

A Dual-Optically-Pumped Polarized Negative Deuterium Ion Source

Y. Mori, M. Kinsho*

National Laboratory for High Energy Physics (KEK)

Oho 1-1, Tsukuba-shi, Ibaraki-ken 305, JAPAN

*Graduate University for Advanced Studies

Oho 1-1, Tsukuba-shi, Ibaraki-ken 305, JAPAN

(abstract)

Acceleration of polarized deuterons in the KEK 12-GeV proton synchrotron is under discussion. To get a highly vector polarized deuteron beam, a new type of optically pumped polarized ion source (OPPIS) with dual optical pumping has been developed. In the preliminary experiment, we found that the dual-pumped polarized scheme had a large potential to generate highly nuclear-spin polarized negative deuterium ions.

I. INTRODUCTION

Polarized protons have been successfully accelerated in the KEK 12-GeV proton synchrotron (KEK-PS) since 1985. Many experiments have been carried out with polarized proton beams so far. Recently, several proposals for the physics experiments with polarized deuteron beams in the KEK-PS are under discussion.

An ordinary deuteron beam was successfully accelerated to an energy of 11.2GeV (5.6GeV/u) in the KEK-PS, the limiting energy of the ring, in 1992. [1] The beam intensity of the accelerated deuterons reached more than 2×10^{12} ppp which was almost the same as that for protons. Acceleration of polarized deuterons in the synchrotron is rather easier than that of polarized protons. Since the anomalous magnetic moment (G) of the deuteron is -0.1426, which is 10 times less than that of the proton, the number of depolarization resonances that are caused by the betatron motions of the beam and imperfection of the ring are quite few during the acceleration of polarized deuterons in the synchrotron compared with polarized protons.

As for polarized ion source, an optically pumped polarized ion source (OPPIS) has been used for generating nuclear-spin polarized negative hydrogen ions so far. It has been believed that this type of polarized ion source is not useful to produce a highly nuclear-spin polarized (vector and tensor) deuterium ions. In this paper, we report the preliminary experimental results which showed that the highly vector polarized negative deuterium ions could be produced by OPPIS with dual-optically-pumped technique.

II. OPPIS FOR DEUTERONS

An OPPIS has been used for acceleration of polarized proton beams in the KEK-PS until now. The idea of this type of polarized ion source was proposed by Anderson[2] and the first operational ion source has been successfully developed at KEK. [3] Afterwards, various institutes have developed the OPPIS for their accelerators. [4][5][6]

In Fig.1, a block diagram of the dual-optically-pumped polarized ion source is shown schematically. An energetic electron-spin polarized hydrogen beam is generated via pickup of a polarized electron by a proton beam of a few keV in an optically pumped alkali vapor. Then the atomic polarization of the hydrogen beam is transformed into nuclear polarization by a diabatic transition between hyperfine sub-levels (Sona transition). Finally, the nuclear-spin polarized hydrogen beam is ionized.

Although OPPIS is very useful to generate polarized protons, it has been thought that OPPIS is inadequate for making highly polarized deuterons. In deuterium atoms, because the nuclear spin, $I=1$, three hyperfine sub-levels ($I_z=+1, 0, -1$) exist. High polarization can not be expected if only a Sona transition is used because of the $I_z=0$ state. The theoretical maximum polarizations, in this case, are $+2/3$ for vector polarization (P_z) and $-1/3$ for tensor polarization (P_{zz}).

To achieve a high polarization, a new scheme which selects a pure nuclear-spin state is necessary. In 1988, Schneider and Clegg[7] proposed a new nuclear-spin state selection scheme. Their idea is as follows: After picking up the polarized electrons from optically pumped alkali atoms, deuterium atoms are electron-spin polarized, for example, in the state of $m_j=+1/2$ as shown in Fig.2. These electron-spin polarized deuterium atoms equally populate three hyperfine sub-levels $I_z=+1, 0$, and -1 in a high magnetic field, which are labeled the states 1, 2, and 3, respectively in Fig.2. Using the Sona transition, the state 1 ($m_j=+1/2, I_z=+1$) goes to the state 1' ($m_j=-1/2, I_z=-1$), the state 2 ($m_j=+1/2, I_z=0$) goes to the state 2' ($m_j=+1/2, I_z=-1$), and the state 3 goes to the state 3' ($m_j=+1/2, I_z=0$), respectively as shown in Fig.2. Therefore, the deuterium atoms with only the hyperfine level of $I_z=-1$ (state 1' in Fig. 2) has an opposite electron-spin state, $m_j=-1/2$, of the other two sub-levels (2' and 3') after Sona transition. When the alkali atoms in the ionizer are also optically pumped and their electrons are to be spin polarized in the $m_j=+1/2$ state, only deuterium atoms with the electron-spin state of $m_j=-1/2$ (state 1') can form negative ions because of the Pauli exclusion principle. This process is shown in Fig.3 schematically. The nuclear-spin state of the negative deuterium ions in this case is $I_z=-1$, the nuclear vector polarization becomes -1 . The nuclear tensor polarization is, in this case, -1 . Using a proper rf transition simultaneously, a pure nuclear tensor polarization of -2 may become possible.

