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THE IONIZATION OF POTASSIUM VAPOR BY LIGHT.

BY R. C. WILLIAMSON.

ABSTRACT.

Photo-ionization of potassium vapor by ultra-violet light to λ 1850 Å.—(1) *Jet method.* To insure that the light was not appreciably absorbed before it reached the vapor under observation, and to reduce thermionic and photo-electric emission to a minimum, a tube was used in which a jet of potassium vapor was directed from a heating chamber into the vacuum observation chamber (pressure about 10^{-4} mm.) and was there condensed on the walls, while a carefully diaphragmed beam from a quartz mercury arc was directed through the jet into a conical light trap. The presence of positive ions in the illuminated vapor was determined bv means of the usual accelerating and retarding electric fields. (2) *Variation with wave-length.* By the use of a series of screens, the long wave-length limit for ionization was found to be between 2,800 and 3,100 Å., in agreement with the limit, 2,856 Å., calculated from the ionization potential by means of the quantum relation. No positive ions were obtained when the radiation was limited to wave-lengths greater than 3,100 Å. or when the jet was intercepted by a sliding shutter. As the wave-length was decreased below 2,800 Å., the ionization rapidly increased in amount; being apparently a continuous function of the wave-length. (3) *Variation with pressure* of the vapor in the jet was found to be linear. (4) *Proportion of exposed atoms ionized* was computed to be roughly 1 in 10^{10} for an exposure time of 10^{-5} seconds or 1 in 10^5 per second for continuous exposure.

Photo-electric emission from potassium metal.—The electrodes, being coated with potassium, gave a photo-electric emission as a result of scattered light, which had to be corrected for in the measurements for the vapor jet. *The long wave-length limit* occurred quite consistently at 4,500 Å.; but there were indications of increased sensitivity below 3,000 Å. These results agree with the view that the limit is the same as for the vapor, provided the emissions observed for wave-lengths 3,000 to 4,500 Å. are due to impurities. A rough calculation indicates that the *proportion of exposed atoms ionized* was about the same as in the case of the vapor, for the same light intensity.

Series of ultra-violet absorption screens, transmitting to various short wave-length limits from 4,000 to 2,300 Å., including various solutions and glasses, are described and a spectrogram showing the transmission of each is reproduced.

EXPERIMENTAL results relative to the ionization of metallic vapors by light have been very meager,[1] and it is difficult to point to any

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[1] Hughes, Bull. Nat. Res. Coun., 2, p. 86, 1921.

phenomena which are due, without doubt, to ionization by radiation of optical frequencies. Steubing[1] describes ionization of mercury vapor by light transmitted through fused quartz, but his results probably are to be explained as ionization in the vapor by collision of photoelectrons from the electrodes. Anderson[2] and Gilbreath[3] have published results obtained in potassium vapor which, however, can be accounted for by wall emission. Kunz and Williams,[4] in a brief abstract, state that while cæsium was not ionized by radiation of wave-lengths greater than 3130 Å., a marked effect was secured at 2,530 Å. No details as to the method seem to have been published.

In estimating the range of wave-lengths which must be used in order to secure ionization, a generalization of the quantum relation has been used by many writers. The equation $Ve = h\nu$, where V is the voltage corresponding to the energy of the electron, e the electronic charge, h the quantum constant, and ν the frequency of radiation, finds application in the field of x-rays, in calculating the maximum frequency of radiation excited in solids by electrons having energy corresponding to the voltage V. Or, conversely, it also can be used in computing the maximum energy of the secondary electrons liberated from solids by radiation of frequency ν.

Work in the metallic vapors indicates that in the case of the alkali metals the principal series of doublets is radiated when ionization of the vapor by electronic collision occurs, and the limiting frequency of the series is given by the substitution of the ionizing potential in the above equation. Conversely, when it is desired to ionize a vapor by radiation, thus liberating electrons, it is natural to assume that frequencies must be employed which are equal to, or greater than, the above limiting frequency calculated from the ionizing potential. The results of Kunz and Williams in cæsium vapor are at least in accordance with this view. In the case of potassium vapor, the observed ionization potential is 4.1 volts[5] and the corresponding series limit is 2,856 Å.[6]

The experiments here described were undertaken in an effort to secure definite evidence of the ionization of metallic vapors by radiation of optical frequencies and to investigate the ionizing power of the radiation as a function of the frequency.

