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Collisions of Hydrogen with Rare Gases II
Absolute Total Cross Sections for Excitation of Lyman-α Radiation

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Abstract. Total cross-sections for excitation of Lyman-α radiation in collisions of hydrogen with He, Ne, Ar have been measured in the energy range 3–55 Kev. The low energy data have been taken with a deuterium beam. Absolute values of the cross sections are obtained by comparison with the known excitation cross sections of Lyman-α radiation in H^+–He collisions [1, 2].

Introduction

The purpose of the present work is the experimental investigation of an inelastic collision in which the interaction between the colliding particles is of short range. This is a case where the Born-approximation to heavy particle collisions should work well. Distortion corrections are expected to be small. The question however, on the type of collision investigated here, is whether multiple excitation processes play an appreciable role or not. The problem is not solved experimentally here, but comparison with theory may give the answer. Calculations have been made for the H–He case [3]. They show that multiple excitation is not of importance in $H(1s)$–$H(2p)$ transitions in collisions with helium in the energy range investigated.

Apparatus and Procedure

A general description of the apparatus has been given in the preceding paper.

The main problem in the present experiment is the measurement of the neutral beam intensity. This is done by the use of Rutherford-scattering. A windowless multiplier (EMI 9603) serves to count particles scattered to an angle of 2.2° (see Figure 1). At such a small angle counting rates are high enough to introduce negligible error in the final results. Some complications arise however because of electron screening effects.

The monitor was calibrated by scattering of protons. This is possible if the multiplier sensitivity is equal for charged and neutral particles. We investigated this point with helium as a target gas. Differential scattering of protons by helium is characterized by a strongly oscillating electron capture probability as a function of energy [4]. Consequently, if the multiplier detection efficiency were different for protons and hydrogen, the total scattered particle counting rate should show some undulations. We could not find such an effect and therefore conclude that the multiplier is equally sensitive to protons (deuterons) and hydrogen (deuterium). The final results are obtained as the ratio of counted light quanta N_L to Rutherford scattering rate N_R.

Further critical parameters of the experiment are the various gas pressures. In order to check whether the charge composition of the beam changed between the neutralizer and the target entrance, we varied the pressure in the target vacuum chamber which was normally 2×10^{-6} by reducing the pumping speed. We found that the pressure may be increased by a factor of ten until an effect on the ratio N_L/N_R is seen.

