Polarization of Light from e^--He Collisions*

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The polarization of light resulting from the excitation of helium by electron impact has been measured as a function of electron energy. We report here our results in the energy threshold region for the following transitions: $3\,^1P \rightarrow 2\,^1S$ ($\lambda = 5016$ Å), $3\,^3P \rightarrow 2\,^3S$ ($\lambda = 3889$ Å), and $4\,^1D \rightarrow 2\,^1P$ ($\lambda = 4922$ Å). The results reported here are in substantial agreement with the results previously reported by McFarland. Also, no dependence of the polarization on the magnetic field parallel to the electron beam was observed.

INTRODUCTION

RECENT interest in the polarization of light resulting from the excitation of helium by energetic electrons has centered about the discrepancy between theory and experiment in the immediate vicinity of the threshold energy for the excitation of a particular atomic transition. For a rather complete list of references on this problem, the reader is referred to the paper by McFarland.[1] Very briefly, while simple angular momentum considerations predict a maximum value for the polarization at the threshold energy for the excitation of a particular atomic transition, earlier results reported by a number of experimentalists indicated that near threshold the polarization tends toward zero, in apparent violation of angular momentum conservation. However, more recent results reported by McFarland,[1] and Heddle and Keesing[2] indicated that, within 0.5–1.0 V of the threshold energy, the polarization rises sharply presumably in agreement with the theoretically predicted threshold value. However, except for the $\lambda = 4922$ Å ($4\,^1D \rightarrow 2\,^1P$) and $\lambda = 4388$ Å ($5\,^1D \rightarrow 2\,^1P$) lines, the highest observed values for the polarization in the immediate vicinity of threshold are not too close to the values as calculated by Percival and Seaton.[3] The results reported here for the polarization in the energy threshold region show basically the same characteristics as reported by McFarland.

EXPERIMENTAL DETAILS

The essentials of the experimental arrangement are shown in Fig. 1. Electrons from the cathode button supplied by Superior Electronics Corporation acquire a given energy through interaction with the electric fields associated with the voltages on the disks of the electron gun. The gun consists of 6 gold-plated bronze disks mounted in a parallel fashion. The disks are $1\frac{5}{8}$ inches in diameter, and each has a central aperture hole of 0.030 inch diameter. The voltages on the various disks during the course of the experiment were as follows (reading from left to right): cathode, $-V_c$; electrode 1, $-V_c-2$; electrode 2, $-V_c+75$; electrode 3, ground; electrode 4, $-V_c+$ (square wave); electrodes 5 and 6, ground. A copper box placed around the electron gun shielded the interaction region from stray fields. The electron beam is chopped at 150 cps by means of a square-wave signal placed on electrode 4. The electron-cup current i is measured by means of a Rubicon galvanometer placed between the cup and ground. During the course of the experiment the electron-cup current was of the order of a few microamperes. The exact value depended upon the cathode voltage. The energy resolution of the electron beam, as measured by the retarding potential method at the cup, was 0.75 eV at a beam energy of 25 eV. The energy resolution of the electron beam used by McFarland[1] was 0.5 V, as measured by the same procedure. However, his ability to resolve the 19.3-eV elastic resonance in helium indicated that the energy resolution of his electron gun is probably less than 0.25 V.

The dimensions of the rectangular shaped brass vacuum chamber are 12 in. long, 8 in. wide, and 4 in. deep. The base pressure in the vacuum chamber was 4×10^{-7} Torr. The helium was leaked into the vacuum chamber via a Vactronic variable leak valve through a hypodermic needle of small aperture inserted into the top cover plate of the chamber. During the course of the experiment, the helium gas was leaked into the chamber and pumped on continuously. Under this dynamic pressure condition, where the system is continuously pumped, we are able to be assured of a low background pressure of 4×10^{-7} Torr. During the course of the experiments, the pressure was monitored by means of an ionization gauge. Data were taken in the pressure range 0.3–0.6 μ, as measured by the ionization gauge. After the completion of the measurements, the ionization gauge was calibrated against a McLeod gauge under the same dynamical conditions of the experiment. The pressure as determined with the McLeod gauge was a constant multiplicative factor of 9 times higher in the range from 0.1–1.0 μ as read on the ionization gauge. Thus, we conclude that the helium pressure at which the measurements were taken was in the range 2.7–5.4 μ.