METHOD.

In preliminary experiments it was found that glass and metals in the presence of potassium vapor at temperatures as low as 150° C. emit

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[1] Phys. Zeit., 10, p. 787, 1909.

[2] PHYS. REV., 1, p. 233, 1913.

[3] PHYS. REV., 10, p. 166, 1917.

[4] PHYS. REV., 15, p. 550, 1920.

[5] Tate and Foote, Phil. Mag., 36, p. 64, 1918.

[6] Hughes, loc. cit., p. 168.

therm-electrons so freely as to mask any ionization currents produced in the vapor by light. Also such surfaces in the presence of potassium vapor, or when covered with solid potassium, may give a marked photoelectric emission if there is any scattered light. The procedure must then be determined so that currents consisting of positive ions due to radiation ionization can be distinguished from these electronic currents.

Absorption of the radiation by the vapor should be limited if possible to the region between the electrodes in order that active wave-lengths may not be absorbed before reaching the electric field.

Where accelerating fields are used, ionization by collision of electrons with the vapor may occur, and such an effect must be distinguished from ionization by radiation.

These considerations led to the adoption of the following method: A jet of potassium vapor *g*, Fig. 1*A*, was directed into a vacuum chamber and condensed partly upon a glass surface *d*, cooled by means of liquid air, and partly upon the walls and electrodes of the chamber. A carefully diaphragmed pencil of light *n* traversed this jet a short distance from the nozzle and then entered a conical glass tube *f* serving as a light trap. A mercury arc in quartz was used as the source of radiation, and absorbing screens could be interposed between the arc and the vacuum

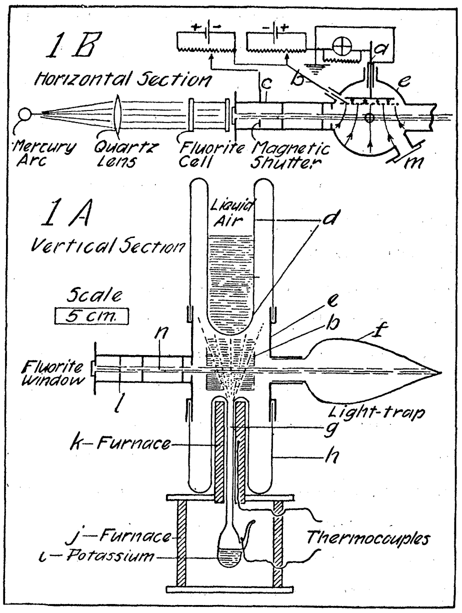

Fig. 1.

chamber. Electrodes were so arranged *a*, *b*, *c*, Fig. 1*B*, that the positive ions formed in the jet could be accelerated through a gauze, there to travel against a suitable retarding field to an electrode connected with an electrometer. Thus it will be seen that the radiation suffered no appreciable absorption till it reached the region between the electrodes, thermionic emission was limited to the parts of the nozzle, and the use of accelerating and retarding fields made it possible to distinguish positive ions from the electrons inevitably present.

Apparatus and Experimental Details.

The liquid air flask *d*, the light trap *f*, and the potassium reservoir and nozzle element *igh*, were all of glass fastened into the brass chamber by means of wax joints. The interior surfaces of the flask *d* and the jet element *h* (save in the tube *g* and reservoir *i*) were silvered and connected electrically to the brass chamber *e* for shielding purposes.

The potassium was distilled two or three times, the final operation carrying it into the reservoir *i*, the inlet tube then being sealed off. The reservoir *i* and the nozzle tube *g* could be heated independently, their temperatures being measured by means of thermocouples.

The sheet copper electrode *a* was provided with split insulation. The gauze electrode was of copper wire, No. 28, 20 to the inch. In both cases care was taken to provide flanges to protect the insulation from vapor scattered diffusely by the nozzle. The walls of the chamber itself served as the third electrode in most of the observations. The accelerating field V_a then was from the walls *ce* to the copper gauze *b*, and the retarding field V_r from the gauze *b* to the electrode *a*, Fig. 1*B*.

A magnetic shutter *l* was placed close to the fluorite window to protect it from scattered vapor while observations were not being made.

In one run, a sliding shutter (not shown in figure) placed over the nozzle of the jet made it possible to take readings with practically no vapor present, without waiting for the reservoir to cool down.

