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THE NEW EXTERNAL ION SOURCES AND THE NEW AXIAL INJECTION SYSTEM AT RCNP

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abstract

A new polarized ion source and a new axial injection system have been constructed at RCNP in order to increase beam intensities and to get high quality beams. We get a proton current of 50 μA in the axial injection system. The polarization of the proton accelerated by a cyclotron is 70% or more. Beams from an ECR heavy ion source were successfully injected into AVF cyclotron through the new axial injection system at the end of September, 1994. We use a spiral inflector instead of the old mirror system to obtain good transmission of beams.

1. Introduction

At the Research Center for Nuclear Physics, Osaka University, a Large fraction of the experimental program is devoted to studies of spin degrees of freedom. The original atomic beam type polarized ion source and the axial injection system were constructed in 1975, and since then extensive researches have been performed with polarized protons and deuterons accelerated by the K140 RCNP AVF cyclotron. In 1991, a ring cyclotron (K=400) was completed as a post accelerator which is designed to accelerate protons up to 400 MeV. Polarized proton beam current on the target in the scattering chamber was a few nA. In order to enhance the opportunities in spin physics research using intermediate energy beams from the ring cyclotron, the construction of a new High Intensity Polarized Ion Source (HIPIS) and a new axial injection system using glaser lenses were proposed as a two years project in 1993. Its design is based on sources in operation at PSI[1], TUNL[2], IUCF[3], and RIKEN[4], which employ cold (~30 K) atomic beam technology and electron cyclotron resonance ionizers. The source is coupled by a high-efficiency bunching system, a high-transmission injection system to the AVF cyclotron and a spiral inflector system. Both polarized ions from HIPIS and unpolarized ions from an ECR source, NEOMAFIOS, are injected through the vertical injection system and the inflection system. Due to this injection system we can not only decrease the maintenance times, but also accelerate highly charged heavy ions from NEOMAFIOS up to higher energies than those from the internal source.

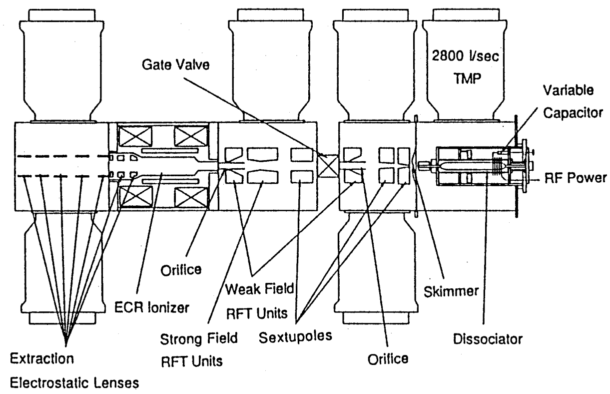

Figure 1: Schematic layout of the RCNP atomic beam source

2. The new External Ion Sources

2.1 High Intensity Polarized Ion Source (HIPIS)

The overall feature of the HIPIS built at RCNP is shown in Fig. 1. The beam of H or D atoms is produced from H_2 or D_2 gas in a 13.6 MHz, 50~200 W discharge contained in a pyrex tube of 20 mm inner diameter. The discharge is cooled by water flowing between the dissociator tube and the second, surrounding pyrex tube of larger diameter, 30 mm. The Macor serves to isolate the nozzle thermally at ~30 K from the high temperature of the discharge. The nozzle is cooled by conduction to the cold head of a 9 W closed cycle helium refrigerator. Helium cooling of the nozzle part of the vessel is very effective to get a high intensity atomic beam. Cooled atoms emerge as a directed jet from a 3 mm diameter nozzle orifice into the first vacuum chamber which is evacuated by a 2800 ℓ/sec turbomolecular pump with a magnetic suspension. With 25 std-cc/min of H_2 flowing into the dissociator, the pressure in the first chamber is $< 6.5 \times 10^{-3}$ Pa.

An atomic beam is formed at the entrance to the second vacuum chamber when the beam passes through a skimmer aperture placed 25 mm from the end of the nozzle. This skimmer separates the first and second chambers. With other two 2800 ℓ/sec turbomolecular pumps on the second chamber, the pressure there is $< 1.2 \times 10^{-4}$ Pa. A third vacuum chamber follows where another 2800 ℓ/sec turbomolecular pump holds the pressure during operation $< 3 \times 10^{-5}$ Pa.