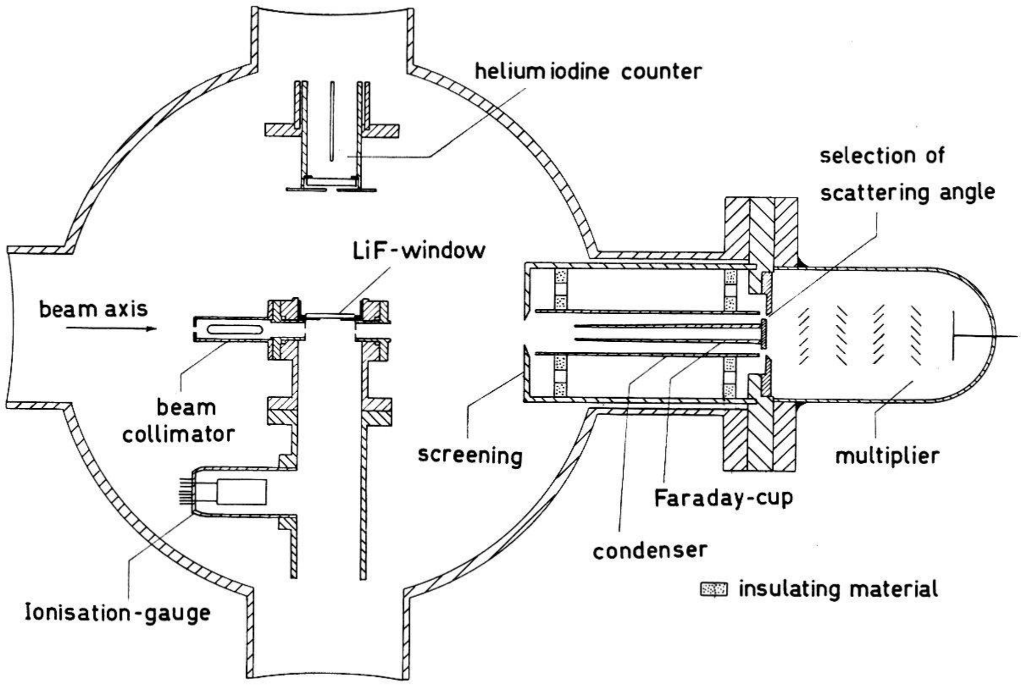

Figure 1

The pressure in the target gas cell is critical in the case of helium only. The ratio N_L/N_R as a function of pressure showed a linear rise in the low pressure range (5×10^{-6}–5×10^{-5} Torr) instead of being a constant. This is due to the fact that even if no gas is admitted to the target cell, the pressure in the cell does not fall below 5×10^{-6} because of the small target apertures. While the Rutherford cross sections of two gases are approximately proportional to the squares of their nuclear charges, this is not the case for the cross sections for excitation of Lyman-α radiation. Taking the Lyman-α cross sections of helium and the residual gas approximately equal we computed the 'mean nuclear charge' of the residual gas to be 6.5.

The neutralizing chamber normally contained hydrogen, the pressure being adjusted to give maximum neutral output. Oxygen, nitrogen, and air have also been used to give an idea of the importance of excited atoms in the beam. The results obtained with the different neutralizing gases agreed within the random error. We therefore treated the different runs as equivalent. Because our beam energies can be reproduced to an accuracy of better than .1%, different runs may be added without smearing out any energy dependent structures.

Results

Since the neutral beam monitor is calibrated with protons and deuterons we have to correct the measured counting rate ratios for screening due to the electron of the hydrogen atom. Calculations of this effect under classical conditions have been performed by DOSE [5]. The results show that at large impact parameters the correction may be quite large. We therefore give in Figures 2, 3, 4 not only the corrected but also the original data. An inconsistency shows up when joining hydrogen and deuterium data. The cross sections for excitation of hydrogen and deuterium should be equal at equal projectile velocities. Taking the corrections from [5] we find that this is only the case for a neon target. For helium and argon targets the deuterium cross sections turn out to be about 20% higher and lower respectively than the hydrogen cross sections. We attribute this to the approximate potentials used in [5] and therefore decided to normalize the deuterium data to the hydrogen data[1]).

