Magnetic-Field Dependence of Polarized Helium Light Excited by Electrons*

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The polarization of light resulting from the excitation of helium atoms by an electron beam has been measured as a function of magnetic field parallel to the electron beam. Results are presented which show that the polarization of the radiation arising from the diffuse singlet transitions in helium is magnetic-field dependent. The polarization of the radiation of the diffuse triplets is not field dependent. Since the magnetic field (parallel to the direction of the electron beam) cannot lead to a reorientation of the atom in its excited state, the polarization of the emitted radiation should not be altered by the magnetic field subsequent to the excitation impact. It would appear, then, that the inelastic scattering of electrons by helium atoms is independent of magnetic field for triplet-state excitation, but dependent for singlet-state excitation.

Since theory, as presently developed, predicts that the population probabilities to diffuse singlet and triplet states should depend only on the orbital angular momentum magnetic quantum numbers, one must conclude that the inelastic scattering that is involved is probably more complicated than is usually assumed.

INTRODUCTION

In earlier papers[1,2] the anomalous behavior of the polarization of light emitted by helium atoms excited by a beam of electrons has been reported. The theory of the polarization of collision radiation which has been reviewed by Percival and Seaton[3] predicts a unique maximum value for the polarization at the threshold energy for excitation. The theory simply depends upon the assumption of the validity of Russell-Saunders coupling and central force interaction. Experimentally determined values of the polarization as a function of electron energy in mercury and helium appear to be zero at the onset of excitation [$\lambda = 3889$ Å ($3\,^3P \rightarrow 2\,^3S$) is an exception] and increase to maximum values at a few volts above threshold.

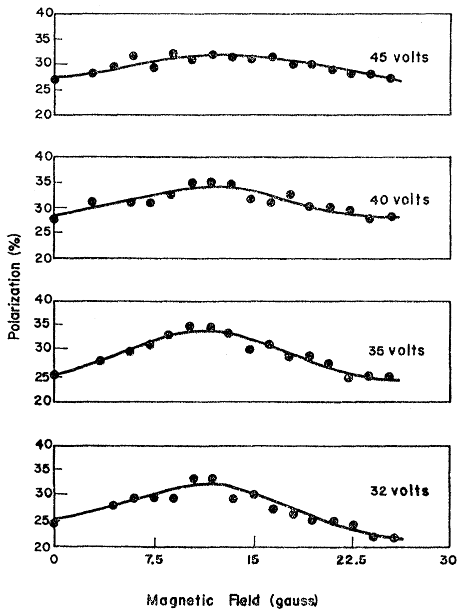

FIG. 1. The polarization of $\lambda = 6678$ Å ($3\,^1D \rightarrow 2\,^1P$) vs magnetic field at four different electron accelerating voltages. The low-field polarization increase is due to electron-path straightening in the observation region. This is enhanced for this line due to the necessary higher beam currents required for the observation.

The experimental measurements reported previously by the above authors were performed with a magnetic field of 15 G parallel to the electron beam. Because of the disagreement between experiment and theory, the dependence of the polarization of the radiation upon magnetic field was investigated. The experimental results presented here show that, while the polarization of

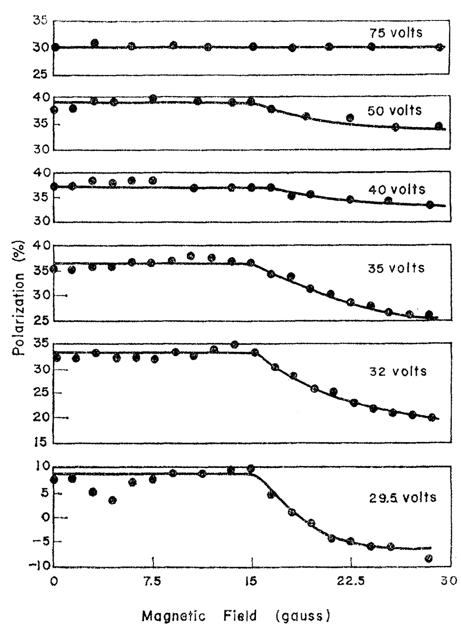

FIG. 2. The polarization of $\lambda = 4922$ Å ($4\,^1D \rightarrow 2\,^1P$) vs magnetic field.

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[2] R. H. McFarland and E. A. Soltysik, Phys. Rev. **128**, 1758 (1962).

[3] I. C. Percival and M. J. Seaton, Phil. Trans. Roy. Soc. (London) **113**, 251 (1958).

