THE PHOTO-ELECTRIC EFFECT OF CAESIUM VAPOR

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Abstract

Long wave-length limit for photo-electric emission from caesium vapor.— Using a special quartz tube and taking precautions to avoid photo-electric emission from the electrodes, a narrow beam of nearly monochromatic light of gradually decreasing wave-length, was focused on the hot caesium vapor, and it was found that above 3220 A the emission was zero, between 3220 and 3145 A the emission changed linearly because of the width of the slit used, and below 3145 A the emission was practically constant. The mean, 3180 A, is taken as the critical wave-length. This is evidently identical with the convergence wave-length 3184.28 A, which is related to the ionization potential V_i according to the equation $V_i = hc/e\lambda_i$. Therefore the separation of an electron from a caesium atom requires the same amount of work whether produced by an impinging electron or by absorption of light.

THE convergence frequency ν_i of the principal series $(1s)-(mp)$ of caesium vapor is given by

$$\nu_i = c/\lambda_i = 3\ (10)^{10}/3.1843\ (10)^{-5}.$$

It has been shown by Foote and Mohler that the ionization potential V_i of caesium vapor is 3.9 volts while the equation $V_i e = h\nu_i$ gives 3.877 volts. If the separation of an electron from an atom of caesium vapor requires the same amount of work, whether carried out by an impinging electron or by absorption of light, then we should expect that light of wave-length 3184.28 A would be necessary to produce the photo-electric effect of the vapor, while light of longer wave-length would give no effect. This conclusion was tested and found to be true by experiments made with caesium vapor by the authors several years ago.[1] During the last winter we have been enabled by the use of a quartz tube with plane parallel end plates supplied to us by the research laboratory of the General Electric Company to repeat the experiments with greater precision.

The experimental determination of the photo-electric effect of metallic vapors and gases involves considerable difficulties. The most serious one consists in the fact that a trace of scattered light within the tube produces photo-electric emission from the metallic electrodes and glass walls covered with alkali metals which is 100 and 1000 times larger than the effect in the vapor itself. Even scattering of the light by the atoms of the vapor is to be feared, but it was found to be absent in the

[1] Williams and Kunz, Phys. Rev. **15**, 550, 1920

experiments to be described. Only small retarding and accelerating potentials can be used; otherwise the moving electrons would acquire sufficient energy to produce ionization by collision. It was thought advisable to measure the positive ions of the caesium vapor, and it was necessary to distinguish between the loss of electrons and the acquisition of positive charges by the plate connected to the electrometer. Surface effects have to be avoided by guard rings, and the thermionic emission from the deposited alkali metal on the electrodes and glass walls must be balanced or separated from a purely photo-electric effect. The temperature of the tube has to be as high as possible, in order that the vapor pressure may be as large as possible, but at high temperatures the caesium vapor begins to attack the quartz, rendering the inner surfaces conductive.

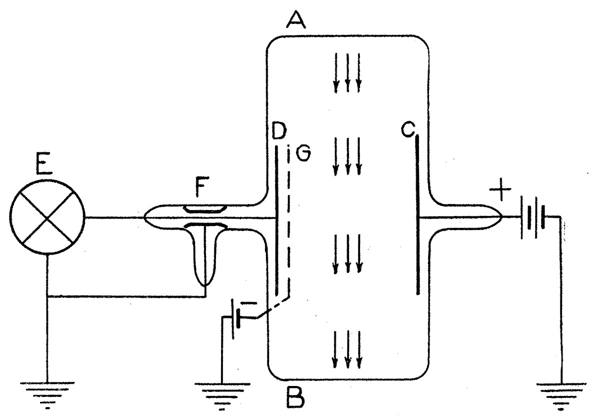

Fig. 1

The Physical Review **21**, 107, 1923, contains an investigation by R. C. Williamson on the ionization of potassium vapor by light. His results are in agreement with our previous observations and with our present experiments. His interesting method suggests the possibility of heating the metallic vapor in a vessel to a considerable temperature, then letting the vapor expand adiabatically and subjecting it to light of frequency ν_i. Condensation might occur as in the corresponding experiment by Wilson.

Apparatus

The essential part of the apparatus used in testing the photo-electric effect of caesium vapor was a quartz tube *AB*, with the necessary electrodes, shown diagrammatically in Fig. 1. The tube, which was 13 cm long and 6 cm in diameter, had plane quartz ends which produced practically no distortion of the light passing through. A guard ring *F* surrounded the electrode D which was connected to the electrometer. The purpose of the grid C was to eliminate the possibility of photo-electric emission from the metal electrode D due to any scattered light that might strike it. The grid G was kept at a negative potential so that no electrons could leave D even though they were produced. The electrodes were of platinum, whose photo-electric threshold is 2800 A, sufficiently removed from the critical wave-length 3184 A.

Light from a Cooper-Hewitt quartz arc was passed through a Hilger quartz prism spectroscope and used as the ionizing agent. The width of the window in front of the tube was such as to permit light of a range of about 80 A to pass through the tube. A quartz converging lens between the window and the tube condensed the rays into a narrow beam.

The arrangement of the detecting part of the apparatus is also shown in Fig. 1. The connections are such that the electron of any ionized atom will go to the plate C and the positive ion to the plate D after passing through the negative grid G, which was of about 5 mm mesh. A few ions, of course, would be lost to the grid. If any light were to fall on the electrode D, negative electrons would be thrown out, and this, it is evident, would produce the same effect on the electrometer as though the plate D were to receive positive ions. Stray light was avoided as much as possible because the photo-electric effect of metals is large compared with that of vapors.