The modulated light, resulting from the excitation of

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[1] R. H. McFarland, Phys. Rev. **133**, A986 (1964).
[2] D. W. O. Heddle and R. G. W. Keesing, in *Proceedings of the Fourth International Conference on the Physics of Electronic and Atomic Collisions, Quebec 1965* (Science Bookcrafters, Hastings-on-Hudson, New York, 1965).
[3] I. C. Percival and H. J. Seaton, Phil. Trans. Roy. Soc. (London) **113**, 251 (1958).

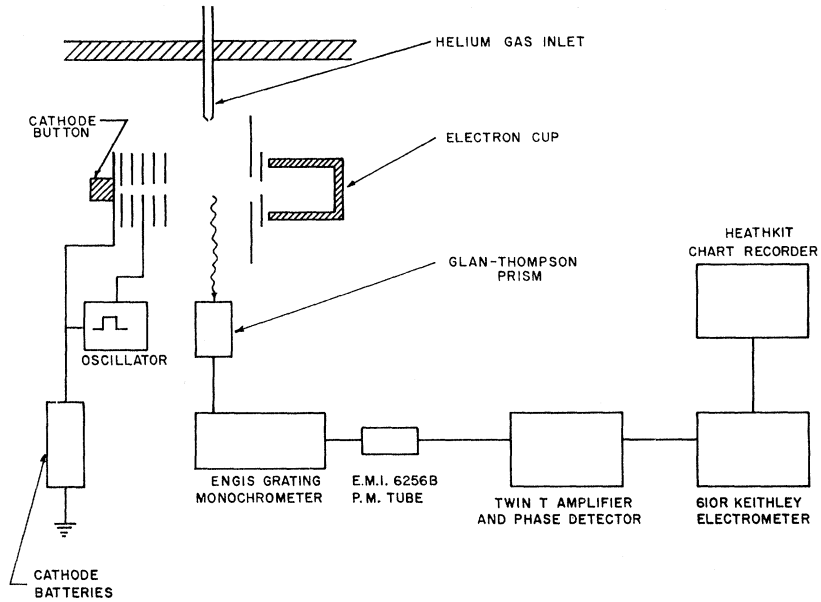

FIG. 1. Schematic diagram of the experimental arrangement.

the helium atoms by the modulated electron beam, passes through a quartz window in the vacuum chamber then through a 1 in. diam. Glan-Thompson prism which can be rotated through 90°. In its two mutually perpendicular positions the Glan-Thompson prism transmits light with its electric vector either parallel or perpendicular to the electron beam, i.e., the Glan-Thompson prism analyzes the polarization of the light with respect to the direction of the electron beam. After passing through the Glan-Thompson prism, the modulated light passes through an Engis high-transmission grating monochromater and onto the photo surface of an E.M.I. 6256B thermoelectrically cooled photomultiplier tube. The resulting modulated electrical signal then passes through a twin T amplifier and is phase-detected. The resulting dc signal is then read on a Heathkit chart recorder. The parameter measured in this experiment is $P=(I_{\parallel}-I_{\perp})(I_{\parallel}+I_{\perp})^{-1}\times 100\%$. $I_{\parallel}$ and $I_{\perp}$ are, respectively, the intensity of the light, viewed at right angles to the electron beam, whose electric vector is parallel and perpendicular to the direction of the electron beam.