In spite of this possibility of making a highly polarized deuteron beam by optical pumping, they concluded eventually in their paper that this dual optical pumping scheme might be

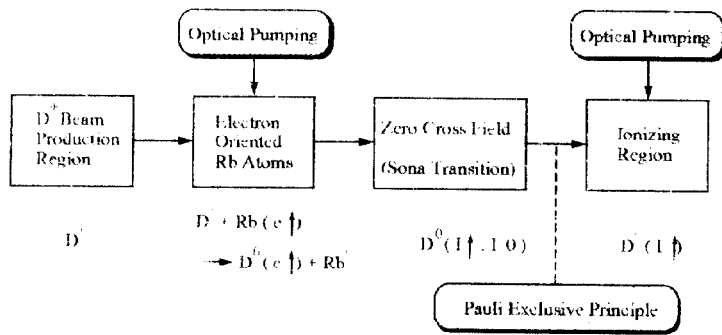


Fig.1 Block diagram of the dual-optimally-pumped polarized ion source.

not practical because efficient optical pumping of the thick target in the ionizer is difficult due to radiation trapping. Radiation trapping is a re-absorption process of fluorescence photons in optical pumping and it limits the maximum polarization of the pumped atoms. However, their conclusion was qualitative and they did not estimate quantitatively the effect of radiation trapping. Recently, we have re-examined the dual-pumped scheme in detail and found that radiation trapping was not a

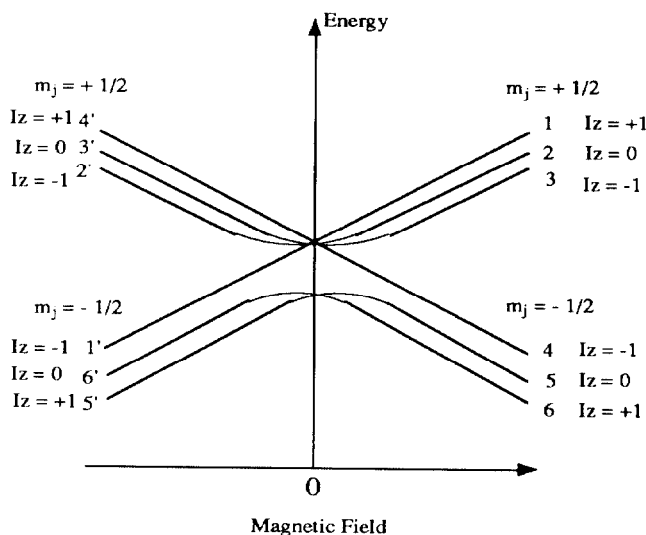


Fig.2 Hyperfine sublevels of deuterium atom in Sona transition.

serious problem and highly polarized deuterons could be obtained with the dual-pumped scheme.[8]

Recently, a preliminary experiment for proving the principle of the dual-pumped scheme has been carried out at KEK. The result of the experiment is shown in Fig. 4. The vertical axis in the figure presents the nuclear vector polarization of negative deuterium ions. The horizontal axis shows the relative change of the beam intensity of the negative deuterium ions by switching the optical pumping of the alkali atoms in the ionizer on and off. Deuterium atoms in only one hyperfine sub-level can become negative deuterium ions by picking up polarized electrons from the optically pumped alkali atoms in the ionizer. Thus, the beam intensity of negative deuterium ions depends upon the population of deuterium atoms in each hyperfine sub-level after the Sona transition. This means that the deuteron vector polarization (P_D) and the electron-spin polarization of optically pumped alkali atoms in the ionizer (P_{IONZ}) affect the beam intensity of negative deuterium ions. These values are related each other as expressed in the following equation.