A side window of quartz *m* was provided as shown in Fig. 1*B*, so that the electrodes could be illuminated directly.

A Compton electrometer shunted with high resistances was used, the sensitivity in most cases being approximately 2,000 mm. per volt.

The arc was a Cooper-Hewitt quartz arc, running on about 73 volts and 4.0 amp.

A quartz lens, $F_{(5,890\text{Å.})} = 7.9$ cm., was used with the arc at about the principal focus for 3,000 Å. to direct the light through the diaphragms.

Fig. 2 shows approximately the limits of the spectra transmitted by the absorbing screens, which gave a fairly regular series of steps from

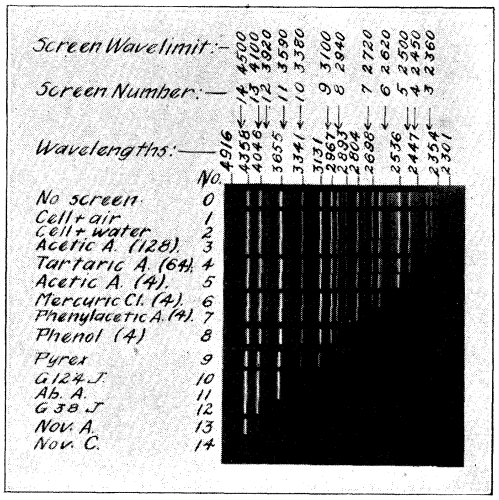

Fig. 2.

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4,500 Å. down to 2,360. The transmissions of the screens through the whole spectrum were not measured. Care must therefore be taken in interpreting the curves obtained with these screens, owing to gradual transition at the boundaries and possible absorptions of from 10 to 50 per cent. in the longer wave-lengths. As shown in the figure, the region from 4,500 to 3,100 Å. was covered by a set of glass screens which had been obtained from the Corning Glass Company. From 3,100 Å. down to 2,360, solutions in distilled water of phenol, phenyl-acetic acid, mercuric chloride, acetic and tartaric acids were used. The figures in parentheses following the substances, Fig. 2, give the number of parts of solution to 1 part of an approximately saturated solution of the substance. The cell was fitted with fluorite windows, the thickness of the fluid layer being 3.2 cm. Suggestions as to proper solutes for this work were due to Mr. Dahm of this laboratory, who will shortly publish more detailed results as to screens for this region.

A liquid air trap was placed between the diffusion pump and the ionization chamber. The pressure during most of the observations was less than 10^{-5} mm. at the gauge. However, since there was a slight leak and some evolution of gas from the different parts, it may have been as high as 10^{-4} mm. in the chamber.

Some trouble was experienced due to unsteadiness of readings at times, the cause of which was uncertain. Thermostats were not used on the furnaces, the heating currents being varied as indicated by the observed thermocouple reading.

It was necessary to work as rapidly as possible at the high temperature used, because the potassium soon distilled out of the reservoir, and the apparatus had to be taken completely apart and cleaned. Therefore no more points were taken on curves than was considered necessary to bring out the main features.

RESULTS SHOWING PHOTO-IONIZATION OF POTASSIUM VAPOR.

Curves *ghi* and *g'h'i'*, Fig. 3*a*, are typical. The former was obtained as follows: Holding the retarding potential constant at 5 volts, the accelerating field was varied and the currents to the electrometer plotted versus the applied accelerating voltages, when the jet was traversed by the beam of unscreened radiation. The terms "accelerating" and "retarding" are used throughout the paper with reference to positive ions. This procedure was then repeated with screen No. 9 interposed, which cut out somewhat gradually wave-lengths less than 3,100 Å., giving the curve *g'h'i'*. Pairs of such curves were obtained for retarding potentials of 1, 5, 10, and 20 volts, as shown by the curves lettered *abc*, *ghi*, *jkl*, and *mno*, respectively, together with the corresponding dotted curves with primed lettering. The data for the 20-volt curves was taken in a different run from the others, with a slightly different arrangement of parts on the interior of the chamber.

