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STRIPPING INJECTION OF H_2^+ AND H^- INTO COSY

(Measurement of Stripping Cross Sections in Carbon and Aluminiumoxide Foils)

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Abstract

To study the stripping injection into the cooler synchrotron storage ring COSY the cross sections for the charge exchange reaction $H_2^+ \to 2p+e^-$, $H_2^+ \to H^0+p$, etc. and $H^- \to p+2e^-$ in carbon and aluminium oxide foils were measured at 30 and 40 MeV/amu. The data are presented in terms of all charge exchange cross sections involved. Monte–Carlo calculations for a special working point of COSY demonstrate the efficiency of this method to fill the ring.

Charge Exchange Measurement

To test the possibility of stripping injection into the cooler synchrotron storage ring COSY cross sections for the following charge exchange reactions were measured:

$H_2^+ \to p+H^0$, $H_2^+ \to 2p+e^-$ and $H^- \to H^0+e^-$, $H^- \to p+2e^-$

A pencil beam of 40 MeV/amu hits a thin foil of carbon or aluminium oxide. The reaction products are magnetically separated and their intensities are measured with position–sensitive detectors. The experimental setup and the method of evaluation are described in [1,2].

The experimental results are presented in fig. 2 to fig. 7. The curves are calculated according to the differential equation:

$$(n)' = (A) \cdot (n)$$

where ()' means differentiation with respect to the target thickness d [$\mu g/cm^2$]. The column vector (n) describes the abundance of the charge states:

$$(n) = \begin{bmatrix} n_1 \\ n_2 \\ n_3 \end{bmatrix} \begin{bmatrix} n(H_2^+) \\ n(p) \\ n(H^0) \end{bmatrix} \text{ and } (n) = \begin{bmatrix} (H^-) \\ n(p) \\ n(H^0) \end{bmatrix}$$

for H_2^+ for H^-

with the corresponding normalization conditions

$$2 \cdot n_1+n_2+n_3 = 2 \quad \text{and} \quad n_1+n_2+n_3 = 1.$$

For the curves in fig. 2 to fig. 7, fitted to the measured data by a χ^2 fit, we used the following matrix elements:

at 40 MeV/amu on ^{12}C

$$A = \begin{bmatrix} -0.110 & 0.0000 & 0.000 \\ 0.198 & -0.0003 & 0.167 \\ 0.022 & 0.0003 & -0.167 \end{bmatrix} \text{ for } H_2^+$$

$$A = \begin{bmatrix} -0.280 & 0.0000 & 0.000 \\ 0.000 & 0.0000 & 0.113 \\ 0.280 & 0.0000 & -0.113 \end{bmatrix} \text{ for } H^-$$

and at 40 MeV/amu on Al_2O_3

$$A = \begin{bmatrix} -0.146 & 0.00000 & 0.000 \\ 0.280 & -0.00014 & 0.138 \\ 0.012 & 0.00014 & -0.138 \end{bmatrix} \text{ for } H_2^+$$

$$A = \begin{bmatrix} -0.370 & 0.00000 & 0.000 \\ 0.000 & 0.00000 & 0.159 \\ 0.370 & 0.00000 & -0.159 \end{bmatrix} \text{ for } H^-$$

The matrix for 30 MeV/amu obtained from H_2^+ on C [1] is given for comparison:

$$A = \begin{bmatrix} -0.200 & 0.000 & 0.000 \\ 0.377 & 0.000 & 0.148 \\ 0.029 & 0.000 & -0.148 \end{bmatrix} \text{ for } H_2^+$$

The coefficients a_{12}, a_{13} for H_2^+ and the $a_{12}, a_{13}, a_{21}, a_{22}, a_{32}$ for H^- are set to zero in a first approximation. The errors of a_{11}, a_{21}, and a_{23} (the last only for H^-–charge exchange) are about 15%; the values for a_{22} for H_2^+–charge exchange give only the order of magnitude.

The corresponding cross sections in $10^{-16}cm^2$ can be found by multiplying the a_{ik} by 0.20 for C and by 1.7 for Al_2O_3.

A recent measurement with an H_2^+ beam of 23.5 MeV/amu incident energy provided cross sections corresponding to HD^+ charge exchange at the same energy per amu. The data are still to be analysed.

The energy dependence of the cross section for H_2^+ charge exchange in thin carbon targets represented by $\lambda = 1/a_{11}$ (the target thickness, where the intensity has decreased by a factor 1/e) is shown in fig. 1. The data are compared with other measurements at lower energies.

