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Mean-life Measurements in He I by the Hanle Effect on High-Velocity Atoms Excited in a Gaseous Target

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Mean lives of He I are deduced from the Hanle curves for high-velocity atoms excited in a gaseous target. For long–mean-life levels we observed oscillations in agreement with a partial precession of the dipoles around the magnetic field. For the $3p\,^1P$ level, the Hanle curve is not perturbed by self-absorption using this method, and the measured mean life (1.8 ± 0.1 nsec) is in good agreement with the theoretical value.

It is well known that, for excited states connected to the ground state by an optically allowed transition, the mean-life measurements can be strongly affected by self-absorption phenomena. Because of the imprisonment of the resonance radiation, one obtains an apparent mean life which is much longer than the natural mean life. For example, for the upper level $3p\,^1P$ of the He I $\lambda5016$ line, methods such as pulsed electron excitation of a helium cell[1-4] give an apparent mean life near 70 nsec for a total imprisonment, whereas the natural mean life is shorter than 2 nsec, because of the high transition probability of the $1s^2\,^1S$-$3p\,^1P$ ($\lambda537$) resonance transition. By studying the apparent mean life as a function of pressure, it is possible to obtain the natural mean life by extrapolation to zero pressure or by correction for the degree of imprisonment. In both cases the uncertainties are very large as a result of either the weakness of the signal at low pressure or the difficulties in the determination of the effective imprisonment radius.

Other methods using polarization measurements, like the classical Hanle method, are strongly affected by the imprisonment of resonance radiation. The effects of trapping and of collisional depolarization lead to coherence narrowing. The measured signals therefore give ensemble-averaged relaxation times instead of natural mean lives.

The beam-foil excitation method with direct measurement of the radiative decay curves of the line intensities seems to be more suitable because of the lack of self-absorption in an ionic beam.[5] Indeed, a beam of some microamperes intensity, for which the particle density is very weak, is optically thin in a direction perpendicular to the beam. But, in this excitation process, the higher levels are strongly populated and the decay curves can be strongly affected by cascades, which generally introduce large uncertainties.

Another possibility for measurement of mean lives, opened by the beam-foil excitation technique, for levels of known g values is to use the Hanle depolarization method on the light emitted by the beam. It is indeed well known that excitation using ion beams produces, like electron excitation, a partial alignment of the excited states. Thus the light emitted is partially polarized. Some experiments have already utilized this alignment to measure g values, fine structure, and sublevel collision cross sections.[6-8]

A gaseous target, which we have used instead of a thin solid foil for the excitation of the beam, can be more appropriate. At pressures of sever-

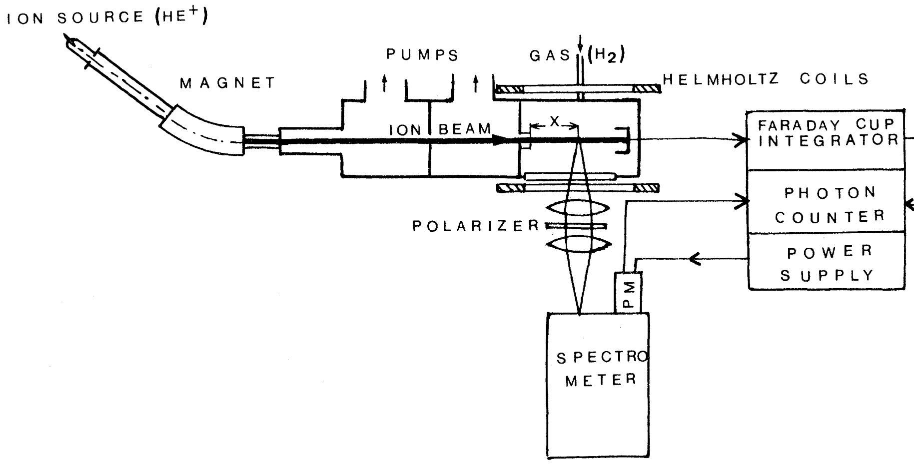

FIG. 1. Experimental setup for Hanle-effect studies. A beam of 80-keV He^+ ions enters a H_2-gas cell. At a distance x downstream a spectrometer observes the radiation $\lambda = 5016$ Å ($3p\,^1P$-$1s^2\,^1S$) emitted in a magnetic field perpendicular to the beam and parallel to the direction of observation. The polarizer wheel can be rotated to measure the intensity of the parallel and perpendicular components of beam radiations. Photomultiplier signals are normalized to equal Faraday-cup signals for each polarizer setting.

