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Total Cross Sections for Electron Capture by Protons from Helium into the Excited 2 *s*- and 2 *p*-States of Hydrogen

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(13. IX. 66)

Abstract. Relative total cross sections for the reactions $p + He \rightarrow H(2p)$ and $p + He \rightarrow H(2s)$ have been measured in the energy range from 3 to 71 keV. The $2p$-cross section has a maximum at 20 keV as found by other authors. The $2s$-cross section shows a broad maximum at 40 keV and has a shoulder at 12 keV. The results are compared with the Born approximation predictions.

Introduction

In 1962 COLLI et al. [1][1]) measured the total cross section of the reaction $p + He \rightarrow H(2s)$ at 7 energies between 7 and 40 keV. They normalized their data at 40 keV to the Born approximation calculations of MAPLETON [2] and found good agreement of theory and experiment down to 22 keV. The same process and the $2p$-cross section were investigated by PRETZER et al. [3] and JAECKS et al. [4] up to an energy of 25 keV. Their absolute values were smaller by about a factor of 6 than those of COLLI. Up to about 22 keV the shapes of the curves of Ref. [1] and [4] agree reasonably well with our measurements. COLLI et al. find a maximum at 22 keV however, while our measurements show the maximum at 40 keV.

Apparatus and Procedure

A block diagram of the equipment is shown in Figure 1. Protons extracted from an RF ion source are accelerated by an RF cascade generator. Mass analysis and energy selection is made by a 90° deflection magnet. The magnet current is stabilized by a nuclear magnetic resonance lock-in circuit. From the exit slits of the 90° magnet a fraction of the beam current is fed into a difference amplifier whose output controls the high voltage. Absolute energies are known to within 2% from a calibration of the high voltage. Relative energy changes are measured by the NMR frequencies and are therefore very accurate. The energy resolution of the magnet was set at 0.6%.

Figure 2 shows the target set-up. The analysed proton beam passes through a collimating aperture of 0.5 mm diam. into the gas target with an entrance aperture of 1.0 mm diam. and an exit aperture of 1.5 mm diam. Because of these small apertures a ratio of target pressure to residual gas pressure as high as $10^3:1$ can be maintained. On the beam axis in the target chamber there are 9 equally spaced plates. The first, third etc. are connected to each other, the second, fourth etc. are connected to ground.

[1]) Numbers in brackets refer to References, page 686.

By applying a voltage between the two groups of plates an electric field parallel to the beam axis is created which serves to quench the H(2s) atoms. The field direction ensures that the beam geometry is not affected by the quenching field. The small distance between the plates allows the use of high electric fields without broadening the energy of the beam appreciably. The interaction region is viewed by a helium-iodine photon counter at an angle of 90° with respect to the beam axis. The counter is temperature stabilized because its sensitivity depends strongly on the iodine vapour density. No oxygen filter is used to avoid Doppler-effect corrections and because in the proton-helium case the only line occuring within the sensitive range of the counter (1080–1260 Å) is the Lyman-α-line.

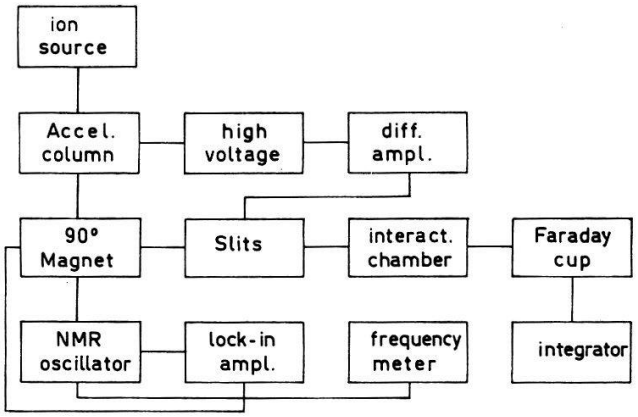

Fig. 1
Back diagram of the apparatus

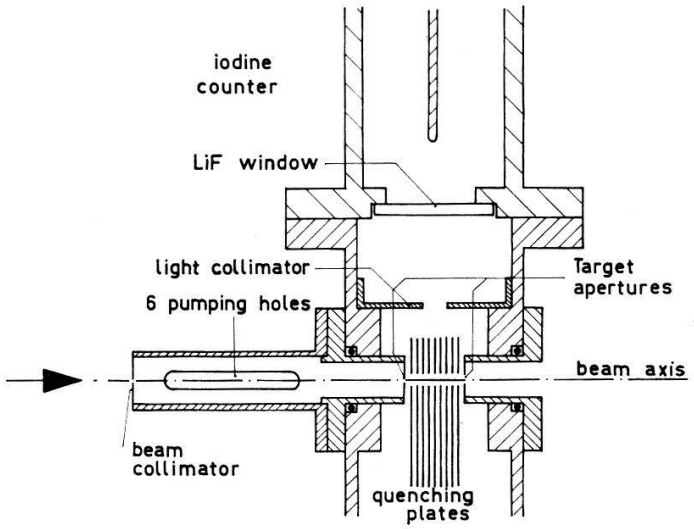

Fig. 2
Target arrangement

The first measurements made with this apparatus showed good agreement with the results of JAECKS and PRETZER. The shape of the cross sections as well as the ratio $\sigma\, 2p/\sigma\, 2s$ was reproduced to within 5%. However a possible source of error had to be investigated: the ratio $\sigma\, 2p/\sigma\, 2s$ can only be directly derived from the measurements

if the effective target length is equal for the production of H($2p$) and H($2s$). Because of the long lifetime of the $2s$-atom this is not the case if $2s$ atoms produced outside the target and in the gas cloud before the target aperture can drift into the field of view of the counter. A collimating aperture was set in front of the counter such that the quenching region extends well beyond its field of view and thus prevents any stray $2s$-atoms from reaching it. This modification resulted in a decrease of the $2s$-signal by about 15% relative to the $2p$-signal. The results presented here were taken with this arrangement. The signals are shown to be linear with pressure and current. The saturation of the $2s$-signal is checked at several energies.

