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POLARIZED POSITIVELY CHARGED HYDROGEN ION BEAMS FROM CHARGE EXCHANGE COLLISIONS BETWEEN METASTABLE H(2S) ATOMS AND HALOGENS

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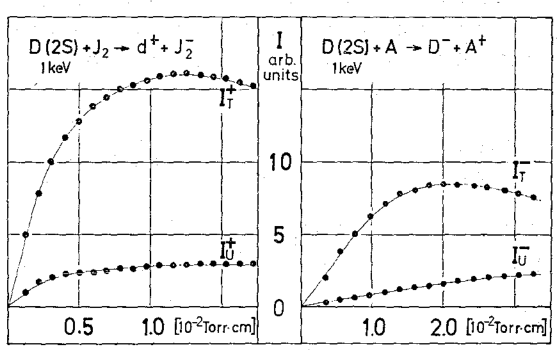
Charge exchange collisions with halogens can be favourably used to produce polarized positively charged hydrogen ion beams in a Lamb shift type ion source. Tensor polarizations up to $P_{33} = -0.75$ were achieved. Iodine exhibits a yield of two times the yield known for the production of polarized negatively charged hydrogen ions from argon.

The method which makes use of the Lamb shift has proved to be powerful means for the production of polarized negatively charged hydrogen ions[1,2]. Taking advantage of the long lifetime in the H(2S) state a beam of metastable hydrogen atoms is polarized by quenching only the atoms from some of the hyperfine structure states to the ground state. For the ionisation a process has to be used which ionizes the polarized metastable atoms selectively. Well defined beams of polarized H^- ions are available due to the characteristics of the charge exchange collisions and to the geometry of such arrangements. The phase space density and intensity of such negative ion beams are superior to the beam qualities which have been obtained up to now by other corresponding procedures. In spite of the advantages of a "Lamb shift source" producing negative ions, investigations were carried out which aimed at an ionisation process converting only the metastable H(2S) atoms to positively charged protons or deuterons selectively. Charge exchange collisions are expected to be suitable for this purpose. As was pointed out in ref. 3 such charge exchange collisions are expected to become increasingly selective if the electron affinity of the exchange atom or molecule approaches the ionisation energy of the metastable hydrogen atom (3.3 eV). The first success in converting D(2S) atoms into deuterons by a selective ionisation was obtained by using hydrogen, deuterium and helium as charge exchange partners[3].

Encouraged by these results we studied especially such charge exchange reactions which exhibit a low-energy defect. Charge exchange collisions with halogens are expected to be favourable candidates for selective ionisation because electron affinities range between 2.4 and 3.8 eV[4]. Selectivity may be due to either a reaction type involving pseudo-crossing potentials or to a large cross section for dissociative attachment of an electron[5]. Both reactions presuppose a low energy defect.

By Knutson some of the properties of the iodine charge exchange reaction $H(2S)+I_2 \rightarrow H^+ + I_2^-$ have been independently investigated[6]. The measurements indicate that this specific reaction can be effectively used for the production of polarized protons in a Lamb shift source. His communication contained results on intensity measurements which were obtained at particularly chosen iodine vapor densities. For a more detailed study, information on the pressure dependence is needed and one is interested in a direct measurement of the nuclear polarization.

As an extension of the investigations of charge exchange reactions[2,3] the reaction $D(2S)+I_2 \rightarrow D^+ + I_2^-$ was studied systematically. Beam polarizations



(a) (b)

Fig. 1. (a) The production of deuterons from metastable and ground state deuterium atoms as a function of the iodine vapor pressure times the length of the charge exchange cell (in torr · cm). The electron affinity of I^- is 3.07 eV [4]) and the value for I_2^- is 2.4 eV [4]). The dissociation energy of I_2 is 1.54 eV. (b) The corresponding measurements as shown in (a) for the production of negative deuterium ions in argon taken at the same experimental conditions. The arbitrary scale of the intensity I is identical for both measurements (a) and (b).

were measured by the asymmetry of neutrons produced in the T(d, n)^{4}He reaction. The experimental set-up described in [2,7]) was used to study the production of deuterons from a neutral beam containing metastable and ground state hydrogen atoms (intensity I_T^+) or from a pure ground state hydrogen atomic beam (intensity I_U^+). These two intensities were measured as a function of the mass density in the iodine charge exchange cell. These systematic measurements were carried out at five different energies between 0.5 and 2.4 keV. Fig. 1a shows as an example the results at at 1 keV beam energy. The corresponding measurement of the production of negative hydrogen ions from argon is shown in fig. 1b for comparison. The selectivity of the iodine reaction is at least equal to the argon reaction, whereas the yield of the iodine reaction is roughly twice as high as the yield of the argon reaction. The nuclear polarization to be expected from the intensity measurements was calculated by using the formula given in ref. 3. The results of the nuclear polarization measurement are shown in fig. 2. The tensor polarization P_{33} was experimentally determined as a function of the density of the iodine vapor (fig. 2a) and as a function of the beam energy (fig. 2b). The measured nuclear polarizations are in good agreement with the values predicted from the measurement of the intensities I_T^+ and I_U^+.

The iodine charge exchange reaction can be characterized by the following features.

First the polarization achieved is almost independent from the iodine vapor pressure. This special feature first observed with iodine might be of great advantage in the application to polarized ion sources. Due to a large ratio between the cross section for the production of positive ions to the cross section for the production of negative ions it is expected that such an independence is a general feature of all exchange reactions leading to positive hydrogen ion beams which exhibit a large selectivity for metastable H(2S) atoms.

Second the achievable polarization decreases with increasing beam energy. This general behaviour was already found in many other reactions[8]). It can be understood qualitatively from the pseudo-crossing theory of charge exchange collisons.

Third the comparison of the argon and iodine reaction shows that iodine yields an IP^2 which is almost two times greater than the corresponding value for the argon charge exchange collision leading to negative hydrogen ions (I intensity, P polarization); IP^2 is a measure of the applicability to polarized ion beams.

The experimental results discussed above are to be compared with the features of other types of sources for polarized ions. Although the corresponding studies are still in progress the Lamb shift type ion source might turn out to be advantageous for the production of polarized proton and deuteron beams also. Deuteron beams with a tensor polarization of $P_{33} = -0.7$ and intensities in the microampere range will be available in small phase space volumes in the near future.

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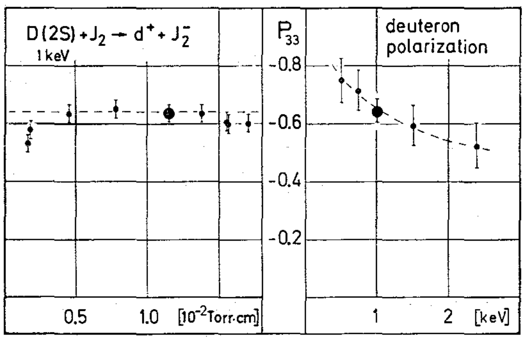

(a) (b)

Fig. 2. (a) The tensor polarization P_{33} as a function of the iodine target thickness measured at a beam energy of 1 keV. (b) The tensor polarization P_{33} as a function of the beam energy. At each energy the iodine density was adjusted to obtain a maximum deuteron intensity.

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