al times 10^{-4} Torr and energy of 80 keV, the gaseous target has approximately the same efficiency for beam excitation as found using a carbon foil. Moreover, the indestructible nature of the gaseous target permits a higher-intensity beam, thus producing more light. Furthermore the alignment, and consequently the polarization fraction, is generally higher using a gaseous target than a solid foil. On the other hand, the Hanle effect seems to be affected by the cascades in a more complex way but to a lesser degree than the radiative-decay curves.[9-10]

Figure 1 shows the experimental arrangement. We used an 80-keV magnetically analyzed He^+ ion beam and a cell filled with H_2. The differentially pumped collision chamber is nonmagnetic and possesses a 20-cm-long quartz window to enable viewing at various distances downstream from the entrance of the gas target. Helmholtz coils produce a homogeneous magnetic field perpendicular to the beam, constant over a length of 12 cm. The field can be varied between 0 and ± 80 G. The light was observed in the direction parallel to the magnetic field. Two polarizers, with axes perpendicular to each other, were automatically interposed alternately in the parallel-light region between the two condenser lenses which focus a beam section onto the entrance slit of the spectrometer. The length of the beam section observed was approximately 0.5 mm. An EMI 6256S photomultiplier with a photon-counting system measured the intensity for a counting time monitored by the beam current collected in a Faraday cup at the end of the target chamber. The instrumental polarization was measured using an unpolarized light source and tested with lines emitted from ^1S levels in He I.

By observing photons emitted by particles excited along the gaseous target, one obtains a Hanle signal which can be different from the classical Lorentzian curve. The excitation can take place at any time between $t=0$ and $t=x/v$, where x is the distance of the observation point from the target chamber entrance and v in the velocity of the ions. Using the classical model of dipole radiators precessing around a magnetic field, an elementary calculation involving an integration between 0 and t gives the following expression for the polarization fraction $P=(I_\parallel - I_\perp)/(I_\parallel + I_\perp)$:

$$P = \frac{\Gamma^2}{\Gamma^2 + 4\omega^2} \frac{1 + e^{-\Gamma t}[(2\omega/\Gamma)\sin\omega t - \cos\omega t]}{1 - e^{-\Gamma t}},$$

where $\Gamma = \tau^{-1}$ is the decay width and ω is the Larmor frequency.

To test this expression, we measured the depolarization curve of the $2p\,^1P$-$4d\,^1D$ transition ($\lambda = 4822$ Å), the upper level of which has a relatively long lifetime (35 nsec). This curve is very different from a Lorentzian and shows oscillations for high magnetic fields. In Fig. 2 are displayed the theoretical depolarization curves for different values of t. The experimental points are well fitted by the theoretical curve for which

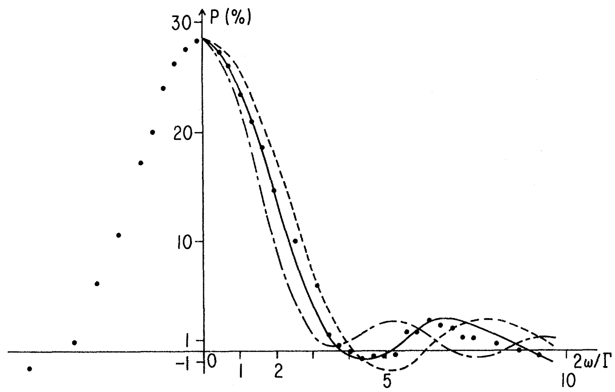

FIG. 2. Hanle-effect resonance on He I $2p\,^1P$-$4d\,^1D$ line (λ = 4922 Å). Circles: experimental data; theoretical curves: solid line for $\Gamma t = 1.15$; dashed line for $\Gamma t = 1.00$; and dot-dashed line for $\Gamma t = 1.50$.