The design of the ECR ionizer was essentially based on that at PSI[1]. The microwave frequency is 2.45 GHz at present. If the magnetic field 87.5 mT deteriorates the proton polarization, we can increase the microwave frequency higher than 6 GHz.

The desired states of nuclear polarization for H_0 and D_0 beams are produced by three sextupole magnets with one weak field radio-frequency transition (RFT) unit between the second and the third magnet, and the second weak field and one (1480 MHz for H_0) or two (455 MHz and 331 MHz for D_0) strong field units following the last sextupole. With this configuration, both the pure vector and the pure tensor states are produced for deuterons.

2.2 ECR Ion Source (NEOMAFIOS)

NEOMAFIOS is the ECR ion source of 10 GHz RF frequency for non-polarized light heavy ions. This ion source has a permanent magnet (Fe-Nd-B) instead of solenoidal coil and was built by R. Geller at Grenoble. Main parameters of NEOMAFIOS is shown in Table 1. Intensities and charge states of typical ions are shown in Table 2.

Magnetic confinement	Mirror + hexapole field
RF frequency	10GHz
Chamber diameter	67mm
Chamber length	170mm
Evacuating pump	520 l/sec TMP

Table 1: Main parameters of NEOMAFIOS

CS	^{1}H	^{4}He	^{7}Li	^{14}N	^{16}O	^{20}Ne	^{40}Ar
1+	500	1100	10			29	
2+		580	16			100	34
3+			2			145	50
4+				110	180	96	51
5+				65	85		
6+				6	35	16	47
7+					2	4	35
8+							35
9+							8

Table 2: Intensities and charge states of typical ions

3. Injection System into the AVF Cyclotron

A new injection line for the AVF cyclotron was designed and constructed. In the new system, both polarized ions and unpolarized ions produced with the NEOMAFIOS are injected through the common vertical injection system and the common inflection system. A schematic layout of the new injection system is shown in Fig. 2. At the exit of the source, protons and deuterons are longitudinally polarized. Protons are deflected by 96.7 degrees with a dipole magnet, and deuterons by 105 degrees, so that the beam remains longitudinally polarized after the 90 degrees deflection into the vertical beam line. For this purpose, small parts of pole pieces are added at the magnet entrance when deuterons are injected into the cyclotron. An electrostatic deflector is used to compensate the beam trajectory shifts. In the system electrostatic lenses are used instead of electrostatic ones used in the previous system. They ensure an efficient focusing and a good vacuum through the line. A beam buncher is plussed 2.5 m upstream from the median plane of the cyclotron. It consists of two parallel mesh plates forming a single gap, and is excited by an RF voltage with a sawtooth-like waveform generated by combining RF sine waves with the first three higher harmonics.