The distance between the interaction region and entrance slit of the monochromator was 15 in. The slit openings were 0.40 mm. The slit edges were perpendicular to the electron beam and the long dimension of the slits were masked down to $\frac{1}{4}$ in. Thus we were viewing a narrow light beam.

The dependence of the excitation functions $I_{\parallel}/i$ and $I_{\perp}/i$ on the helium-gas pressure was measured at a few voltages. All polarization measurements were taken in the linear pressure region, thus ensuring that the light observed resulted from single-atom collisions. In addition $I_{\parallel}$ and $I_{\perp}$ were measured as a function of the beam current and were found to be linear. The polarization of light as a function of electron energy was measured at least three separate times for each line, with particular emphasis given to the threshold region, and all results agreed within a few percent. The results presented in this paper show the results for one typical run for each line.

INSTRUMENT POLARIZATION

All results have been corrected for the inherent instrument polarization according to the formula

$$P=(P_M-p_0)(1+P_M p_0)^{-1}, \quad (1)$$

where P_M is the measured polarization and p_0 is the instrument polarization. The instrument polarization as a function of wavelength was determined by placing a current-carrying tungsten wire inside the vacuum chamber. First, the tungsten wire was oriented in essentially the same position as the electron beam, and the polarization was measured; then the tungsten wire was rotated 90° so that its axis of symmetry was perpendicular to the direction of the electron beam, and again the polarization was measured. These two measured polarizations are not equal. It is simple to show that the instrument polarization p_0 is the arithmetic sum of the polarizations measured for the two mutually perpendicular orientations of the tungsten wire. The instrument polarization for the lines reported here are as follows: $\lambda=3889$ Å, $p_0=+11\%$; $\lambda=5016$ Å, $p_0=+13\%$; $\lambda=4922$ Å, $p_0=+16\%$.

At this point, we wish to mention that we had originally assumed that the light from a straight tungsten wire was unpolarized. This is not true, as was first pointed out by Worthing[4] in 1926. In fact, he reports that the polarization of light from a straight tungsten wire of circular cross section viewed normal to

[4] A. G. Worthing, J. Opt. Soc. Am. and Rev. Sci. Instr. 13, 635 (1926).

