Zeitschrift: Helvetica Physica Acta

Band: 41 (1968)

Heft: 3

Artikel: Collisions of hydrogen with rare gases. I, Polarization of Lyman--radiation

Autor: Dose, V. / Gunz, R. / Meyer, V.

DOI: https://doi.org/10.5169/seals-113887

Collisions of Hydrogen with Rare Gases I
Polarization of Lyman-α Radiation

by **V. Dose, R. Gunz** and **V. Meyer**
Physikinstitut der Universität Zürich

(27. X. 67)

Abstract. The polarization of Lyman-α radiation in collisions between hydrogen and He, Ne, Ar has been measured in the energy-range from 3–55 kev. The low energy data are taken using deuterium. In all three cases we find positive polarizations over the entire energy range. The absolute values of the polarization are not accurate enough to correct total cross-section measurements in which the emitted radiation is observed under an angle of 90° with respect to the beam direction [1, 2].

Introduction

Polarization measurements in connection with the knowledge of total cross sections are a valuable help in understanding the mechanism of inelastic collisions. Even though the total cross section may be in good agreement with theory, this is not necessarily the case for the polarization. Coupling between magnetic substates as well as coupling to other nearly degenerate states may change the cross sections for excitation of particular magnetic substates leaving the total cross section unchanged because of cancellation effects. We hope to show the importance of such coupling effects in a subsequent paper.

Experimental Setup

Ions produced in an rf ion source are accelerated by a cascade generator. Mass analysis and energy selection is provided by a 90° deflection magnet. The magnetic field is stabilized by a nuclear magnetic resonance lock-in circuit. From the exit slits of the magnet a fraction of the beam current is derived which after amplification by a difference amplifier controls the high voltage. Beam energies are known absolutely to 2% by a calibration of the high voltage. Relative energy changes as determined by the NMR frequencies are much more accurate.

The mass and energy selected beam passes through a neutralizing chamber. The charged component of the emerging beam is then removed by an electric field of 1 kev/cm over 10 cm length. This field serves as well to quench metastable hydrogen atoms.

Target and detector arrangement are shown in Figure 1. The neutral beam passes through a collimating aperture of .5 mm diam. into the target gas cell. Entrance and exit apertures are 1.0 and 1.5 mm in diam. respectively. The Lyman-α radiation passes through a LiF window to the radiation counters of the usual helium-iodine type first described by Fite et al. [3].

The angular distribution of the Lyman-α radiation can be written as

$$I(\vartheta) = \frac{3\,I_0}{4\,\pi}\,\frac{1 - P\cos^2\vartheta}{3 - P} \tag{1}$$

where P is the radiation polarization defined by

$$P = \left.\frac{I_{\parallel} - I_{\perp}}{I_{\parallel} + I_{\perp}}\right|\vartheta = 90^\circ \tag{2}$$

$I_{\parallel}$ and $I_{\perp}$ are the radiation intensities with electric field vector parallel and perpendicular to the beam axis and ϑ is the angle relative to the beam axis. To obtain the polarization P, one has to measure radiation at only two different angles. We use three counters. Two of them are arranged at 54° and 126°, the third views the interaction region at right angle. The three counters can be rotated simultaneously around the X-axis. This provides a good check on their symmetry and, in addition, permits to measure the relative sensitivities of the counters. The complications arising from the LiF window at the target are discussed in the next section.

