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New Charge Exchange Reactions for Production of Polarized Positive Charged Hydrogen Ions

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New charge exchange reactions for production of polarized positive charged hydrogen ions*)

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Abstract

From considerations concerning the potential curves of ion systems $X^- + H^+$ special charge exchange reactions are supposed to be able to produce polarized positive hydrogen ions selectively from metastable H(2S) atoms. Metastable D(2S) atoms were used to investigate charge exchange reactions with H_2, D_2 and He. From the experimental results it can be concluded that these reactions are selective in respect to the metastables and therefore suitable to produce polarized positive hydrogen ions. The tensorpolarization P_{33} was measured with the $T(d,n)^4He$ reaction by neutron asymmetry and can be evaluated from the experimental values for the ion beam intensities. For polarized ion beam applications these reactions have the advantage of higher cross-sections than the charge exchange reaction with argon which is now currently in use for the production of negative ions.

The physics involved in the production of polarized ion beams received increasing interest in the last few years since nuclear physics and high energy physics demand polarized ion beams for the investigation of polarization phenomena. Lamb and Retherford [1] proposed in 1950 to produce polarized hydrogen ions by taking advantage of the different lifetimes of the metastable $2S_{1/2}$ state and the $2P_{1/2}$ state of the hydrogen ion.

The first attempts to verify these proposals were made by Zavoiskij [2] and Madansky and Owen [3]. Due to the lack of a suitable ionisation process, which ionises the metastable atoms selectively, these attempts were not successfull. In 1965 Donally [4] proposed the use of charge exchange reactions like $H(2S)+A \rightarrow H^- + A^+$ for the production of negative ions from metastable hydrogen atoms. This process is selective with respect to the metastables. The advantages of the production of polarized negative ions by using beams of metastable hydrogen atoms were discussed by several authors and results were published by six groups [5-8].

Up to the present positive polarized ions were only produced with the method of separation of atomic hydrogen beams into the hyperfine structure components. Strong inhomogeneous, focusing magnetic fields were proposed for this purpose by Clausnitzer, Fleischmann and Schopper [9].

From simple considerations concerning the potential curves of an ion system $X^- + H^+$ some charge exchange reactions are expected to be able to produce positive hydrogen ions selectively from metastable H(2S) atoms. The idea of this proposal is illustrated in fig. 1.

Shown are the energy levels of the systems X+D(1S) and X+D(2S). The potential curve of the charged ion system $X^- + D^+$ is also to be seen in this figure. The potential curve has a crossing point with the D(2S)+X level only in the case if the binding energy of a supplementary electron to X is less than the ionisation energy of the D(2S) atom. The corresponding radius of this crossing point is r_{2S}. The crossing with the D(1S)+X level occurs at r_{1S}. The selectivity of such a charge exchange reaction has to be inferred from the matrix elements for the transition between the X+D(1S) or X+D(2S) system to the $X^- + D^+$ system.

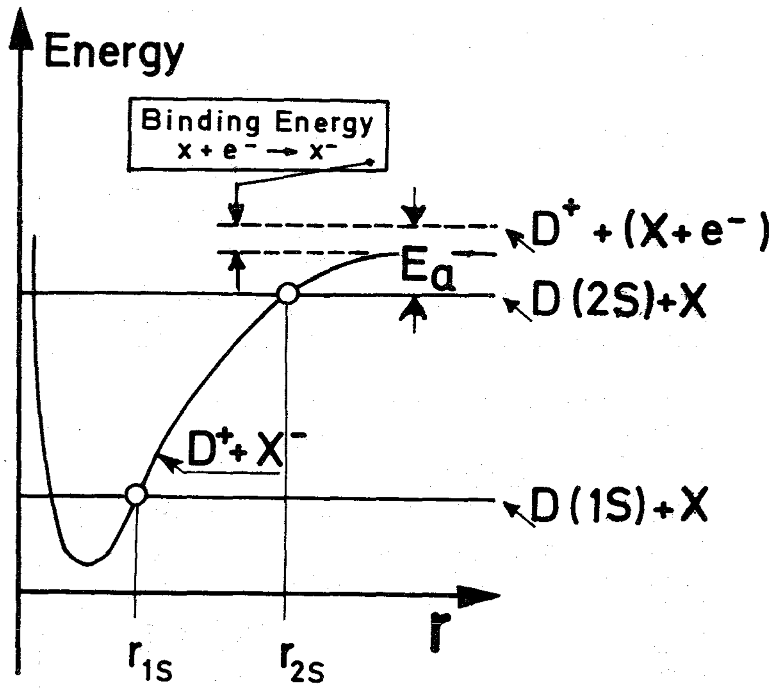

Fig.1 Schematic representation of the potential curve of the $D^+ + X^-$ ion system. E_a is the ionisation energy of the D(2S) atom. The radius r_{1S} is defined by the crossing point between the potential curve and the D(1S) + X energy level. The radius r_{2S} corresponds to the D(2S) + X level. If the binding energy of the system $X + e^-$ exceeds the binding energy of the D(2S) atom the radius r_{2S} does not exist.

a)
b)
c)