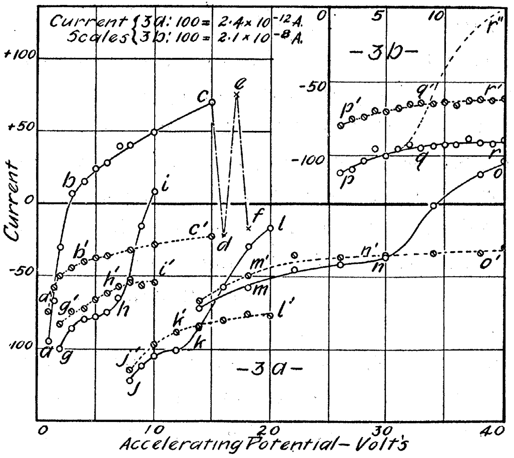

Fig. 3.

Considering the curve *ghi*, we see that beginning at about 2 volts there is a negative current *gh*, which decreases in magnitude, at first rapidly, then slowly, and then shows a decided bend upward *hi* just above 5 volts. The portion *gh* is due to photoelectrons from the gauze which are carried to the electrode *a* by the retarding field, together with some thermions from the nozzle of the jet, and the decrease is due to diversion of some of this current by the accelerating field. The upward bend *hi* is due to the superposition of the positive ions which are driven by the accelerating field through the retarding field to the electrode *a*. If the curve *ghi* were continued to higher voltages, it would turn toward the right again, approaching saturation, as shown in the corresponding part *bc* of the curve *abc*, where the initial portion corresponding to *gh* does not occur, owing to the low voltages.

The potential at which the inflection due to the positive ions appears is not equal to the retarding potential, since these ions start from a point intermediate between the electrodes, and the energy which they acquire in the accelerating field is equal to some fraction of the applied accelerating potential V_a. By extrapolating the portions of maximum slope of the parts *hi*, *kl*, and *no*, to intersect with the continuations of the portions *gh*, *jk*, and *mn* respectively, this fraction is seen to be approximately 2/3 for the greater number of the positive ions.

When the beam of radiation is screened, the negative current *gh* is reduced in magnitude to *g'h'*, because of intensity loss in the beam both by reflection and by the screening out of the region below 3,100 Å. The inflection, however, showing the presence of positive ions has disappeared, and there is no indication of ionization comparable in magnitude with that observed without the screen.

These positive ions are not due to ionization by collision of photoelectrons from the gauze, for the following reasons.

In the case of curves taken at low potentials, it might be true that the interposition of the screen would reduce the initial energy of the photoelectrons from the gauze to such an extent that the energy gained in the accelerating field would not be sufficient to produce ionization, thus producing the difference observed in the screened and unscreened curves. However, even if we suppose that the screen reduces the emission energy of the gauze electrons to zero, the dotted curves should show an inflection as soon as the accelerating potential V_a becomes greater than 3/2 of the ionizing potential, and also greater than the retarding potential V_r. As a matter of fact, also, the majority of the photoelectrons have very low initial energies, so that the curve *abc* should not show strong ionization until $V_a > 6.2$ volts $> V_r$, whereas it approaches saturation at about 3 volts. The inflection due to the positive ions thus depends upon the retarding and not upon the accelerating potential. Slight inflections were observed in some of the screened curves (not published) which occurred around 5 volts, which would correspond approximately to ionization by collision, but they were too small for any definite conclusions to be drawn.

A further test of the above question was made by illuminating the gauze directly so as to make its photo-electric emission of a larger order of magnitude than the emission in the previous observations. The results are shown in Fig. 3*b*. The negative currents here were of the order of 10^{-8} amp. as compared with 10^{-12} amp. in the previous measurements. Curves were taken as before with and without a screen, at a retarding potential of 5 volts. The unscreened curve *pqr* in this case shows no noticeable indication of positive ions formed by collisiom, which would cause a deflection about as shown by the dotted portion *qr''*.

The above curves, then, are considered as conclusive evidence that the ionization of potassium vapor by means of radiation of wave-lengths between about 3,100 Å. and 1,850 Å. (the latter being taken as the approximate lower limit of the quartz arc spectrum) has been obtained.

SCATTERING OF LIGHT BY VAPOR.

