THE INTENSITY MAXIMA IN THE CONTINUOUS HELIUM SPECTRUM

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Abstract

The position of the maxima of the continuous spectrum of helium was measured with an arc in which measurements of ion concentration was made. The displacement of the maxima to the red by stray fields in the gas was calculated from the formula $E=-2e(eF)^{1/2}$ given by Robertson and Dewey and more recently by Kudar. The observed displacement is always larger than the calculated. Reasons for this are discussed.

IN A paper in this journal[1] H. P. Robertson and the author suggested an explanation of the displacement of the maxima of continuous atomic spectra to the red of the limit of the spectral series. It was assumed that the effect is due to the stray fields set up in the gas by the ions and free electrons, and the least energy for which aperiodic orbits are possible was calculated from the complete formula for the Stark effect on the basis of the classical quantum theory. Kudar[2] has recently obtained the same value for this limit of the continuous spectrum from general reasoning on the basis of the quantum mechanics. It is not possible to carry through the calculation in quantum mechanics as the complete equation is not soluble and is known to give no discrete states unless some restriction is imposed. Since the quantum mechanics must go over into ordinary mechanics for large quantum numbers, or atomic states of energy close to zero, the classical mechanics should give the correct formula for the displacement of the spectral limit. The uncertainty which it introduces lies rather in the fact that it gives no information as to the relative probabilities of the various transitions which are possible.

Experimental Procedure

The spectrum of a hot cathode helium arc very similar to that described in an earlier paper[3] was photographed, with a Hilger E3 quartz spectrograph, and the position of the maximum intensity in the continuous spectra determined with a recording microphotometer. The cathode of the arc was a cylinder of platinum foil, coated with barium oxide and heated by a current put through it lengthwise. A Langmuir exploring electrode used to measure the electron concentration was placed in the center of the cylinder with its axis perpendicular to the axis of the cylinder. One photograph on which the intensity of the continuous spectra could be measured was obtained with a

[1] Robertson and Dewey, Phys. Rev. **31**, 973 (1928).
[2] Kudar, Zeits. f. Physik **57**, 705 (1929).
[3] Dewey, Phys. Rev. **32**, 918 (1928).

Schüler tube containing a similar electrode. Even when the exploring electrode was small (1 mm of seven mil wire) the discharge tended to avoid its neighborhood, as could be seen by visual observation of the tube. This was probably due to recombination of the ions on the glass insulation of the electrode and to the cooling effect of the electrode. As the curves from which the electron temperatures and concentrations were obtained were regular and obtained without difficulty, the removal of electrons by the electrode itself cannot have caused a serious disturbance. The most serious difficulty in the measurement of ion concentration was that it sometimes caused a sudden increase in the current which melted the glass insulation from the electrode. The ion concentration which could be obtained in the tube was limited by the heating effect.

Helium was chosen rather than an alkali metal to avoid the possibility of the atomic spectrum being complicated by unresolved bands or continuous molecular spectra. The helium recombination spectra have been observed by Paschen[4] and more recently by Mohler and Boeckner.[5] For purposes of photometric measurement they have the serious disadvantage of being accompanied by bands. Mohler and Boeckner report that the bands are greatly reduced in intensity by the addition of a trace of mercury to the helium but in the discharges used in this investigation this did not appear to be the case. It was not found possible to eliminate the bands in any way except by the reduction of both pressure and ion concentration, which also reduced the intensity of the recombination spectra. The arc was more suitable than the Schüler tube as the bands were strong only when a high current was put through the arc. The tube used by Mohler[6] and by Mohler and Boeckner apparently would give better spectra but has the disadvantage that the ion concentration must be measured by an indirect method. Probably the bands were weakened on the one plate taken with a Schüler tube on which the intensity of the continuous spectra could be measured by some impurity accidentally present. This was the first plate taken with a newly set up Schüler tube and all subsequent exposures showed very strong bands. The difficulty of estimating the intensity of the continuous spectrum when bands appear on the plate can be seen on the excellent reproductions which accompany Paschen's paper. The bands are strongest in the neighborhood of the $2p$ limit but the weak bands in the ultra-violet also make measurements on the $2s$ limit difficult. The small dispersion of the spectrograph used made measurements at the $2p$ limit of parhelium impossible. The range of ion concentrations included in these results is small and the estimated fields uncertain but, as it was necessary to discontinue the investigation, it seemed worthwhile reporting such results as were obtained.

Table I gives the results. The field is calculated from the formula of Holtsmark,[7] taking account of the presence of both ions and electrons by doubling

[4] Paschen, Berl. Sitzb. Math. Phys. K. 1926, p. 135.

[5] Mohler and Boeckner, Bureau of Standards Jour. of Research **2**, 489 (1929).

[6] Mohler, Phys. Rev. **31**, 187 (1928).

[7] Holtsmark, Ann. d. Physik **58**, 577 (1919), Phys. Zeits. **20**, 162 (1919) and **25**, 73 (1926). The formula used is $F=3.9n^{2/3}e$. This gives the most probable field. The mean field is somewhat larger.

the electron concentration. This probably gives too small a field. Under "displacement of maximum" the distance in cm^{-1} of the maximum intensity of the continuous spectrum from the limit of the spectral series for zero field

TABLE I

Series limit	Electron concentration	Calculated field (e.s.u. per cm)	Displacement of maximum observed	calculated
$2p$	3.6×10^{12}	0.69	160 cm^{-1}	91 cm^{-1}
$2s$	3.6×10^{12}	0.69	140	91
$2p$	5.1×10^{12}	0.87	175	105
$2s$	9.1×10^{12}	1.3	185	125
$2s$	1.1×10^{13}*	1.4	205	130

* Schüler tube.

is given. From the formula $E=-2e(eF)^{1/2}$ the calculated displacement is obtained, where F is the field and e the charge on the electron.

DISCUSSION

The displacement of the limit observed is in every case larger than that calculated. This is to be expected from the serious error in the electron concentrations introduced by the avoidance of the neighborhood of the exploring electrode by the discharge. Since the intensity of the continuous spectrum increases as the square of the electron concentration the spectrum observed will be essentially the spectrum of the region of the discharge in which the concentration is highest. All other sources of error, both in measurement and in calculation, will probably result in discrepancies in the same direction, but it is probable that this error is so large as to mask all others. One source of error in the calculation may be large. Oppenheimer[8] has pointed out that there is a possibility of dissociation, and therefore of recombination on the basis of the new mechanics even when the energies of the ions and electrons do not permit it according to classical mechanics. The general argument that the results of the two types of mechanics must approach each other for large quantum number makes it improbable that this introduces serious error, although it is conceivable that it might. It is not possible to estimate the magnitude of the effect from Oppenheimer's or Kudar's formulae as for the upper excited states of the atom the change in energy due to the field is as large as the total energy of the states even for small fields and cannot be calculated from perturbation theory.

A more complete study of the effect would be desirable, accompanied if possible by a determination of the field in the source by an independent method, such as the intensity of forbidden lines appearing in its spectrum, as it appears to give a reasonably direct method of estimating the ion concentrations in stellar sources.

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[8] Oppenheimer, Phys. Rev. **31**, 66 (1928).