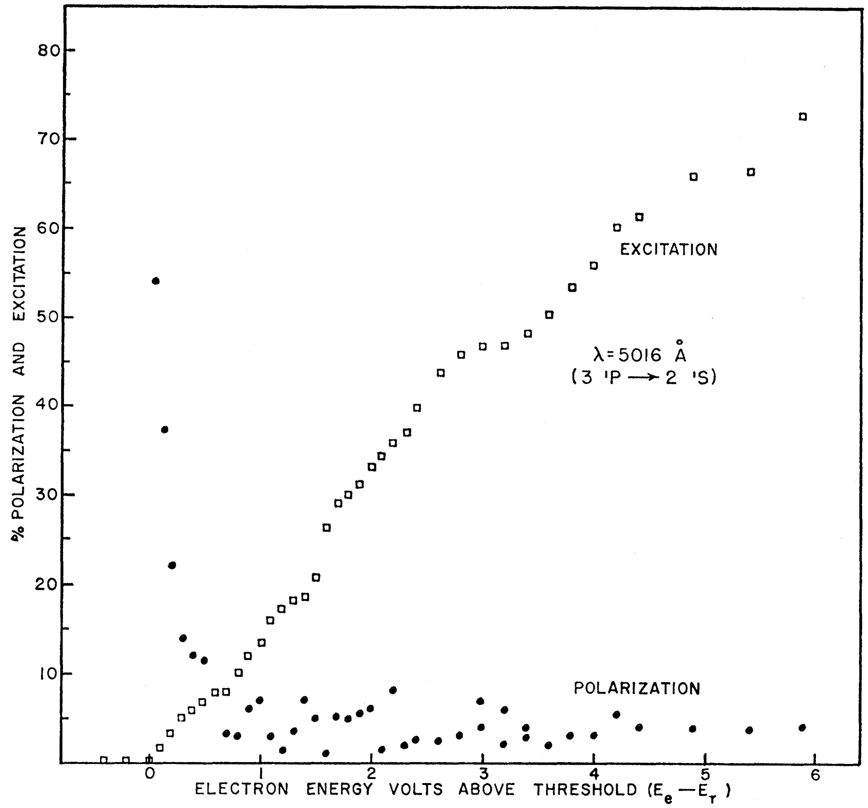

FIG. 2. % polarization $P = (I_{\parallel}-I_{\perp})(I_{\parallel}+I_{\perp})^{-1}\times 100\%$ and excitation $(I_{\parallel}+I_{\perp})/i$ for the $\lambda = 5016$ Å line as a function of the electron-beam energy.

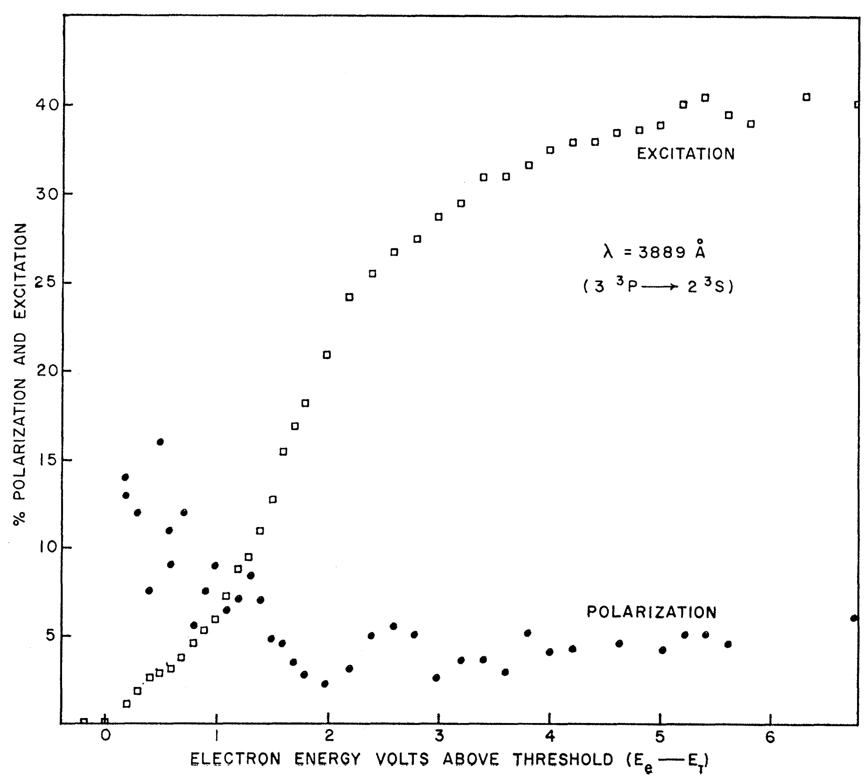

FIG. 3. % polarization and excitation for the $\lambda = 3889$ Å as a function of the electron-beam energy.