Results

A number of series of readings were taken in most of which the results were positive, i. e., light below a critical wave-length produced a photo-electric effect whereas light above the critical wave-length produced no effect. The procedure was to throw the light on for a given period (from one to five minutes) and then shut it off for the same period, observing in the meantime the drift of the electrometer. Observations were made at temperatures ranging from 140° C to 200° C. In starting any series of readings the first tests were made at 3360 A and 2530 A. It was soon found that the critical region lay between 3250 A and 3130 A. In practically all of the observations it was noted that the effect for the first interval of time, say one half minute, was greater than for subsequent intervals of time.

The first observations were made with light of wave-length well above and well below the critical wave-length. The effect was zero in the former case, quite strong in the latter case.

Tables I and II give the results of two series of readings. The effect at each point is the mean of several readings. In order to obtain the wave-length where ionization takes place, a curve was drawn between the wave-length and the deflection of the electrometer. The results in Table II, which proved to be the most regular, were chosen for this purpose and the resulting curve is shown in Fig. 2. Since the effect

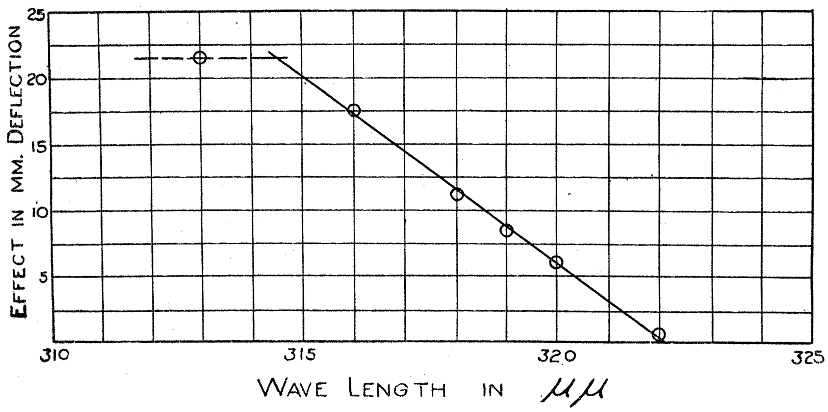

Fig. 2

begins when the edge of the window opening is at the critical wave-length and is a maximum when the entire window has reached that

TABLE I

λ	T	Deflections (5 min. periods)
3130A	140°C	21.3 mm.
3180	140	10.5
3190	140	8.3
3200	140	3.0
3220	140	.9
3250	140	.0
3360	140	.0

TABLE II

λ	T	Deflection (2 min. periods)
3360A	154°C	.0 mm
3250	155	.0
3220	158	.6
3200	160	6.0
3190	160	8.4
3180	160	11.1
3160	161	17.5
3130	161	21.5

point, the position of the critical wave-length as read by the middle of the window opening will be half way between where the effect begins and where it is a maximum. Applying this to Fig. 2 we obtain 3183 A for the critical wave-length or that wave-length above which no ionization takes place and below which ionization does take place. This is remarkably close to the theoretical value, even closer than the experimental sources of error would lead one to expect.

Other curves very similar to that shown in Fig. 2 gave the same critical wave-length of 3180 A. The part of the curve to the left of 3140 A need not necessarily be straight nor parallel to the X-axis but the results of other observations indicate that the effect at 2530 A is not widely different from that at 3130 A.

Our measurements therefore show that λ_i is between 3160 and 3200 A and is probably close to 3180 A. Within the limits of experimental error, this agrees with the convergence frequency 3184.28 A.

If light of the convergence frequency ν_i is able to raise the electron from the level *1s* to the level $\infty\, p$ or clear out of the atom with zero velocity, then the question arises whether light of higher frequency will also produce a photo-electric effect. In this case the electron would leave the atom with an initial velocity given by:

$$\tfrac{1}{2}\, mv^2 = h\nu - h\nu_i$$

Evidently this effect is very different from what we should expect from any classical resonance theory. But that this effect exists is probable from the discovery by R. W. Wood of the absorption band which extends from the convergence frequency toward higher frequencies. But even if it is found that the photo-electric effect exists for frequencies higher than ν_i, the question still remains whether the whole absorption of light is due to the photo-electric effect or whether the photo-electric effect is only an accompanying effect of absorption. In the former case we would have from the conservation of energy

$$E_a = neV_i = IV_i$$

Where E_a is the energy of light of wave-length, λ_i absorbed per unit time, n the number of electrons liberated per unit time, and I the electronic current. We are engaged in the further test of this equation, which should be independent of the temperature of the vapor. On the other hand, if only a part of the absorbed energy were transformed into electric energy by the separation of an electron from the atom, how could an atom of the Bohr type take up the rest of the energy of frequency ν_i in such a way as to raise the temperature of the gas?

The question of absorption of light is also important in connection with the resonance potential V_r which is given by $V_r e = h\nu_r$ where $\nu_r = c/\lambda_r = (1s) - (2p)$ is the first line of the principal series. Theoretically two resonance potentials are possible corresponding to the two levels p_1 and p_2, but so far only one resonance potential has been measured. Moreover we should expect, on the basis of the theory of the Bohr atom, that by means of electronic bombardment of increasing velocity or with light of decreasing wave-length we should be able to detect resonance potentials according to the energy levels *3p*, *4p*, *5p*. . . . With each higher resonance potential one to two more lines should be emitted and when finally ionization sets in, all lines of the principal series should be given out. Experiments in this direction are still in progress.

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