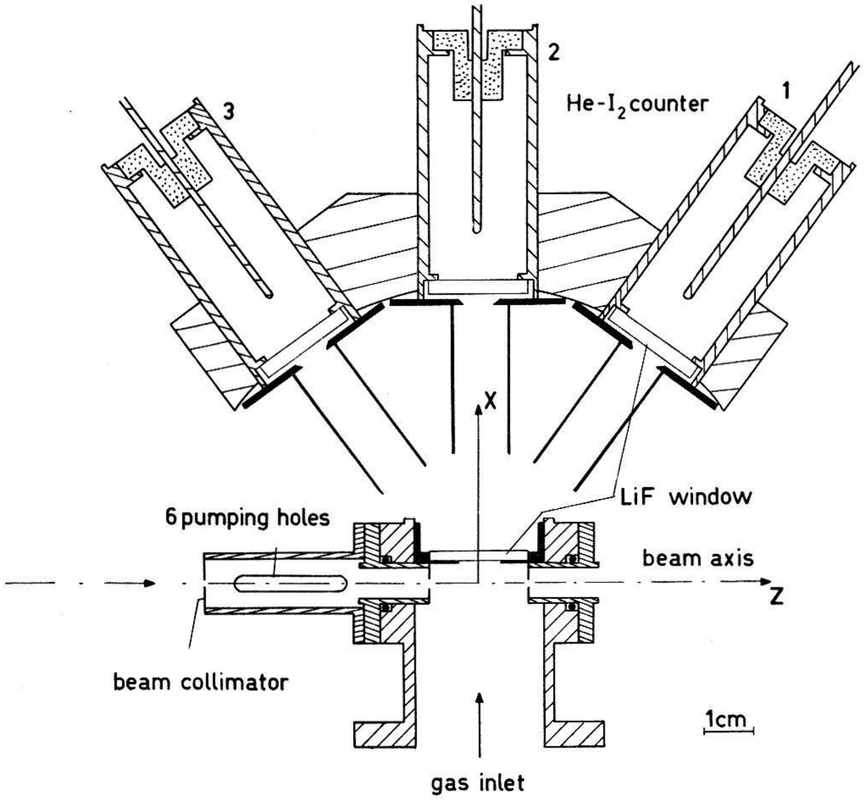

Figure 1
Target and detector arrangement.

A change of the neutralizer gas from hydrogen to N_2, O_2 and air showed no influence on the relative counting rates indicating that excited components of the neutral beam are not of importance. The target gas pressure was held low enough to give counting rate ratios independent of pressure. The final results consist of the sum of several runs. We believe the summation of different runs to be permissible because our beam energies can be reproduced with an accuracy better than .1%.

Corrections and Discussion of Results

Let us first consider the effect of the LiF window at the target. Eliminating P in Equation (1) with the help of (2) we have

$$I(\vartheta) = I_{\|} \sin^2 \vartheta + I_{\perp} (1 + \cos^2 \vartheta) . \tag{3}$$

The first term describes contributions of transitions with $\Delta M = 0$, the emitted light being linearly polarized. The second term arises from transitions with $\Delta M = \pm 1$, the emitted light being elliptically polarized. Denoting with I_p and I_s the radiation intensities with electric field vector parallel and perpendicular to the plane through the three counters, we have

$$I_p = I_{\|} \sin^2 \vartheta + I_{\perp} \cos^2 \vartheta \qquad I_s = I_{\perp} . \tag{1}$$

According to Fresnel's formulas the transmission coefficients a for I_p and b for I_s are different. At $\vartheta = 54°$ and $\vartheta = 126°$ we obtain $a = .940$ and $b = .819$. The refractive index of LiF was taken from [4] to be $n = 1.635$. If the plane through the counters contains the beam we therefore have for the counting rate of counter 1

$$\beta\, I(54°) = \frac{2}{3}\, a\, I_{\|} + \left(\frac{1}{3}\, a + b\right) I_{\perp} . \tag{5}$$

If on the other hand the beam is normal to the plane through the counters we have for counter 1

$$\beta\, I(90°) = I_{\|}\, b + I_{\perp}\, a . \tag{6}$$

Equivalent relations hold for counter 3.

The counting rate of counter 2 is, of course, independent of the angle of rotation and therefore serves to normalize the counting rates of 1,3 in the two positions.

β is a factor allowing for different counter efficiencies, solid angles and different absorptions of the LiF window in the directions of counters 1, 2, 3. In our measurements which took about 3 months β was a slowly and monotonically varying function of time. This may be explained by chemical processes in the counters. We measured the value of β usually three times during a run. The resulting value of β was then inserted in Equation (5) and P was taken from measurements of I (54°).