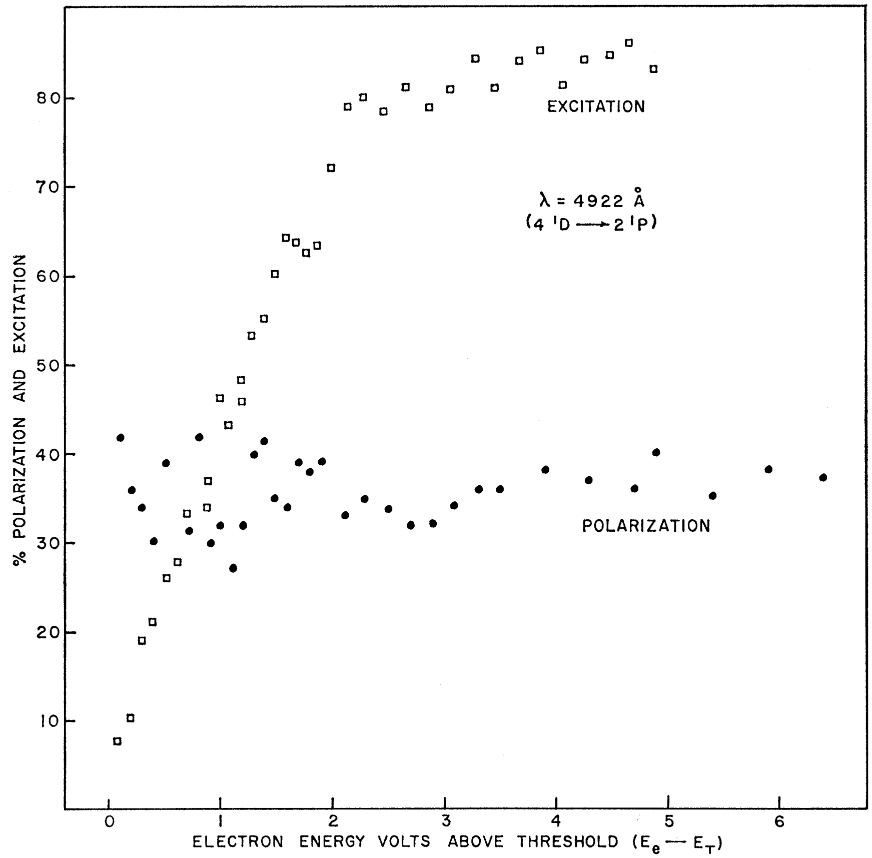

FIG. 4. % polarization and excitation for the $\lambda = 4922$ Å line as a function of the electron-beam energy.

its axis of symmetry is 19%; and he cautions that when cylindrical wire filaments are used in polarization experiments, this polarization of light from tungsten may be of concern. To this we say amen. From our measurements of the polarizations of light from the tungsten wire in its two mutually perpendicular positions we were able to obtain the polarization of light from the tungsten wire as a function of wavelength. The polarization was virtually independent of wavelength and amounted to about 15%, in reasonable agreement with the result reported by Worthing. We also measured the polarization of the $\lambda = 4713$ Å ($3\,^3S \rightarrow 2\,^3P$) line in helium; and, after applying the instrument polarization correction ($p_0 = 10\%$ at $\lambda = 4713$ Å), we found the polarization of this line to be zero and independent of electron energy. This is what one expects for light originating from a spherically symmetric initial atomic state. Thus, we feel confident that our measurement of p_0 as a function of wavelength is correct.

RESULTS

Although measurements were taken for electron energies up to 300 V, we present here only the results for the threshold region, since this is really the region of interest.

$\lambda = 5016$ Å ($3\,^1P \rightarrow 2\,^1S$). Figure 2 shows the % polarization and the excitation as a function of the electron energy in volts above threshold in the neighborhood of the threshold energy. One notices the rapid rise in the polarization within 1 V of threshold. The results agree reasonably well with those of McFarland.

$\lambda = 3889$ Å ($3\,^3P \rightarrow 2\,^3S$). Figure 3 shows the % polarization and excitation in the neighborhood of the threshold energy for this line. Again, one notices the rapid increase in the polarization close to threshold. The results are similar to those reported by McFarland.

$\lambda = 4922$ Å ($4\,^1D \rightarrow 2\,^1P$). Figure 4 shows the % polarization and excitation for this line in the threshold region. Our results are consistent with those of McFarland; but, because of the larger scatter of our points, we are not able to verify definitely the dip in the polarization close to threshold which he reported.