In one run as shown at the end of curve *abc*, Fig. 3*a*, the jet was interrupted by means of the sliding shutter over the nozzle. The current then dropped from *c* to *d*. That is, the positive current disappeared, leaving the negative photoelectric current from the gauze. When the shutter was withdrawn, the current rose to the value at *e*, approximately the same as at *c*. Then the screen was inserted and the current again dropped to *f*, showing that the effect of putting in the screen was about the same as that of stopping the jet. This indicates that radiation scattered by the vapor is not an appreciable factor in producing the photo-electric emission from the gauze, and that most of the scattered light is from the diaphragms and the trap. In this connection, it might be noted that if there was fluorescence in the vapor jet, it was not strong enough to be visible. However, conditions were not particularly favorable for the detection of faint fluorescence.

IONIZATION AS A FUNCTION OF WAVE-LENGTH.

The series of filters was then used to investigate the ionizing power of the different portions of the arc spectrum. With the retarding potential set at 1.2 volts and the accelerating potential at 10 volts, readings were taken as the screens were successively inserted in the path of the light, giving the curve *cde* in Fig. 4. The curve *cfg* was taken later, when the

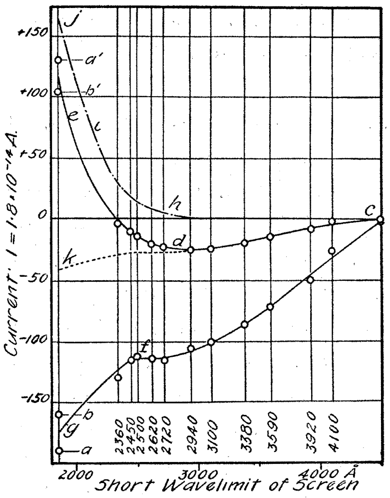

Fig. 4.

potassium in the reservoir was at room temperature, no vapor being present, thus giving the effect of the screens upon the photo-electric current from the potassium-covered surfaces due to scattered light. The current scale does not apply to this curve. The points *a* and *a′* were taken with the radiation unscreened; *b* and *b′* were taken with the empty fluorite cell inserted. The mean of the two was taken as an approximate correction for reflection at the surfaces of the screens. Using this curve, a rough extrapolation of the branch *cd* can be made as shown in the dotted portion *dk*. The ordinates then between *dk* and *de* are a measure of the positive current and are plotted in the broken curve *hij*. This current starts in the vicinity of 2,900 Å. and increases very rapidly as the wave-length decreases. The energy contained in the arc spectrum between 1,850 and 2,360 Å. is probably about equal to that between 2,360 and 2,500, while it is less than 2 per cent. of that between 4,100 and 4,500 Å., according to estimates made from mercury arc energy distribution curves given by Suhrman.[1] Therefore the ionization per unit incident energy seems to be increasing very rapidly as the wave-length decreases. The form of the curve between 1,850 and 2,360 Å. is conjectural, and there is no information as to where a possible maximum would occur. The wave-length at which the positive current begins is somewhat uncertain owing to the characteristics of the screens. Three curves were taken, two at different times with one set-up, and the third with a slightly different internal arrangement, and in all three the positive current sets in between 2,800 and 3,100 Å. This agrees, within the limits of experimental error, with the calculation from the ionizing potential, using the quantum relation, which gives 2,856 Å. as the critical wave-length.

This ionization of the vapor by radiation does not seem to be associated with a resonance phenomenon, such as the absorption of a single wave-length in the vicinity of 2,856 Å. Rather, it appears to be a continuous function of the wave-length, starting near the convergence wave-length of the principal series and increasing quite rapidly as the wave-length decreases, giving a continuous absorption of energy below this limit. It is of interest to note in this connection the region of continuous absorption described by Wood[2] in the case of sodium vapor, which extends from the convergence wave-length of the principal series on down in the ultra-violet, thus corresponding with the region of ionization and probable consequent absorption observed for potassium.

Ionization as a Function of Pressure.

An attempt was made to obtain the current due to the positive ions as a function of the pressure in the reservoir. With the accelerating

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[1] Ann. d. Phys., 67, p. 79, 22.

[2] Phil. Mag., 18, p. 531, 1909.

and retarding potentials set at 10 and 1 volts respectively, readings were taken with and without screen No. 9, as the reservoir cooled down. At low temperatures, the ionization current is very small compared with the additive negative current correction. This probably accounts for the variation of values for the two runs at low pressures, and the intercepts obtained. The results are shown in Fig. 5. The data for the saturated vapor pressures of potassium were taken from a paper by Kroner.[1] The point at 1.5 mm. was taken between the two runs and was used in plotting both curves. The temperatures of the reservoir ranged from 225 to 356° C.