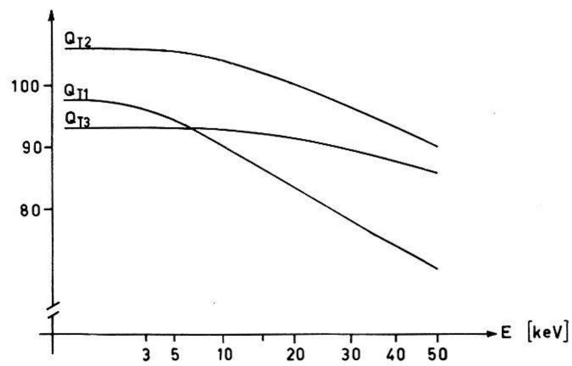

Figure 2

The curves show the velocity dependent corrections to the counters. $Q_{T1,2,3}$ correspond to counter 1, 2, 3 respectively of Figure 1. The vertical scale is in arbitrary units.

A second correction arises from the finite lifetime of the excited $2P$-level. Though this lifetime is rather small ($T = 1.6 \times 10^{-9}$ sec.) it is not negligible compared with the transit time of the beam through the target and therefore causes a nonuniform radiation intensity $I(z)$ along the beam. Taking the origin at the target entrance[1]) we obtain

$$I(z) \sim \int_0^z e^{-(z-z')/vT}\, dz' \tag{7}$$

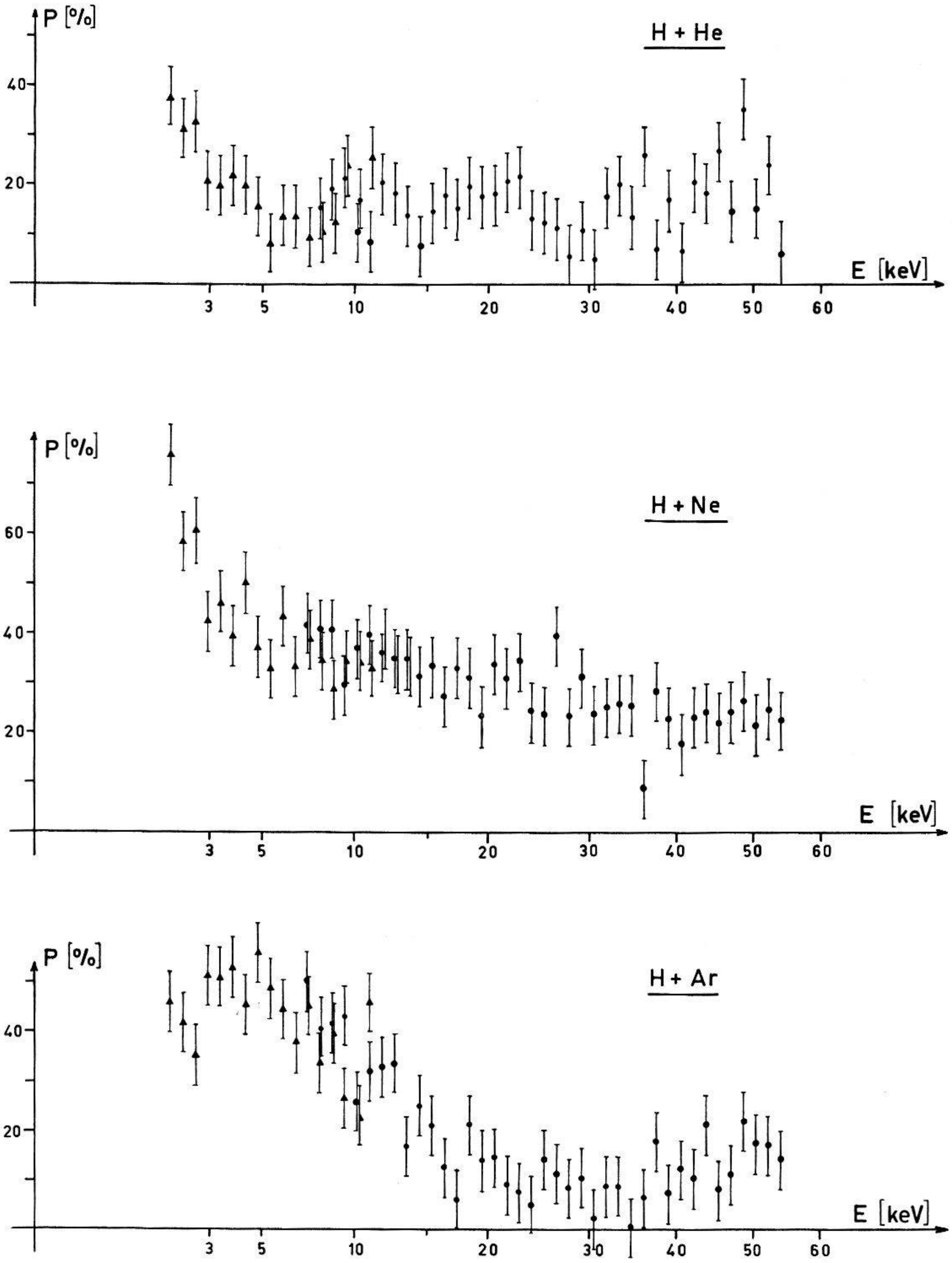

Figure 3

Final results. The error bars indicate the random error only. The systematic error in P is estimated to be $\Delta P = \pm 10\%$. Circles refer to hydrogen data, triangles to deuterium data. The energy scale is for hydrogen; deuterium data are plotted at the equivalent hydrogen velocity.

---

1) By the use of Knudson's law we calculated the contributions from the gas cloud in front of the target to be negligible, even for small z.

where v is the beam velocity. As the counters see different parts of the beam, we get an energy dependent correction different for each counter. Figure 2 shows the function

$$Q_{T_i} = \int_{\omega_i} I_i(z)\, d\omega_i \tag{8}$$

for the three counters. The correction is unexpectedly large and has a marked influence on the final results.

