DECEMBER, 1926 PHYSICAL REVIEW VOLUME 28

POLARIZATION BY ELECTRON IMPACT

By J. A. Eldridge and H. F. Olson

Abstract

If the spectrum excited by low velocity electrons in mercury vapor at low pressure be observed from a direction normal to the electron beam it has been found that many of the lines are polarized (Ellett, Foote and Mohler, and Skinner). Except when the excited atom is in a state having a minimum value for j, the usual theory predicts such polarization, and further indicates that the polarization (electric vector) should be parallel to the electron stream for lines which have $\Delta j = \pm 1$ and normal to the electron stream when $\Delta j = 0$. The observation shows that for the first subordinate series the polarization is in accord with this theory. For the second subordinate series the polarization is always much weaker, and the indication is that the sense of this polarization is not in agreement with that predicted by theory.

Ellett, Foote and Mohler[1] have pointed out that when an electron having the energy required to cause an electronic displacement collides with an atom that the change in angular momentum of the atom (proportional to Δj) must have its vectorial direction in a plane normal to the velocity of the electron. This is quite easily seen. The angular momentum of this impacting electron with respect to any nearby atomic center is in a plane normal to the velocity. Since after collision its velocity is zero, the *change* in the angular momentum is perpendicular to the velocity. So it is for the exciting electron and so it must be for the excited atom.

If the energy is greater than this critical value so that after collision some velocity is retained the angular momentum given to the atom will no longer be confined to this normal plane but may be in directions making considerably less than 90° with the velocity the electron had before striking. Indeed we may suppose that the direction of Δj will be the more nearly in this plane the smaller v and the larger Δj. If Δj is 0 there is no reason to expect selective orientation.

The actual direction of the angular momentum of the atom in space will be given by the vector sum $j_s + \Delta j$ where j_s is the angular momentum of the initial ($1S$) state. j_s is 0, $\frac{1}{2}$ or 1 according respectively to Sommerfeld, Landé and Bohr. Consequently, unless we adopt Sommerfeld's hypothesis, the actual direction of j will depart somewhat from the direction of Δj and particularly will this be the case for small values of j.

[1] Ellett, Foote and Mohler, Phys. Rev. **27**, 31 (1926).

Take the specific case mercury vapor. If the vapor be excited by an electron stream having a velocity higher than the ionizing velocity, the electrons will be displaced from the normal $1S$ orbit to higher orbits and usually to orbits with greater angular momenta and the j vectors will in this excited state be, to some degree of approximation, confined to the normal plane. Exceptions are the nS and np_3 orbits which have the same inner quantum numbers ($\frac{1}{2}$ according to Landé) as the $1S$ orbit. It is probable that this orientation will be more exactly obtained for the $d_1(j=7/2)$, the d_2, D, $p_1(j=5/2)$ orbits than for the d_3, p_2, P and $s(j=3/2)$ orbits.

Granting this approximate orientation it is possible from the correspondence principle to predict the type of polarization. It follows from this principle if $\Delta j=\pm 1$ that the light given out by the atom should be circularly polarized about Δj axis and if $\Delta j=0$ the light is linearly polarized along the j axis (the Δj refers at present to the change occurring in the return of the electron and is not to be confused with the Δj of the former paragraph). We may suppose for simplicity that the Δj of the returning electron is a vector in the same direction as j itself.

If the beam of electrons be sent in the direction v and the tube be viewed perpendicularly to the beam as shown in Fig. 1 the atoms in all

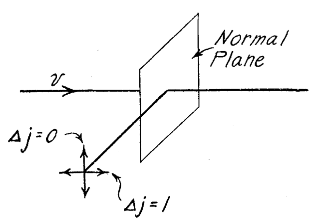

Fig. 1.

states other than nS and np_1 will be oriented according to this theory approximately in the plane normal to v. Transitions from such a state involving $\Delta j=0$ should result in lines polarized perpendicularly to the electron stream. Transitions involving $\Delta j=\pm 1$ which give out light circularly polarized at random directions in the normal plane result, in statistical aggregate, in light polarized parallel to the electron stream. The maximum possible value for perfect atomic orientations will be 100 percent for the perpendicular lines and 33 percent for the parallel.