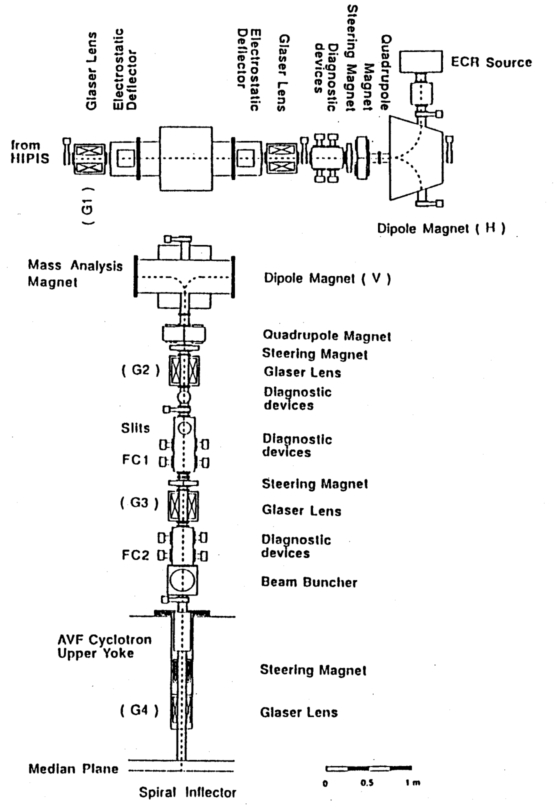

Figure 2: Injection system of the RCNP AVF cyclotron

A spiral inflector system was designed and fabricated. In the previous axial injection system, an electrostatic mirror system[6] has been used to inflect polarized ions on the median plane of the cyclotron. A spiral inflector seems more suitable for high intensity beams than a mirror system, because there are no grids intersecting beams. A spiral inflector can be treated as a component of a beam transport system either analytically or numerically. The shape of electrodes was designed based on the analytic solution of the Lorentz equation[7]. The electric radius was taken to be 24 mm, and the magnetic radius of the first cyclotron orbit 15.1 mm. For 65 MeV protons the injection energy is 15 keV. These parameters were determined by the simulation of a particle orbit in the central region of the cyclotron. Numerical integrations of the equation of motion were performed with an impulse approximation assuming a Dee voltage 70 kV. The electrode spacing is 6 mm and the electrode width is 16 mm. Results of initial testing of the new system are summarized in Table 1. In the table, the efficiency is the ratio of the beam intensity extracted from the AVF cyclotron to the beam current measured after the mass analysis magnet in the axial line. The accelerated beam current increases by a factor 3 $\sim$ 6 by using the buncher.

4. Development of the Source

4.1 Reliability

During initial off-line testing of the source, it was noticed that the ECR ionizer worked stably for periods of more than two months. On the other hand, the atomic beam intensity from the dissociator dropped by a factor procedure, warming the copper nozzle to room temperature then cooling it under vacuum, could not recover the source. The accumulation of green spots was observed on the surface of the copper nozzle. The material of the nozzle was changed from copper to aluminum. In the beginning of the operation, the aluminum nozzle produced an atomic beam of similar intensity as the copper nozzle, and the source could be recovered by a heat cycle. It was found that the cold nozzle occluded with frozen ammonia. By reducing the N_2 gas flow rate to the cold nozzle, the dissociator now runs stably for periods of longer than one month before nozzle cleaning is required. With nominal source operating conditions, a proton current of 50 $\sim$ 100 μA was measured at 15 keV after the mass analysis magnet in the axial injection line. A maximum proton current of 8 μA was extracted from the AVF cyclotron at 65 MeV.

4.2 Polarization

When the source began to deliver beams for experiments last November, the proton polarization was much lower than expected. The beam line polarimeter measurements indicated an average polarization of $p = 0.55$ or less. Extensive investigations have been performed to optimize source parameters in order to improve proton polarization. It was found there were two kinds of sources of unpolarized protons; one was residual hydrogen molecules and the other recombined molecules[1]. The former is now reduced by improved pumping of the plasma region. The latter was due to atoms from the dissociator which were not ionized in the ECR ionizer and recombined on the surface of quartz vessel containing the plasma or on electrodes. In the RCNP source, since we use permanent magnet sextupoles to focus the atomic beam, there are no ways to adjust the hardware of the atomic beam transport system, so it had to be optimized by simulations using a Monte-Carlo code. Diameters of the nozzle, the skimmer aperture, and the spacing between them were optimized to improve proton polarization. The optimum diameter of the nozzle orifice was 3 mm which is the same as that initially designed. The skimmer aperture diameter was reduced from the initially designed 6 mm to 4 mm. Additional orifices were installed at weak field RF transition units to reduce the undesired flow of molecules and atoms to the ionizer. Each orifice has a conductance of 6 ℓ/sec for air at room temperature. One of two turbomolecular pumps initially installed at the dissociator was moved to the exit chamber of the ECR ionizer for improved pumping of the plasma region. These modifications improved the average polarization to $p \sim 0.75$.

Conclusion

The RCNP atomic beam source was successfully constructed on schedule, and has delivered polarized proton for nuclear physics experiments at intermediate energies. It has operated stably for periods of longer than one month of continuous operation without maintenance. With normal source operating conditions, a proton current of 50 $\sim$ 100 μA was obtained from the AVF cyclotron at 65 MeV and a polarization is about 0.75. Future development will be devoted to improve the degree of polarization, and to get polarized deuterons.

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