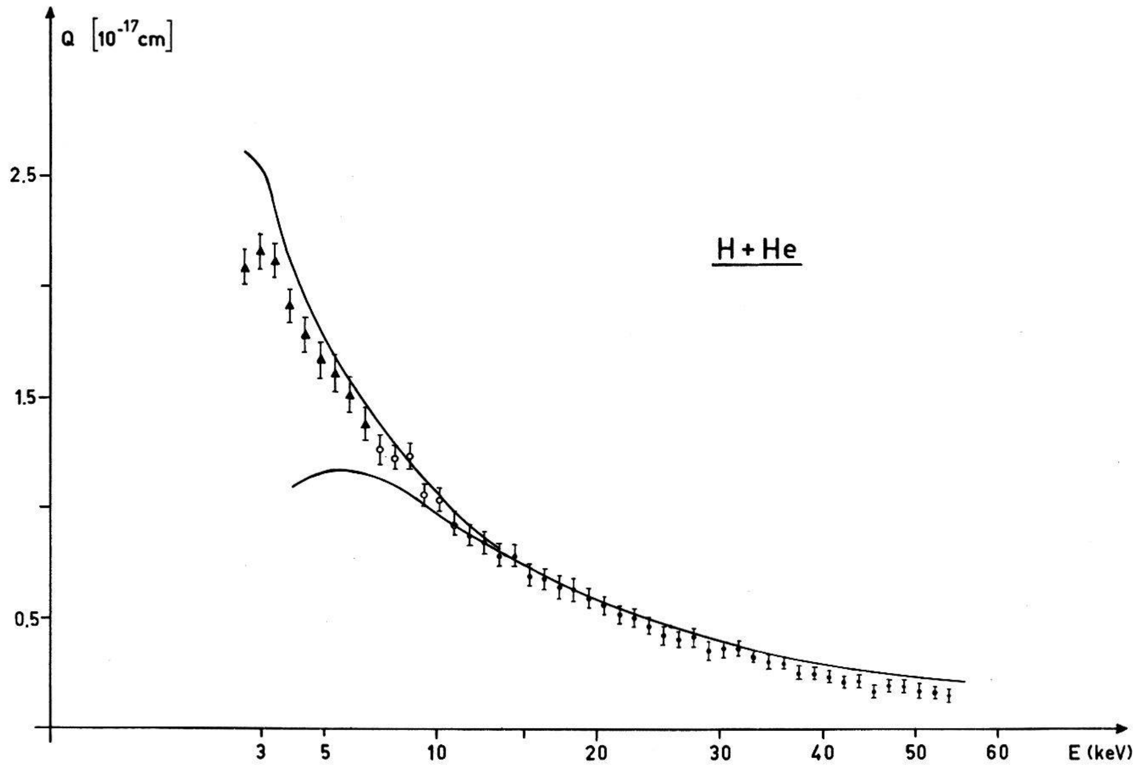

Figure 2

Total cross section for excitation of Lyman-radiation in H–He collisions. Full circles refer to hydrogen, triangles to deuterium data. Open circles represent the average of hydrogen and deuterium data. The upper solid line indicates the uncorrected values. The lower line is the distortion approximation. The energy scale has to be multiplied by two for deuterium.

Absolute cross sections were obtained by comparison with electron capture of protons from helium [1, 2]. Using the absolute values for excitation of hydrogen in collisions with helium the neon and argon scaling factor was computed from the corresponding Rutherford cross sections at high energies where the influence of screening is smallest.

Cross sections for excitation of hydrogen in collisions with helium and neon have been measured before by ANKUDINOV et al. [6]. Comparison with the present results

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[1]) This procedure was further justified for a helium target. Calculating the gauging factor for deuterium and hydrogen seperately by comparing with [1, 2] the corresponding cross sections turn out to be equal at equal projectile velocities.

show that ANKUDINOV's values are about 20% higher than ours, while the shapes of the cross sections are in good agreement. As ANKUDINOV estimates the accuracy of his results to be about ± 15% [7] the difference is not significant.