Ellett, Foote and Mohler excited the line $1S-2p_2$ ($\lambda 2537$) with voltages slightly above the resonance potential and found this line perpendicularly polarized, contrary to theory. Because of the long life of the $2p_2$ state, this polarization is found only at very low pressures and with a neutralized earth's field. Skinner,[2] examining the visible mercury spectrum, found the lines originating in *s* or *S* orbits unpolarized. Those originating in *d* or *D* orbits (with one exception) were polarized in every case parallel to the current.

The present writers have observed the polarization of the lines of the mercury spectrum from λ2400 to λ4400 with greater dispersion than used by Skinner, who was unable to resolve the *d*, *D* levels. The tube used is shown diagrammatically in Fig. 2. A Pyrex tube was lined with a

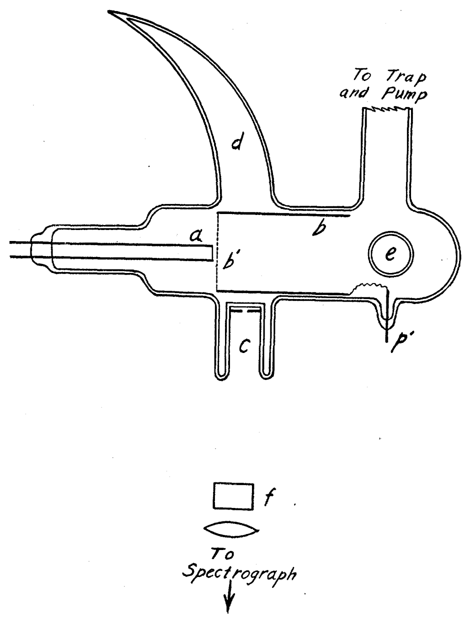

Fig. 2. Diagram of apparatus.

copper cylinder *b* and gauze *b'*. An oxide coated platinum strip *a* electrically heated placed within 1 or 2 mm of the gauze served as a cathode giving a well defined stream of electrons when suitable voltage was applied to *b'*. A well *e* containing mercury could be maintained at any desired temperature. At *c* a reentrant quartz window was sealed to a table containing a suitable diaphragm and opposite it was a light trap *d*. The light through the diaphragm opening was focussed on the slit of a quartz spectrograph being first separated into two oppositely polarized images by means of a Wollaston prism *f*. A large quartz spectrograph, Hilger, 2 meter focus, Littrow mount, was used.

[2] Skinner, Nature **117**, 418 (1926).

For the lines investigated (which did not include λ2537) the amount of polarization is not greatly affected by the vapor pressure even when the mercury is kept at a temperature as high as 60°C. Only when conditions are such that an arc is started in the tube, is the polarization greatly reduced. The results here presented were obtained at room temperature. Since, as one would expect, the polarization is weakened at higher voltages, it was found advisable to work within two volts of the ionization potential. Under the conditions of the experiment the emission is not very strong and exposures of several days were necessary to bring out some of the weaker lines. The results are given in Table I.

TABLE I

λ	Transition	Pol	Δ_j	λ	Transition	Pol	Δ_j
4358	$2p_2-2s$	∥	0	3021	$2p_1-4d_1$	∥	−1
4344	$2P-4D$	∥	−1	2967	$2p_3-3d_3$	Weak ⊥	−1
4108	$2P-4S$	Weak	+1	2925	$2p_1-4s$	Weak	+1
4077	$2p_2-2S$	Weak	+1	2894	$2p_2-3s$	∥	0
4047	$2p_3-2s$	Weak	−1	2848	$2p_2-3S$	∥	+1
3907	$2P-5D$	∥	−1	2804	$2p_1-5d_2$	⊥	0
3663	$2p_1-3D$	⊥	0	2803	$2p_1-5d_1$	∥	−1
3655	$2p_1-3d_2$	⊥	0	2760	$2p_1-5s$	Weak	+1
3650	$2p_1-3d_1$	∥	−1	2753	$2p_3-3s$	Weak	−1
3341	$2p_1-3s$	Weak	+1	2701	$2p_1-5D$	⊥	0
3131	$2p_2-3D$	∥	−1	2700	$2p_1-5d_2$	⊥	0
3125	$2p_2-3d_2$	∥	−1	2699	$2p_1-5d_1$	∥	−1
3027	$2p_1-4D$	⊥	0	2655	$2p_2-4D$	∥	−1
3026	$2p_1-4d_3$	Weak	+1	2653	$2p_2-4d_3$	Weak	0
3023	$2p_1-4d_2$	⊥	0	2652	$2p_2-4d_2$	∥	−1

We have been unable to measure with consistency the polarization of the more weakly polarized lines. Our results agree with those of Skinner to the extent that we find that lines corresponding to transitions from the s or S orbits are polarized weakly if at all. There seemed to be no question as to the polarization in some cases but for the most part, though it is very likely that some small amount of polarization is present, it is not great for these lines and we have not indicated the trace of polarization found in these cases.