$$P_D = -2\varepsilon/P_{IONZ}(1-\varepsilon). \quad (2)$$

Here, $\varepsilon = (I_{off} - I_{on})/I_{off}$, where I_{off} and I_{on} are the beam intensities of negative deuterium ions when the optical pumping of the alkali atoms in the ionizer is turned off and on, respectively. The solid line in Fig.4 presents the relation between P_D and ε when $P_{IONZ} = 1$. The closed circle in the figure shows the experimental result. The electron-spin polarization of alkali atoms

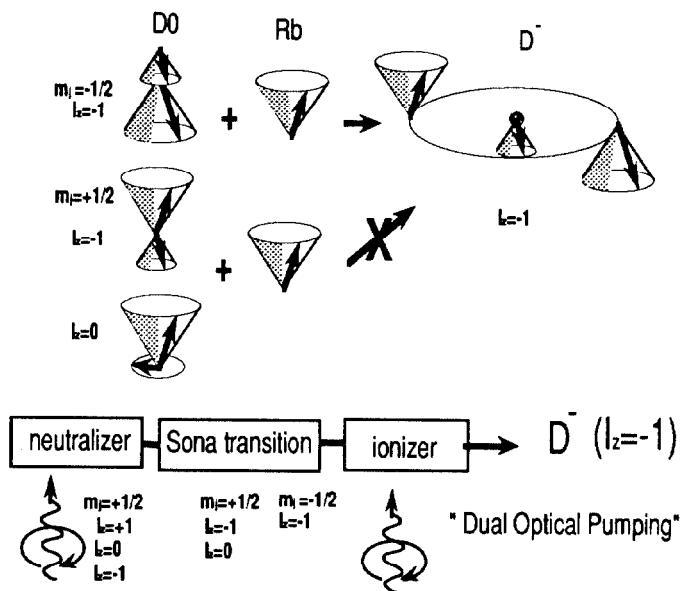


Fig. 3 Principle of dual-pumped polarized negative deuterium ion source.

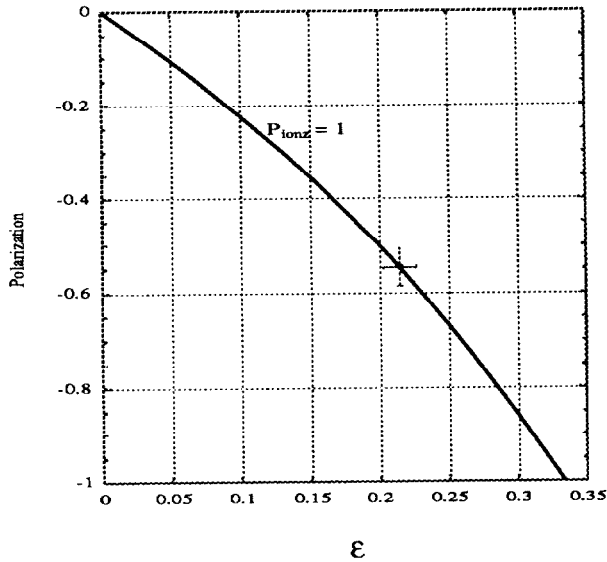


Fig.4 Relation between P_D and ϵ when $P_{\text{IONZ}} = 1$. The closed circle in the figure shows the experimental result.

in the ionizer (P_{IONZ}) was measured using a Faraday rotation method. The errors shown in the figure present the fluctuations of the data taken at different times.

In the preliminary experiment, we obtained $P_D = -0.55 \pm 0.04$. In the present apparatus where the magnetic field strength at the neutralizer is 1.1T, the theoretical maximum polarization is limited to less than 80%. This is because the spin-orbit coupling in neutral deuterium atoms, created by picking up polarized electrons from the optically pumped alkali atoms in the neutralizer, reduces the electron-spin polarization at this magnetic field strength. Thus, the obtained deuteron-spin polarization was almost 70 % of the maximum limiting value. This is very encouraging and it may be said that the dual-optically pumped scheme for producing highly polarized negative deuterium ions has worked in principle.

III. CONCLUSION

A new dual-optically-pumped scheme to obtain a high deuteron-spin polarization in an optically pumped polarized ion source has been examined in detail. The results of the preliminary experiment are very encouraging and it is shown that the new scheme, in principle, has worked. It was previously thought that the optically pumped polarized ion source was not useful for producing highly polarized deuterons. Our results may open up a new possibilities for the optically pumped polarized ion sources.

There seems to be no fundamental problem for polarized deuteron acceleration in the KEK-PS.

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