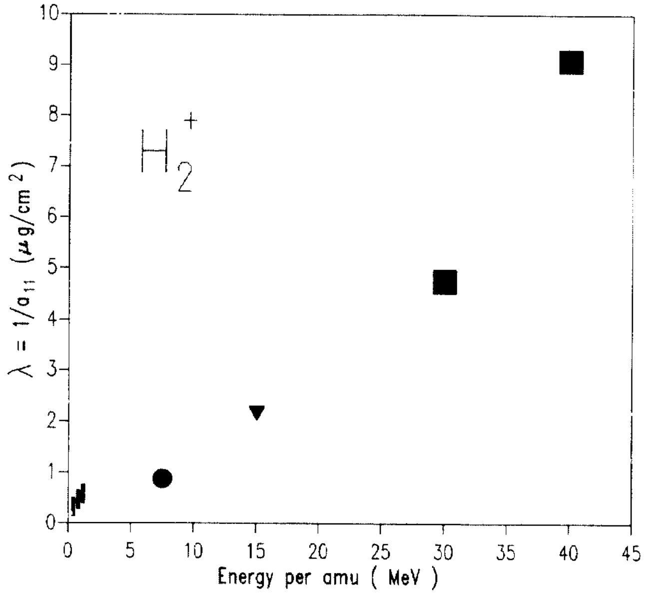

Figure 1:
$\lambda = 1/a_{11}$ as a function of energy per amu for H_2^+. The squares represent our results. The data at 0.4, 0.8, 1.2, 7.5 and 14 MeV are taken from [3, 4] and [5].

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Stripping Reactions

$H_2^+ \rightarrow H_2^+$, $H_2^+ \rightarrow 2P + e^-$, $H_2^+ \rightarrow P + H^o$

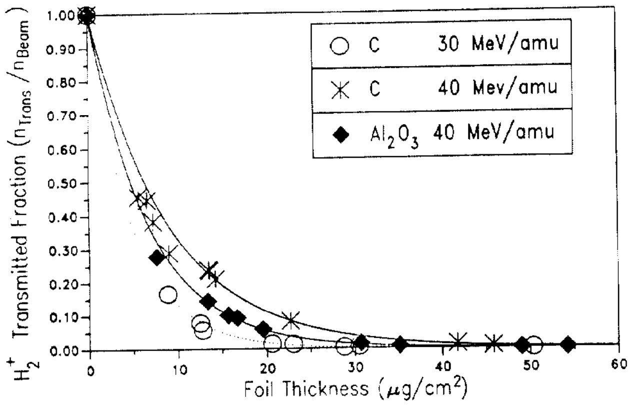

Figure 2:

H_2^+ **Transmitted Fraction as a Function of the Target Thickness**

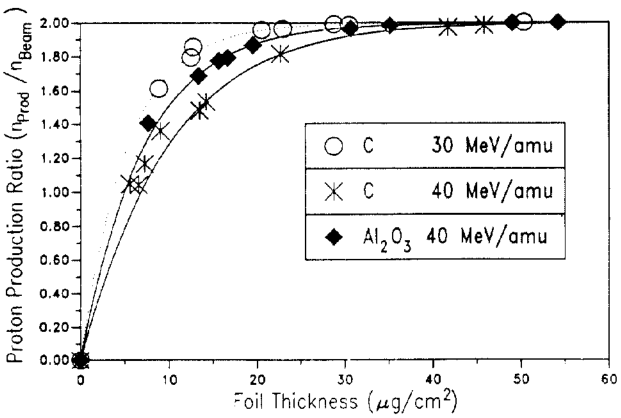

Figure 3:

Proton Production Ratio as a Function of the Target Thickness

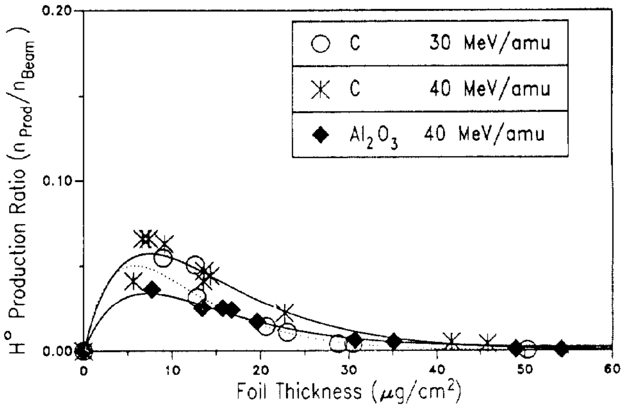

Figure 4:

H^o **as a Function of the Target Thickness**

Stripping Reactions

$H^- \rightarrow H^-$, $H^- \rightarrow P + e^-$, $H^- \rightarrow H^o + e^-$

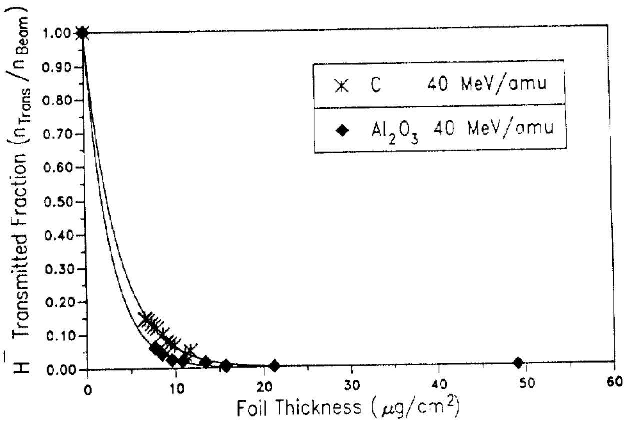

Figure 5:

H^- **Transmitted Fraction as a Function of the Target Thickness**

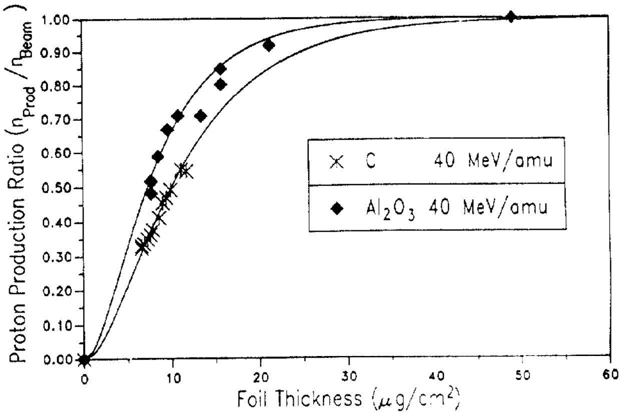

Figure 6:

Proton Production Ratio as a Function of the Target Thickness

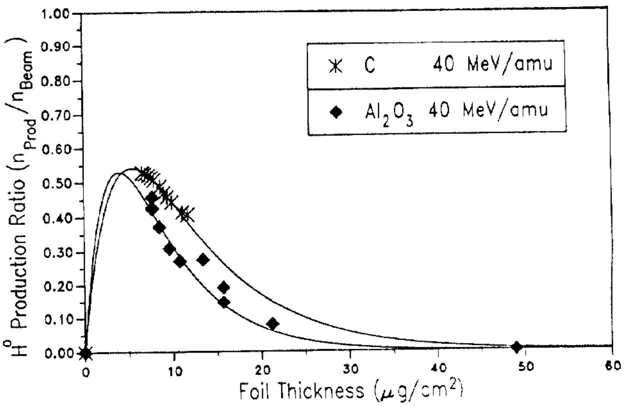

Figure 7:

H^o **as a Function of the Target Thickness**

Injection of Ions into COSY

Fig. 3 and fig. 6 show that with a target thickness of about 20 $\mu g/cm^2$ practically complete stripping yield is reached. The results of a Monte–Carlo calculation [6] for the intensity relations in the ring are displayed in fig. 8. The solid lines show the reduction B in percent of the injected proton intensity by scattering losses in the stripping foil as a function of the number of turns. In this case only one burst is fed into the ring. The dotted line shows the accumulation factor G of beam intensity (in units of the incomming p–beam) in the ring during permanent injection.

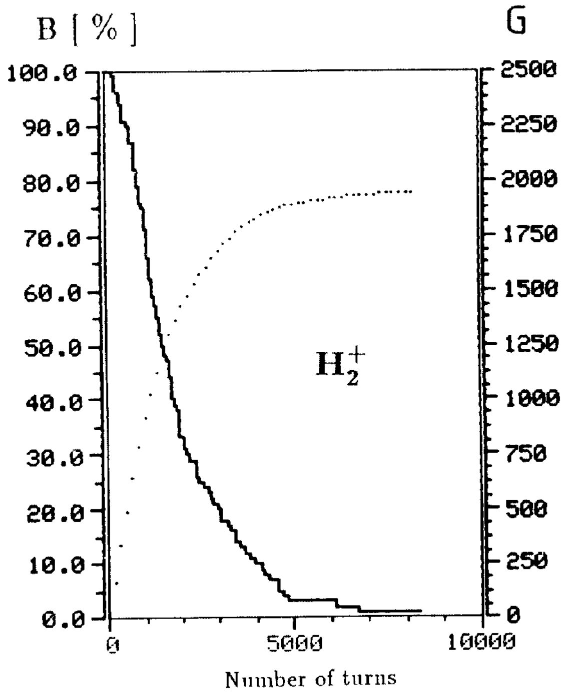

Figure 8:
Results of Monte–Carlo calculations for the beam intensities in the ring.

Solid line:	decrease of intensity by scattering in the stripper foil in the single injection mode.
Dotted line:	increase of intensity in the ring in the permanent injection mode for the case that the particles are crossing the foil in each turn.

The results show that stripping injection in the energy range around 80 MeV H_2^+ successfully competes with multiple scattering and coulomb explosion to fill the storage ring with some hundred to thousend turns even under these simple conditions.

The beam intensity in the ring can be further improved by
- making use of the beta oscillations to reduce the number of passages of the proton beam through the target after charge exchange (targets in an U–type frame, ribbon targets)
- removing the beam from the target by bumpers in horizontal and vertical direction (combined stripping and kicker injection)
- changing rigidity or bending field to shift the position
- repeated cooling and injection cycles.

For questions concerning preparation of carbon and aluminium oxide see [7,8].

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