STRIPPING INJECTION OF $H^+_2$ AND $H^-$ INTO COSY

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

Kernforschungsanlage Jülich GmbH, D-5170 Jülich, FRG
H. Neuburger, W. Polster
ISKP, Universität Bonn, D-5300 Bonn, FRG

Abstract

To study the stripping injection into the cooler synchrotron storage ring COSY the cross sections for the charge exchange reaction $H^+_2 + p \rightarrow H^0 + p$, etc. and $H^- + p \rightarrow H^0 + e^-$ 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:

$H^+_2 + p \rightarrow H^0 + p$;
$H^- + p \rightarrow H^0 + e^-$

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:

$$ \frac{dn}{dx} = \sum a_{ik} n_i $$

where $\frac{dn}{dx}$ means differentiation with respect to the target thickness $d$ [µg/cm²]. The column vector $n$ describes the abundance of the charge states:

$$ n = \begin{bmatrix} n(H^+2) \\ n(H^-) \\ n(p) \\ n(e^-) \end{bmatrix} $$

for $H^+_2$ and $H^-$.

with the corresponding normalization conditions

$$ 2n_1 + n_2 + n_3 = 2 $$

and

$$ n_1 + n_2 + n_3 = 1 $$

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

at 40 MeV/amu on $^{12}$C

$$ A = \begin{bmatrix} -0.370 & 0.0000 & 0.0000 \\ 0.000 & 0.0000 & 0.1500 \\ 0.370 & 0.0000 & -0.1500 \end{bmatrix} \text{ for } H^- $$

The matrix for 30 MeV/amu obtained from $H^+_2$ on C [1] is given for comparison:

$$ A = \begin{bmatrix} -0.200 & 0.000 & 0.000 \\ 0.377 & 0.000 & 0.148 \\ 0.020 & 0.000 & -0.148 \end{bmatrix} \text{ for } H^+_2 $$

The coefficients $a_{12}, a_{13}, a_{21}, a_{22}, a_{23}$ for $H^+_2$ and the $a_{13}, a_{14}, a_{21}, a_{22}, a_{23}$ for $H^-$ are set to zero in a first approximation. The errors of $a_{13}, a_{21}$, and $a_{22}$ (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 10⁻¹⁶cm² can be found by multiplying the $a_{ik}$ by 0.20 for C and by 1.7 for $Al_{2}O_{3}$.

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](image-url)

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

\[ H_2^+ \rightarrow H_2^+ , \quad H_2^+ \rightarrow 2P + e^- , \quad H_2^+ \rightarrow P + H^0 \]

Stripping Reactions

\[ H^- \rightarrow H^-, \quad H^- \rightarrow P + e^- , \quad H^- \rightarrow H^0 + e^- \]
Injection of Ions into COSY

Fig. 3 and fig. 6 show that with a target thickness of about 20 μg/cm² 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 incoming p-beam) in the ring during permanent injection.

The results show that stripping injection in the energy range around 80 MeV H₂⁺ successfully competes with multiple scattering and coulomb explosion to fill the storage ring with some hundred to thousand 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].

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.

References
[8] C.W. Planner, Rutherford Appleton Laboratory, Chilton, Didcot OXON, U.K., private communication