Magnetic field measurements. Previous experiments[5] reported a dependence of the polarization of light on the magnetic field parallel to the electron beam for light arising from the diffuse singlet transitions in helium. There is no theoretical explanation for these

[5] R. H. McFarland and E. A. Soltysik, Phys. Rev. **128**, 2222 (1962).

results. We have measured the polarization as a function of magnetic field at various electron-beam energies corresponding to the values previously reported. However, we found no dependence of the polarization on the magnetic field up to 30 G for the lines reported in this paper. This is of course what one expects theoretically. It also confirms the suggestion by McFarland[1] that the previously reported results are fallacious and can be explained in terms of wall effects. It is to be remembered that the vacuum chamber used in these experiments is much larger than that used in the previous measurements.

CONCLUSION

Our results on the polarization from helium bombarded by slow electrons are in reasonable agreement with the results reported by McFarland. Also, the polarization of light shows no dependence on the strength of the magnetic field parallel to the electron beam.

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Radiative Lifetimes for uv Multiplets of N II through N V

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The foil-excitation technique has been used to measure radiative lifetimes of eighteen uv multiplets in N II through N V. The multiplets were produced by passing a N^+ beam of known energy through a thin carbon foil that could be moved in small steps along the axis of the beam. The beam energy was either 1 or 2 MeV and the foil thickness either 500 or 1000 Å. A grazing-incidence monochromator instrumented for photoelectric counting was used to measure the decay of the multiplet as a function of distance downstream from the intersection of the foil and beam. The wavelengths of the measured multiplets were from 1085 Å (N II) to 162 Å (N V). Most of the multiplets were transitions to the ground-term configuration. The mean lifetimes range from about 3×10^{-9} to 0.5×10^{-10} sec, the measured accuracy being between 5 and 15%. Corrections for cascading were necessary for many of the multiplets. Transition probabilities obtained from the lifetime measurements are compared with other experimental and theoretical determinations.

I. INTRODUCTION

One experimental method to obtain lifetimes of excited states of an atomic system utilizes the foil-excitation technique.[1,2] A monoenergetic ion beam is passed through a thin foil which serves to create multiple ionization of the incident beam and also to excite the ions. The emergent ion beam, therefore, contains a mixture of ion species, having known velocities, in various states of excitation. If cascades into the excited levels are negligible, a measurement of the decay of a transition from the excited level as a function of distance downstream from the intersection of the foil and beam gives a direct measurement of the lifetime of the upper level. Because the density of the ion beam usually is extremely low, the excited levels will not be subjected to any appreciable external influences such as Stark-effect broadening, and the measured lifetime will be essentially that of an isolated atom. Reabsorption of the emitted radiation also will be negligible because of the low ion densities. Cascading into the upper levels often occurs, but if the cascading lifetimes are either significantly different from the lifetime of the excited level or the cascading transitions into the excited level do not contribute significantly to the population of the level, reasonable corrections for cascading usually can be made. When only one transition occurs from the excited term, the lifetime measurement is also a direct measurement of the transition probability for the transition.

Several measurements of lifetime have been obtained recently with the foil-excitation technique. Bashkin *et al.*[3] obtained an estimate of the lifetimes of the $2p^4\,{}^2D$ term of Ne IV and the $2p^2\,{}^2D$ term of Ne VI by measuring the decay of the multiplets Ne IV 470 and Ne VI 561 at two positions along the ion beam. This experiment illustrated that the foil-excitation technique could be used to measure lifetimes as short as 10^{-10} sec from the observation of multiplets in the uv with fairly good spectral resolution (approximately 3-Å bandpass) and good spatial resolution along the length of the ion beam. Berkner *et al.*[4] measured the transition probabilities of the $2s$-$2p$ transitions in the ions of the Li-like sequence between C IV and Ne VIII by observing the decay of the uv resonance multiplets with a vacuum monochromator having a bandpass of 32 Å. Bickel and Bashkin[5] obtained the lifetime of the $2p^2\,{}^1D_2$ level in O V by monitoring the decay of the emission line of O V at 1371 Å

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