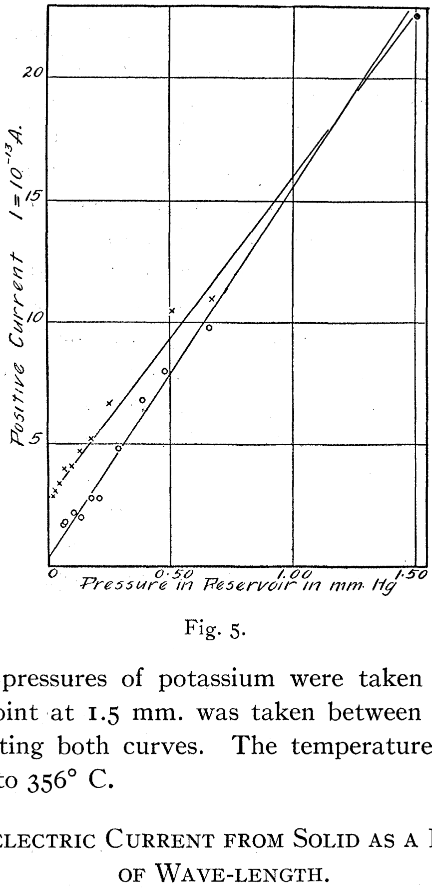

Fig. 5.

PHOTO-ELECTRIC CURRENT FROM SOLID AS A FUNCTION OF WAVE-LENGTH.

Referring to curve *cfg*, Fig. 4, it is seen that the long wave limit under the conditions of these experiments was about 4,500 Å. as compared with about 5,500 Å. which has been obtained in some previous work by Souder[2] and Pohl and Pringsheim[3]. As Hughes[4] states, results are very conflicting as to the long wave limit for solids, and the above seems to be further

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[1] Ann. d. Phys., 40, p. 447, 1913.

[2] PHYS. REV., 8, p. 318, 1916.

[3] Verhand. d. Deut. Phys. Ges., 8, p. 357, 1910.

[4] Loc. cit., p. 102.

evidence to that effect. In several curves taken during these experiments, the limit occurs quite consistently at 4,500 Å. Some of the curves were taken while the jet was active and fresh potassium depositing, and others taken some hours after the jet had ceased, the surfaces standing in the vacuum. However, the vacuum conditions were not of the best, and the pressure was probably at no time lower than about 10^{-4}mm.

There is a rather interesting possibility suggested by the curve *cfg*, Fig. 4. In the absence of accurate data as to the transmissions of the screens throughout the whole range of wave-lengths, the curves may be interpreted in two ways. According to one viewpoint, the wave-length sensitivity of the solid is of the same order of magnitude from about 4,000 Å. down to 2,500, where a minimum occurs, followed by a very rapid rise *fg*. This increase of sensitivity of the solid may correspond to the ionization of the vapor, though it is shifted to somewhat shorter wave-lengths according to the curve. Hallwachs[1] considers that for pure metals the long wave limit should be the same in the solid state as in the vapor, and that currents observed for longer wave-lengths are due to modification of the photo-electric properties of the metal by impurities. Thus the current above 2,900 Å. in this case would be due to impurities present when the potassium was deposited in the vacuum chamber, while the current below 2,900 would represent that due to the pure metal. However, it is quite possible that this increase in current *fg* is due to variation with concentration of the general absorption of the screens throughout the longer wave-lengths. Thus the rise at 2,360 and 2,450 Å. would be due not so much to the additional energy below these limits as to that in the region up to 4,500.

RELATIVE PHOTO-ELECTRIC SENSITIVITY OF VAPOR AND SOLID.

The term "sensitivity" is here used to apply to total emission throughout the solid, rather than to the electrons escaping from the surface. Using results from the above experiments, an estimate can be made as to the order of magnitude of the number of atoms exposed for a second to a given intensity of radiation, for each electron ejected, in the vapor state as compared with that for the solid. Certain assumptions are involved which will be stated. For the vapor calculations, current data is obtained from curve *hij*, Fig. 4, for the region from 2,500 to 1,850 Å. In the case of the solid, it will be of interest to consider two regions of wave-length, that from 3,920 to 3,590 Å. (max. sensitivity in longer wave-lengths), and also from 2,500 to 1,850 Å.. corresponding to the region

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[1] Phys. Zeit., 21, p. 565, 20.

chosen for the vapor. The current data for the solid calculations are taken from curve *pqr*, Fig. 3*b*, together with curve *cfg*, Fig. 4, from which the current distribution with wave-length is taken.