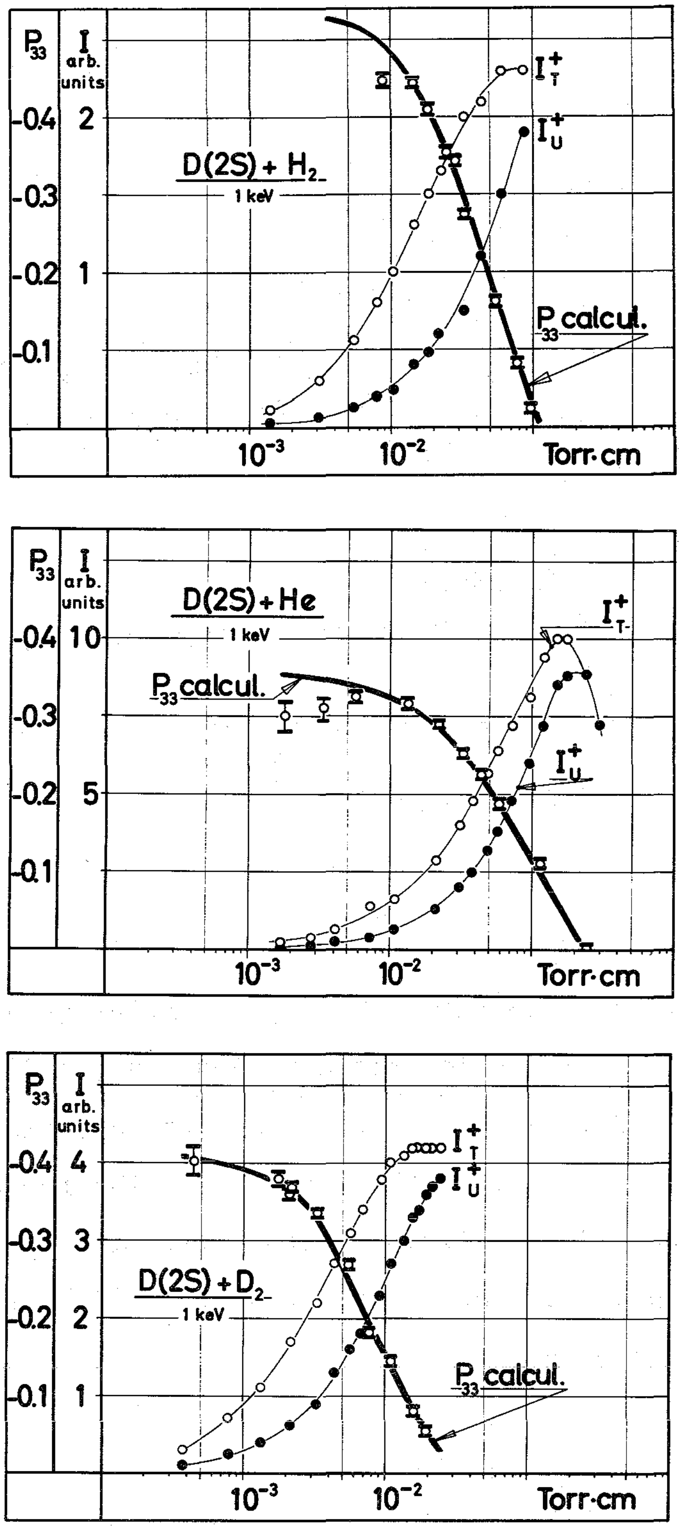

Fig.2 Experimental data for the Tensorpolarisation P_{33} and the intensities I_T^+ and I_U^+ versus density of the charge exchange gases H_2, D_2 and He. The polarisation P_{33} was calculated (drawn curve) from the measured intensities I_T^+ and I_U^+.

The evaluation of these matrix elements is thought to be based on the pseudocrossing theory [10] which predicts a strong energy dependence [4]. But even without this theory, which is not completely clear in all its details, one might conclude that the ratio of the two matrix elements is mainly proportional to the square of the ratio of r_{2S} and r_{1S}. Only this ratio determines the selectivity of the process. The absolute values of the matrix elements determine the yield of ion production. Thus the reaction will become increasingly selective if the binding energy of the electron in X^- approaches the ionisation energy E_a of the D(2S) atom.

Based on these considerations the reactions D(2S)+H_2, D(2S)+D_2 and D(2S)+He were investigated with a beam of metastable deuterium atoms produced by charge exchange in cesium. The experimental arrangement is based on conventional atomic beam techniques, details are described in [8]. The results are shown in fig. 2 a-c. Measured was the intensity of the positive ion beam I_T^+ as a function of gas density. In addition the intensity of a positive ion beam obtained by quenching all the metastable atoms to the ground state was measured.

For quenching a transverse electrical field located between the cesium cell and the charge exchange cell was used. The so measured intensity is called I_U^+. Furthermore the tensor polarization P_{33} was determined after accelerating the beam from 1 keV to 150 keV by measurement of the asymmetry of the neutrons from the $T(d,n)^4He$ reaction.

The results clearly show the selectivity of the investigated reactions. This can be concluded since a high tensor polarization P_{33} can only be obtained with a selective ionisation process. It should be mentioned, that the method proposed by Sona [11] to increase the polarization by non-adiabatical transitions at zero magnetic field was used for these experiments. Details of the results on the non-adiabatical transitions will be published elsewhere [12].

The tensor polarization P_{33} can be calculated from the measured intensities I_T^+ and I_U^+. Assuming that the primary neutral beam contains much more atoms in the ground state than in the metastable $2S_{1/2}$ state one finds

$$P_{33} = - \frac{I_T^+ - I_U^+}{I_T^+ + 2I_U^+} \quad .$$

The calculated curves for P_{33} are also shown in fig. 2 a-c. The agreement between prediction and experiment is surprisingly good.

The observation of these new charge exchange reactions producing polarized positive ions selectively from metastable hydrogen atoms will lead to a more extensive insight into atomic beam physics and will make the application of Lamb-Retherford ion sources feasible for accelerators which can only be operated with positive ions. For polarized ion beam applications these reactions have the advantage of higher cross sections than the charge exchange reaction with argon [4] which is now currently in use for the production of negative ions.

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