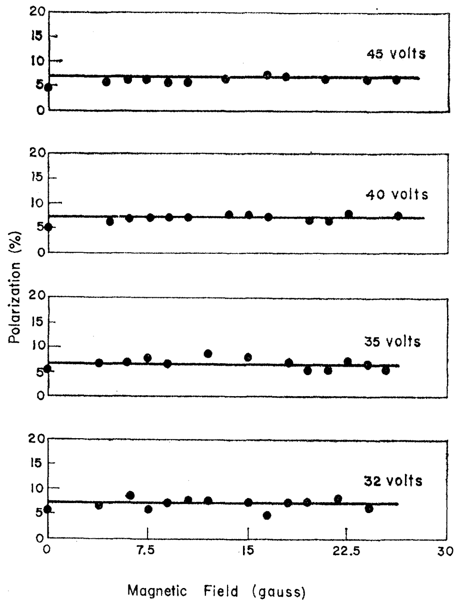

FIG. 3. The polarization of $\lambda=5876$ Å ($3\,^3D\rightarrow 2\,^3P$) vs magnetic field.

light originating from diffuse orthohelium states is independent of magnetic fields less than 30 G, the polarization of light originating from the diffuse parahelium states does show a magnetic dependence at the lower electron energies.

In addition to the results presented here, measurements of the polarization of $\lambda=3889$ Å line in helium by

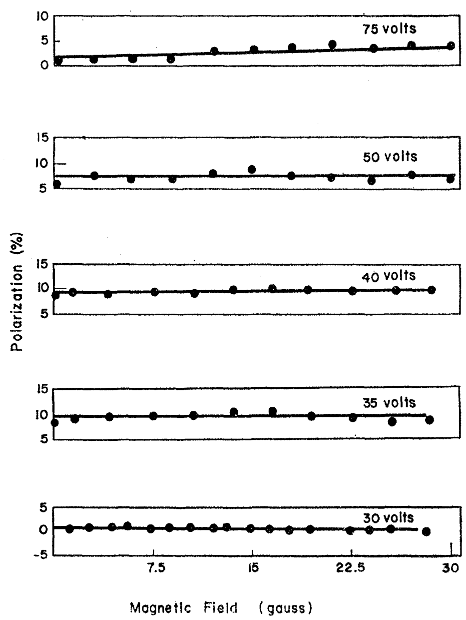

FIG. 4. The polarization of $\lambda=4472$ Å ($4\,^3D\rightarrow 2\,^3P$) vs magnetic field.

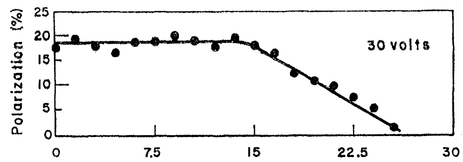

FIG. 5. The polarization of $\lambda=4388$ Å ($5\,^1D\rightarrow 2\,^1P$) vs magnetic field. The polarizations at other voltages were comparable to those of $\lambda=4922$ Å.

Hughes[4] with no magnetic field, by Lamb and Maiman[5] at a few hundred gauss, and by the authors[1,2,6] at 15 G all agree. This indicates the polarization of this line to be independent of magnetic field.

An adequate description[1,2] of the apparatus used for the results presented here has been published previously. The magnetic field parallel to the electron beam was produced by 25-in.-diam Helmholtz coils oriented to supplement or oppose the earth's field. The interaction chamber was at the center of the coils in the uniform field region. The gas pressure for the results to be reported was 5 μ.

RESULTS

Figures 1 through 4 are representative of the magnetic-field variation of the polarization of the helium lines 6678 Å ($3\,^1D\rightarrow 2\,^1P$), 4922 Å ($4\,^1D\rightarrow 2\,^1P$), 5876 Å ($3\,^3D\rightarrow 2\,^3P$), and 4472 Å ($4\,^3D\rightarrow 2\,^3P$). Although the diffuse triplet transition, 4026 Å ($5\,^3D\rightarrow 2\,^3P$), was not sufficiently resolved from 4009 Å ($7\,^1D\rightarrow 2\,^1P$) to provide unambiguous information, its singlet counterpart, 4388 Å ($5\,^1D\rightarrow 2\,^1P$) is shown at 30 V in Fig. 5. The polarization of $\lambda=4388$ Å magnetic-field dependence is comparable to that of the 4922-Å line at other voltages. Figure 6 shows the dependence of the collector cup current i_c and the ratio of the light emitted I to the collector cup current.