According to the theory no polarization is expected in the case of the terms involving S since there is in the theory no reason to expect atomic orientation; no change of angular momentum takes place at the impact. The observation shows that the polarization for these lines is usually certainly very small. The polarization of terms involving s is equally weak and this is less easily accounted for. The value of j in this case is not large and from the theory sketched above we might expect the atomic orientation to be much less perfect in such a case than when a level having a large angular momentum is involved. The difficulty is that in some cases these lines are definitely polarized and in other cases probably polarized slightly and in such cases the polarization is as often as not contrary to the theory. The first line in the table illustrates this point.

Considering, now, lines corresponding to transitions from the $d(D)$ levels, lines of the first subordinate series, one finds in most cases very striking polarization, the one component being often two or three times as strong as the oppositely polarized component. In these cases, which usually involve large values of j, we expect the orientation of the atom to be most perfect and for these lines there is close agreement between our results and those predicted from the theory. Indeed this agreement is perfect except that in the case of transitions from the d_3 level the polarization is weak and our results have not been entirely consistent. The line $2p_3-3d_3$ should be polarized parallel and this line is unquestionably so polarized, though the polarization is not strong. The lines $2p_1-3d_3$ and $2p_2-3d_3$ cannot be observed as they were not separated from the stronger lines $2p_1-3D$ and $2p_2-3D$. The higher members $2p_1-4d_3$ and $2p_2-4d_3$ are polarized weakly and our observations have not been consistent for these lines. This is not very satisfactory, yet it does appear to be in line with our other observations. It should be noticed that the value of j in this case is only 3/2 (Landé) and from the results in the case of the s terms we are led to believe that small values of j are accompanied by weak polarizations and polarizations as often as not contrary to theory.

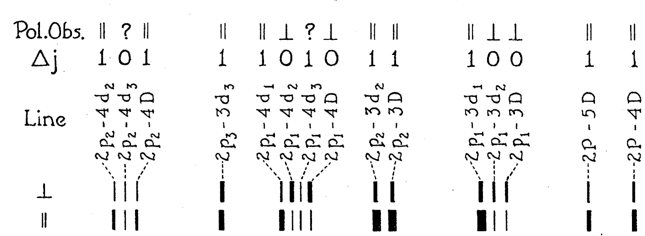

Fig. 3. Graphical representation of results for the first subordinate series of mercury

In Fig. 3 are presented graphically the results in the case of the first subordinate series. We show here the two oppositely polarized spectra, somewhat as they appear in the spectrographs except that the components of the triplet have been separated for the sake of clearness.

It appears that for larger values of j there is a good agreement between our results and the theory. The agreement with the theory for the larger values of angular momentum and disagreement for the smaller reminds one somewhat of the correspondence which so often occurs between atomic phenomena and classical theory for the larger orbits. Whether there is indeed much significance in the generalization which we have made can only be determined by an extension of the work.

Hall of Physics,
University of Iowa,
September 24, 1926.

Note (November 1, 1926). In a recent paper Skinner gives results which are in substantial agreement with those presented in this paper. (Proc. Roy. Soc., October, 1926.) In this paper we have used the concept of Rubinowicz that the atom emits circularly or linearly polarized light according as its angular momentum does or does not change. Skinner invokes the hypothesis of spectroscopic stability to account for the sign polarization. Either theory suffices to explain qualitatively the results in the diffuse subordinate series and neither explains satisfactorily results in other series. However it appears from recent quantitative measurement that in at least one case ($2P$—$4D$) it is possible to obtain a line polarized 60% parallel to the exciting current. The theory as developed above permits but 33% polarization parallel to the current. Indeed such a result seems quite inexplicable by a theory (such as that of Rubinowicz) which assumes the radiation in question is composed of circularly polarized light quanta; such a result supports the hypothesis of spectroscopic stability. To be sure by substituting the concept of elliptically polarized for circularly polarized light the theory given above could probably be made to accomodate this quantitative result.