and depolarization processes. The depolarization is mainly caused by the interaction of sodium atoms with the wall surface of the sodium cell [7]. Therefore, it is necessary to choose a wall material with a long relaxation time in order to obtain a large polarization at a relatively weak laser power. For this purpose, we examined some wall materials, such as copper, pyrex glass, and pyrex glass coated with dry-film [8].

In Fig.3-a), the observed polarizations are shown as a function of the intensity of pumping light for a pyrex-glass wall coated with and without dry-film,together with the results of theoretical calculations. In Fig.3-b), the observed polarizations and the results of theoretical calculations are shown as a function of the external magnetic field at the sodium cell. Here,the calculations were obtained by assuming that the relaxation mechanism was mainly caused by the local magnetic fields felt by the sodium atoms during their adsorption on the wall surface. The calculations also took the effect of radiation trapping into account;a photon emitted from an excited sodium atom is absorbed by a nearby polarized sodium atom,eventually decreasing the overall polarization [10]. From the comparison of the measured polarization with the calculations, the strengths of local fields are determined, They are 0.4kGauss for the dry- film coated wall, 1.5kGauss for the pyrex glass wall, and 2.0kGauss for the copper wall, respectively. The detailed description of the calculations is presented in ref 9. In Fig.4, observed polarizations were plotted as a function of the sodium vapor thickness. The polarization decreases as the sodium thickness increases. It is found that the overall observed behaviors are reproduced by the calculations.

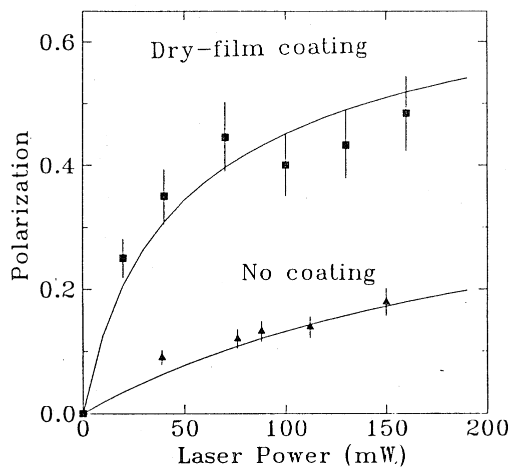

Fig.3 a) Observed polarization as a function of the pumping light intensity.

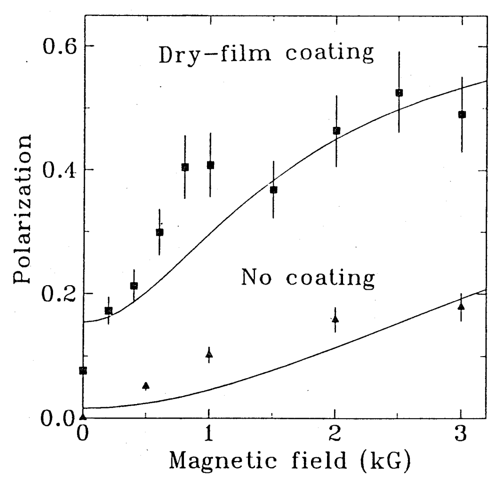

Fig.3 b) Observed polarization as a function of the external magnetic field.

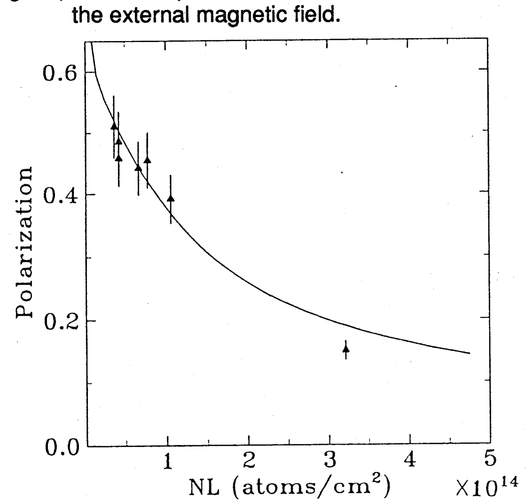

Fig.4 Observed polarization as a function of the sodium thickness.

4 Conclusion and Future Prospect

We could extract about 1eμA $^3He^{2+}$ from the ECR ion source at an extraction voltage of 10kV. For the polarization of sodium atoms, we attain about 50% polarization at the vapor thickness of 10^{13}atoms/cm^2. If we assume the efficiency of spin and charge exchange collisions is 10%, and the beam transport efficiency about 30%, about 15nA of $^3He^+$ with 25% polarization will be expected under the present condition.

In near further, we hope to increase the $^3He^+$ beam current by improving the ECR ion source, and also to increase the polarization by employing more intense laser and stronger magnetic field at the spin and charge exchange part. Thanks to the development of a Ti:Sapphire laser, the use of rubidium atoms instead of sodium atoms may be possible for the benefit of an increase of the spin and charge exchange efficiency.

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