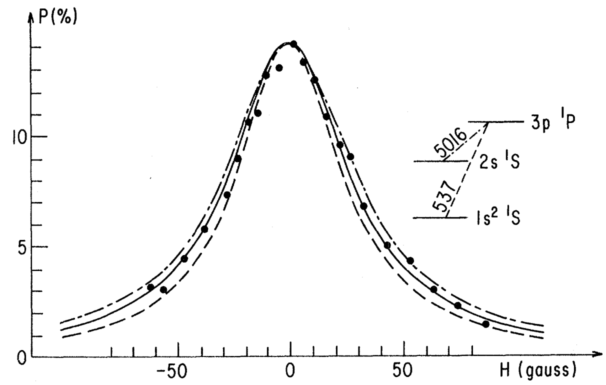

FIG. 3. Hanle-effect resonance on He I $2s\,^1S$-$3p\,^1P$ line. Circles: experimental data. Solid line, the best fit by a Lorentzian curve with $\tau = 1.8$ nsec; dashed line and dot-dashed line, Lorentzian curves with $\tau = 20$ and 1.6 nsec, respectively.

$\Gamma t = 1.15$, a value which exactly corresponds to the chosen geometric distance $x = 8$ cm in the target cell.

The $3p\,^1P$ level, on the other hand, has a very short mean life (1.8 nsec) which corresponds to a value $\Gamma t = 23$, for which the corrections are totally negligible. Consequently, the experimental Hanle curves for not too high target pressures ($p < 5\times10^{-3}$ Torr) are fitted well by a pure Lorentzian (Fig. 3). The zero value for the polarization scale is obtained by measuring the instrumental polarization fraction for the nearest unpolarized line, $2p\,^1P$-$4s\,^1S$ (λ = 5047 Å in He I). The polarization in zero field is nearly constant for target pressures varying between 10^{-5} and 5×10^{-3} Torr, showing that the secondary processes can be neglected. We therefore measured the Hanle signals for different pressures near 10^{-4} Torr. They correspond to a mean life $\tau = 1.80 \pm 0.1$ nsec, which is in good agreement with the theoretical value 1.74 nsec.[11]

The result obtained with the $3p\,^1P$ level of He I gives a good test of the method used, and we point out again its usefulness for lines subject to photoabsorption.

In addition, the perturbations due to alignment transfer, which are weak compared to population transfer by cascades, can be studied by observing Hanle curves taken at different positions along the beam in a vacuum cell after the gaseous target. Thus it will be possible to study the alignment transfer and to correct mean life measurements for its perturbing effect on Hanle signals in high-velocity atoms.

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[1]P. J. Kindlmann and W. R. Bennett, Jr., Bull. Amer. Phys. Soc. 8, 87 (1963).

[2]W. R. Pendleton, Jr., and R. H. Hughes, Phys. Rev. 138, A683 (1965).

[3]K. A. Bridgett and T. A. King, Proc. Phys. Soc., London 92, 75 (1967).

[4]L. Allen, D. G. C. Jones, and D. G. Schofield, J. Opt. Soc. Amer. 59, 842 (1969).

[5]I. Martinson, W. S. Bickel, J. Bromander, H. G. Berry, L. Lundin, R. Buchta, and I. Bergström, J. Opt. Soc. Amer. 60, 352 (1970).

[6]C. H. Liu, S. Bashkin, W. S. Bickel, and T. Hadeishi, Phys. Rev. Lett. 26, 222 (1971).

[7]J. Andrä, Phys. Rev. Lett. 25, 325 (1970).

[8]I. A. Sellin, C. D. Moak, P. M. Griffin, and J. A. Biggerstaff, Phys. Rev. 184, 56 (1969).

[9]O. Nedelec, thèse, Grenoble (France), 1966 (unpublished).

[10]R. K. Wangsness, Phys. Rev. A 4, 1275 (1971).

[11]B. Schiff and C. L. Pekeris, Phys. Rev. 134, A638 (1964).