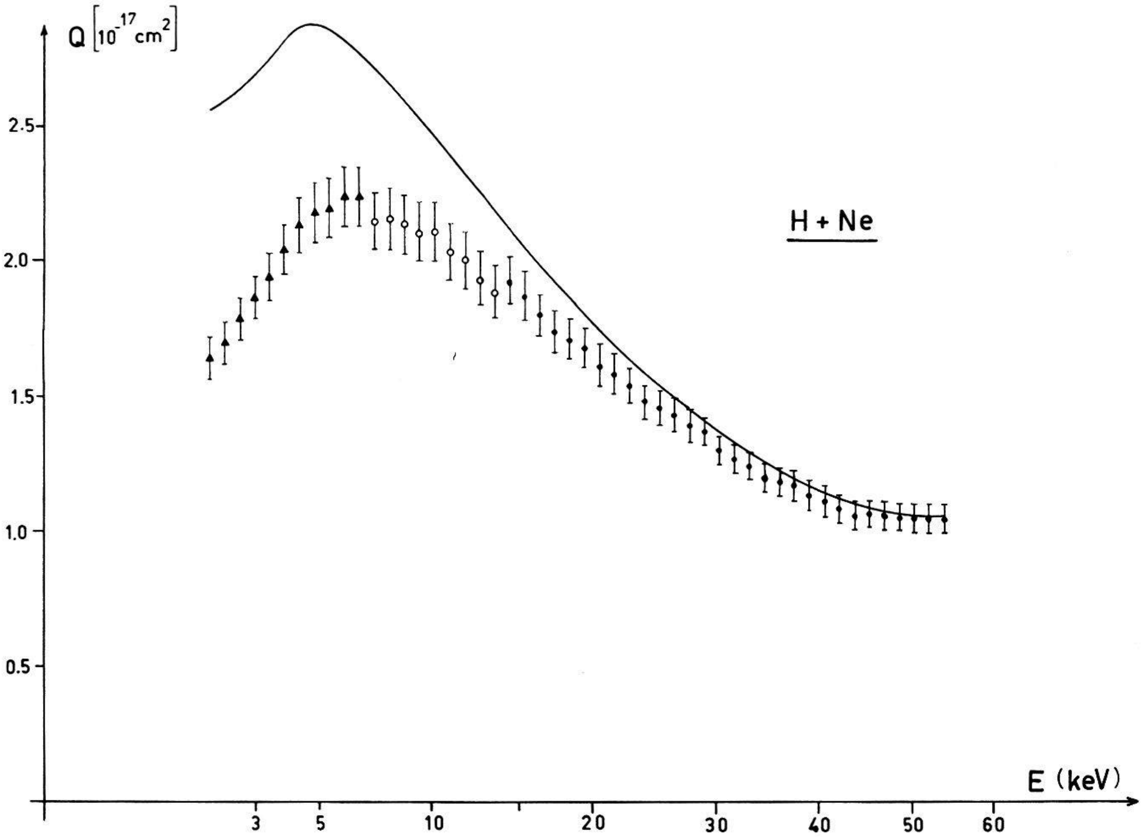

Figure 3

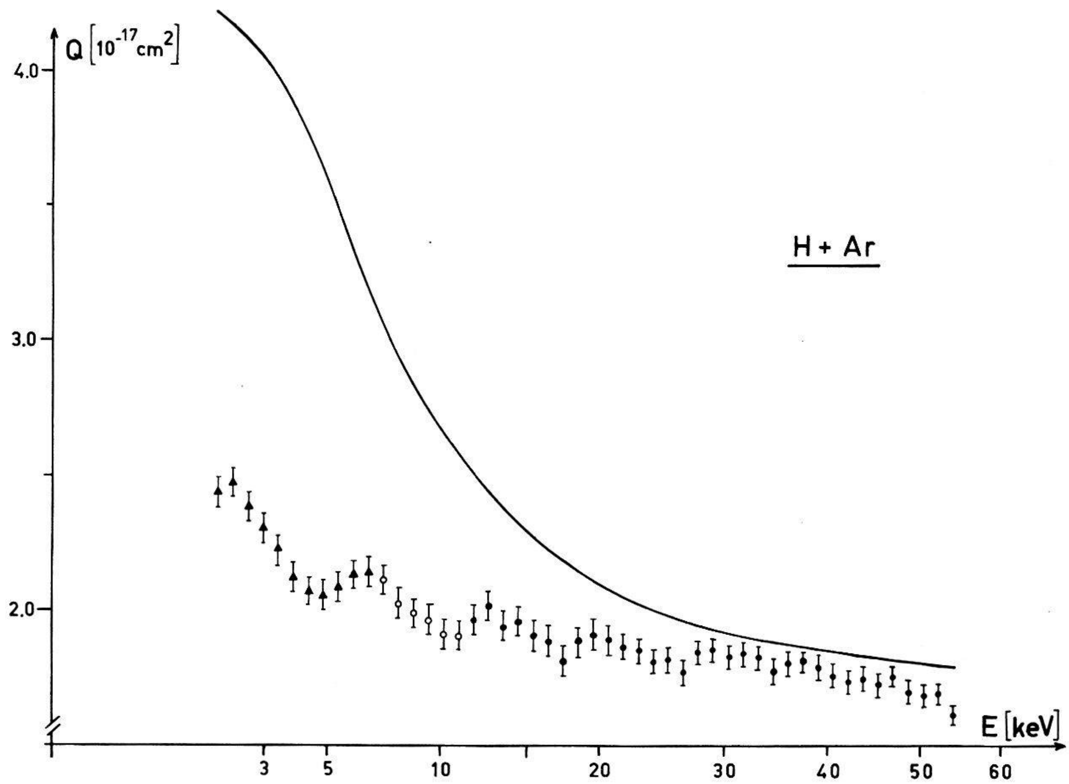

Figure 4

Figure 2 shows a distortion approximation calculation together with the experimental results for helium. The theoretical curve is scaled by a factor of 1/2. The same factor is found in the H^+–He case by SIN FAI LAM [8] who calculated the cross section for electron capture into the $2p$-state in a four state atomic eigenfunction expansion. We therefore suggest that the experimental data [1, 2] are wrong by a factor of two.

The neon data in Figure 3 are not substantially different from the helium data. This is not true for the argon case of Figure 4. The cross section shows small oscillations. They show up more clearly in the corrected data but are not introduced by the screening correction which is monotonic. Bearing in mind that the helium and neon curves do not show any structure we attribute the oscillations in the argon cross section to coupling between the first excited states in argon and the hydrogen $2p$-state. These states have nearly the same energy ($\Delta E \approx 1$ eV) and may be considered degenerate during the collision. Coupling between degenerate states can result in oscillations of the total cross section as is shown in [3]. This explanation is supported by ANKUDINOV et al. [6] whose data points do not exclude a similar effect for H–Kr collisions.

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