Figure 3 displays the results. The error bars indicate the random error only. The error in absolute values arises from two different sources. The first contribution is due to determining β. This part has again a statistical nature. The second and larger part which can only be estimated arises from Equation (8). The relevant geometrical measurements were done most carefully, but (8) is very sensitive to these quantities. We estimate the absolute accuracy to be $\pm$ 10%. In spite of this error we can state that with all three target gases the polarization remains positive over the entire energy range. A similar result has been obtained by Gaily and Geballe in the case of electron capture by protons from rare gases [5]. This behavior is, in the case of H–He collisions, in contradiction to the Born approximation [6] which predicts zero polarization at about 6 kev and a value of – 35% at high energies. This clearly shows that further theoretical investigations are needed. In connection with this we strive for a remeasurement of the polarization by the use of Brewster's law [7]. This method is likely to provide a better accuracy.

References

[1] V. A. Ankudinov, E. P. Andreev, A. L. Orbeli, V. International Conference on the Physics of Electronic and Atomic Collisions, Leningrad, U.S.S.R., July 17–23, 1967, Abstracts of Papers, page 312.
[2] V. Dose, R. Gunz, and V. Meyer, Helv. phys. Acta *41*, 269 (1968).
[3] R. T. Brackmann, W. L. Fite, K. E. Hagen, Rev. Sci. Instr. *29*, 125 (1958).
[4] E. G. Schneider, Phys. Rev. *49*, 341 (1936).
[5] T. D. Gaily, R. Geballe, Leningrad Conference, Abstracts of Papers, page 314.
[6] V. Dose, to be published.
[7] W. R. Ott, W. E. Kauppila, W. L. Fite, Leningrad Conference, Abstracts of Papers, page 534.