Case 1 — Vapor.

Data:

Wave-length 2,500 to 1,850 Å.
Mass potassium evaporated = 5 g.
Time = 19,800 sec.
Average temp. reservoir = 325° C.
Average vapor pressure in reservoir = 0.7 mm.
Cross section at nozzle of jet = 0.28 sq. cm.
Length of jet tube = 22 cm.
Cross section of pencil of light = 0.20 sq. cm.
Distance nozzle to light pencil = 2 cm.
Current = 3×10^{-12} amp.

Assumptions:

Velocity of discharge equals thermal velocity corresponding to temperature of reservoir.

Limiting cases were determined by assuming:
cylindrical vapor jet distribution, or
cosine distribution as in effusion, where free path is comparatively large;
cylindrical pencil of light, or
rough estimate of actual distribution.

Number of ions formed is proportional to the time of exposure. The time of exposure of each molecule in the jet being about 10^{-5} sec., reduction to 1 sec. exposure is made on basis of porportionality.

Current reaching receiving electrode represents total current, neglecting grid loss and incomplete saturation. This may involve a factor of two or three.

On the above basis, in the case of the vapor, it is calculated that the number of molecules N exposed to the given intensity of radiation for one second, for each ion formed, was between 10^5 (effusion distribution) and 2×10^6 (cylindrical distribution). 10^5 is considered to be more nearly correct for the following reasons: The density at the mouth of the jet was calculated from the mass discharged and the time of discharge as 1.6×10^{-8} g. per c.c. The density in the reservoir, from the vapor pressure, was 0.7×10^{-6} g. per c.c. Hence the free path at the nozzle is comparatively large, being about 1 cm., using argon as a basis. In support of the low pressure obtained at the nozzle may be mentioned a check calculation as to the rate of discharge, using an empirical formula by Knudsen.[1] Substitution of a negligible pressure at the nozzle, and 0.7 mm. in the reservoir, gives about 4 g., which is in good agreement with about 5 g. observed.

Case 2—Solid.

Data: (Notation given below)

Wave-length 3,920 to 3,590 Å.

Current = 3×10^{-9} amp. per sq. cm.

$\alpha = 0.17 \times 10^6$.

$\gamma = 3.75 \times 10^6$ cm.$^{-1}$.

$I_0 = 3I$.

Assumptions:

Photoelectrons produced on the interior which do not emerge can be allowed for by using a method of analysis somewhat similar to that of Compton and Ross.[2] On this basis it is found that

$$n_1 = \frac{\nu I_0}{2}\left[\frac{\gamma}{\alpha^2}\log\frac{\gamma}{\gamma+\alpha} + \frac{1}{\alpha}\right],$$

where

n_1 = no. electrons emergent per sq. cm.

ν = no. of photoelectrons per unit intensity of radiation per cu. cm.

I_0 = intensity of light just inside surface of metal.

I = incident intensity.

$1/\gamma$ = mean free path of electron in metal.

α = coefficient of absorption of light in metal.

Where α is small relative to γ as in the present case, a sufficiently close approximation is obtained upon taking the limit as α approaches zero of the above expression. In which case

$$n_1 = \frac{\nu I_0}{4\gamma}$$

and

$$N = \frac{\text{No. of atoms per cu. cm.}}{\nu I}.$$

γ for platinum is used, since the value for potassium is not known. The two are probably of the same order of magnitude, the free path in potassium possibly being two or three times that for platinum.

α was obtained by extrapolation, using optical constants given by

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[1] Ann. d. Phys., 28, p. 78, 1909.

[2] PHYS. REV., 13, p. 376, 1919.

Duncan.[1] It seems safe to assume a decrease in α for wave-lengths as low as 1,850 Å., in view of the transparency of the homogeneous films obtained by Wood[2] at low temperatures.

The intensity I is assumed to be the same as for the vapor, since the arrangement of the arc and lens was practically the same as in the case of the vapor observations.