It is observed that all three singlet transitions exhibit magnetic-field dependence above 15 G, while the triplet transitions do not. The increasing of the polarization of

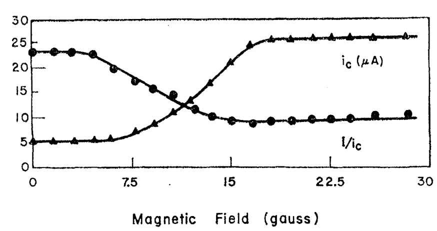

FIG. 6. The beam current collected at the anode i and the excitation efficiency I/i_c (I is the radiation intensity) vs magnetic field. These two curves taken at 30 V and 5 μ pressure for $\lambda=4922$ Å were typical of those observed for the other lines.

[4] R. H. Hughes, R. B. Kay, and L. D. Weaver, *Abstracts of the 14th Annual Gaseous Electronics Conference*, General Electric Co., Schenectady, New York, 1961 (unpublished).

[5] W. E. Lamb and T. H. Maiman, Phys. Rev. **105**, 573 (1957).

[6] R. H. McFarland and E. A. Soltysik, Bull. Am. Phys. Soc. **6**, 423 (1961).

the 6678-Å line with field below 10 G appears to be due to the magnetic-field confinement of the beam current as indicated by Fig. 6. This variation with field has been eliminated from the 4922- and 4388-Å measurements by a reduction in the beam current. Intensity considerations required the $\lambda = 6678$ Å measurements to be made at a higher beam current.

Additional measurements have been made at pressures extending to as low as 0.8 μ with the beam current space-charge limited; as well as emission limited, with and without differential pumping, and with variation in the electron gun geometry. Except for small shifts due to changing contact potentials, the results have uniformly indicated that the polarization of light from diffuse singlet transitions is magnetic-field dependent. The polarization of the diffuse triplets, however, is not.

Polarization P is defined as

$$P=\frac{I_{\parallel}-I_{\perp}}{I_{\parallel}+I_{\perp}}\times 100\%.$$

Further, with the assumption of spin independence of the interaction and Russel-Saunders coupling, it has been shown[1,3] that for diffuse singlet transitions the polarization is

$$P=3\frac{\sigma_0+\sigma_1-2\sigma_2}{5\sigma_0+9\sigma_1+6\sigma_2}\times 100\%.$$

For the diffuse triplets, the polarization is

$$P=213\frac{\sigma_0+\sigma_1-2\sigma_2}{671\sigma_0+127\sigma_1+1058\sigma_2}\times 100\%,$$

where σ_0, σ_1, and σ_2 refer to the cross sections for electrons excited to states with $m_l=0$, 1, and 2, respectively.

Referring to Fig. 6, the excitation probability I/i_c remains reasonably constant with magnetic fields above 15 G, indicating the constancy of the sum, $\sigma_0+\sigma_1+\sigma_2$. (The decrease in I/i_c from $0\rightarrow 15$ G is due to an increase in i_c as the field compresses the electron beam.) However, the decrease in polarization, for the diffuse singlet-state transitions with magnetic field (becoming negative at low electron energies), indicates an increase in σ_1 and σ_2 and a decrease of σ_0 with increasing magnetic field. On the other hand, the constancy of the polarization of the diffuse triplets with magnetic field indicates that the triplet set of σ's are not directly related to those for the singlets through their m_l values as given by theory. Why theory departs from the experiment is not clear.

Obviously, the magnetic field increases the acceptance in the interaction region of larger perpendicular components of electron beam velocity; but at 30 G, the geometry of the systems limits the ratio of the perpendicular to parallel velocities to less than one-tenth. Even granting that this could have an effect on the singlet transitions, it should have the same effect on the triplets.

An unsuccessful attempt has been made to explain the diffuse singlet-state transition magnetic-field dependence. At higher pressures, a transfer of energy by collisions between excited ^1P states and ground-state atoms to form ^1D excited states has been reported.[7] An explanation of the magnetic-field dependence of polarization would require a preferred population by collision of the $m_l=1$ and 2 substates of $^1D_2$ levels at the higher magnetic fields. The magnetic splitting of the $^1D_2$ states, however, at 30 G is insignificantly small; and the expected pressure dependence (decreased magnetic effect with decreasing pressure) has not been found.

In conclusion, a magnetic-field dependence of the polarization of light arising from diffuse singlet-state transitions in helium excited by electron impact has been observed. This cannot be explained in terms of presently available electron inelastic scattering theory. Work is being continued toward a better understanding of the phenomenon.

[7] H. S. W. Massey and E. H. S. Burhop, *Electronic and Ionic Impact Phenomena* (Clarendon Press, Oxford, 1956), p. 431.