Discussion of Results

Figure 3 shows the experimental results. The points are taken in a linear velocity scale. The $2p$-cross section has a maximum at 20 keV proton energy. The $2s$-cross section reaches its maximum at 39 keV. A pronounced shoulder which we find at 12 keV is already indicated in the data of JAECKS et al. The Born approximation is expected to hold best at high energies and far away from the maximum of our cross sections. A normalization was therefore tried at 70 keV on the $2p$-cross section (Figure 3). However the fact, that the experimental and theoretical curves intersect at a rather large angle shows that the Born approximation does not hold even at 70 keV. Furthermore the $2s$-cross section would be underestimated by the Born approximation even near its maximum in contrast to the general behaviour of Born approximation calculations.

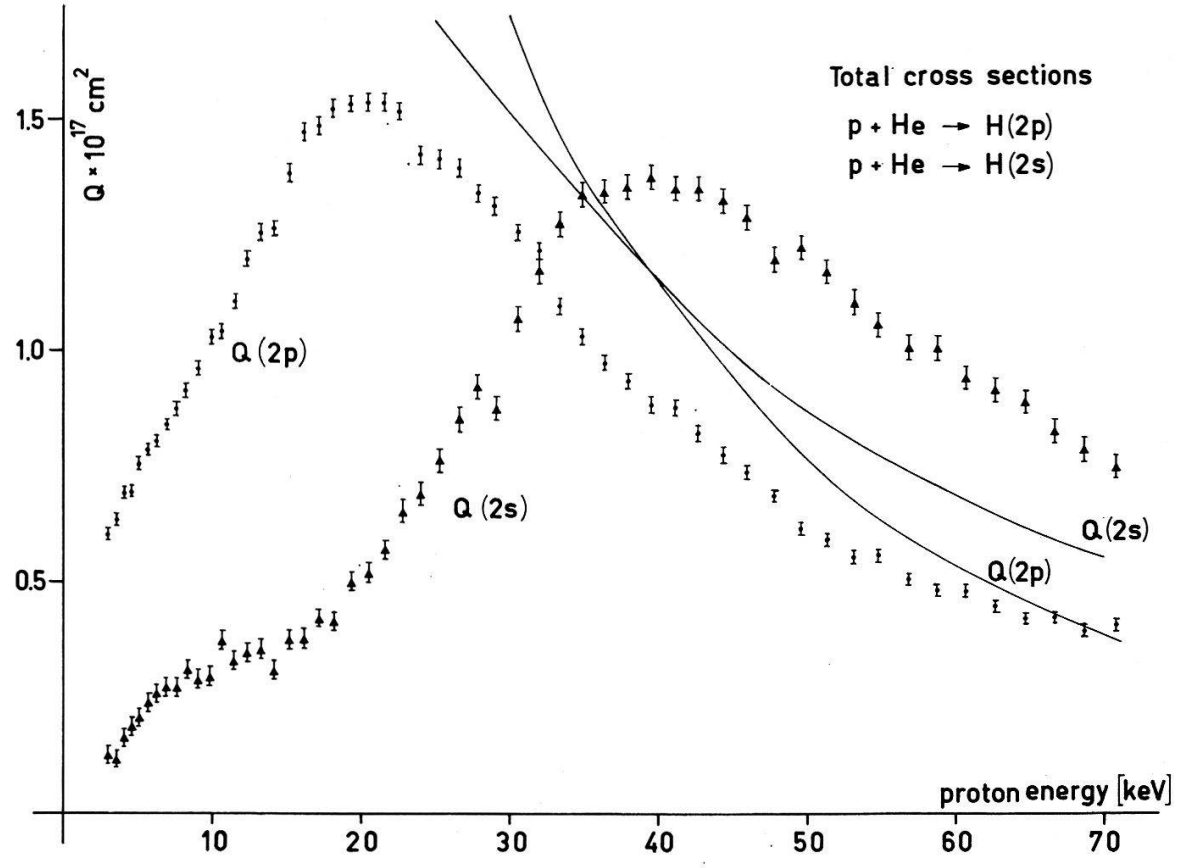

Fig. 3

As suggested already by the results of JAECKS et al. we conclude that the absolute values of our data are well below Born approximation results throughout our energy range and a normalization is therefore impossible. This conclusion disagrees with the results of COLLI et al. Moreover it is rather unexpected because the Born approximation fits the data well down to 40 keV in the case of total charge-exchange cross sections. It would be interesting to see how the two state impact parameter method recently applied with good success to the total charge transfer cross section by GREEN et al. [5] would work in the case of charge transfer to excited states.

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