The area illuminated was assumed to be of the order of magnitude of 1 sq. cm. This is very approximate, since a gauze was used, which was illuminated directly and by reflection on the reverse side.

The relation $I_0 = 3I$ was obtained by estimating the energy in the radiation from 3,920 to 3,590 Å. as compared with that for 2,500 to 1,850 Å. from the curves of Suhrman, and correcting for reflection by means of data from paper by Miss Frehafer.[3]

Calculations based upon the above data and assumptions give the number of atoms exposed for a second to the radiation I, per electron ejected, as 1.4×10^5.

A similar calculation for the region from 2,500 to 1,850 Å., where

$$\text{Current} = 7 \times 10^{-9} \text{ amp. per sq. cm.},$$
$$\alpha < 0.17 \times 10^6,$$
$$I_0 = I,$$

gives $N = 2 \times 10^4$, which is of the same order of magnitude as for the longer wave-lengths.

Comparing these figures with that for the vapor, we see that they are of the same order of magnitude, and that about one in 10^5 atoms exposed to the intensity of radiation used in the above experiments was ionized per second, whether in the vapor or in the solid state. It seems useless to speculate further in this matter until more accurate results have been obtained. The investigation is being continued.

SUMMARY.

The foregoing results can be summarized as follows:

(1) It is believed that conclusive evidence of ionization of potassium vapor by ultraviolet light has been obtained.

(2) This ionization begins with wave-lengths of about 3000 Å., and increases rapidly and continuously in amount as the wave-length of the exciting radiation decreases from 3,000 to 1,850 Å., the limits investigated.

(3) The wave-length at which the ionization appears is in agreement,

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[1] PHYS. REV., 1, p. 294, 1913.

[2] Phil. Mag., 38, p. 99, 1919.

[3] PHYS. REV., 15, p. 117, 1920.

within limits of accuracy of experiments, with that calculated from the ionization potential by means of the relation $Ve = h\nu$.

(4) The long wave limit of the photo-electric emission from solid potassium, obtained under the conditions of these experiments, was about 4,500 Å., as compared with about 5,500 Å., obtained by other observers.

(5) There was indication of a rapid increase in the photo-electric emission from solid potassium, beginning slightly below the wave-length at which the ionization of the vapor begins. This may be interpreted in accordance with the view that the long wave limit for pure potassium in the solid state is the same as for the vapor, and that the emission observed at longer wave-lengths is due to the action of impurities.

(6) Calculations were made which furnish evidence that the number of atoms exposed for a second to a given intensity of radiation, per electron ejected from an atom, is of the same order of magnitude in the solid as in the vapor state, for wave-length regions corresponding to marked sensitivities in each case. For the intensities used in these experiments, this number was about 10^5.

University of Wisconsin,
Madison, Wisconsin,
August 26, 1922.

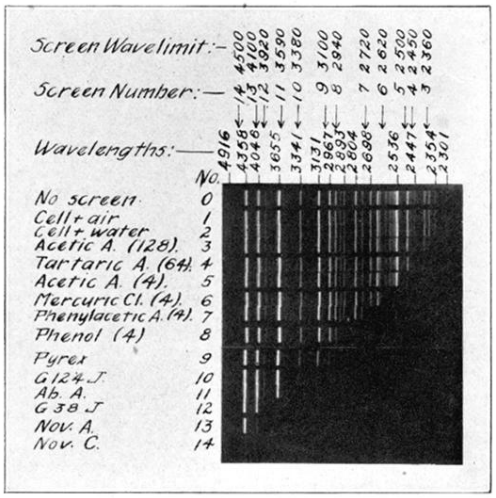
Screen Wavelimit:-
4500
4100
3920
3590
3380
3100
2940
2720
2620
2500
2450
2360
Screen Number:—
14
13
12
11
10
9
8
7
6
5
4
3
Wavelengths:——
4916
4358
4046
3655
3341
3131
2967
2893
2804
2698
2536
2447
2354
2301
No.
No screen 0
Cell+air 1
Cell+water 2
Acetic A. (128). 3
Tartaric A. (64). 4
Acetic A. (4). 5
Mercuric Cl. (4). 6
Phenylacetic A. (4). 7
Phenol (4) 8
Pyrex 9
G 124 J. 10
Ab. A. 11
G 38 J 12
Nov. A. 13
Nov. C. 14

Fig. 2.