THE ABSORPTION COEFFICIENT FOR SLOW ELECTRONS IN ALKALI METAL VAPORS

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Abstract

The absorption coefficient for electrons has been measured in the vapors of the alkali metals, Na, K, Rb, and Cs. Measurements were made with a beam of electrons bent by a magnetic field through a series of slits arranged on a circle so as accurately to determine the velocity. The path length was kept constant while the pressure was varied by changing the temperature of the metal. The actual value of the vapor pressure is not known accurately and consequently the magnitude of the absorption coefficient is a little uncertain. The shape of the curve is independent of this uncertainty. The absorption coefficient for all the alkali metals increases monotonically from high to low velocity except in the region of the critical potentials where a sharp peak is superimposed on the monotonic rise.

THE absorption coefficient for slow electrons has been measured in most of the stable gases. A satisfactory theoretical interpretation of the results has not been possible because the molecules are of complicated structure. Because of experimental difficulties the simplest atom, monatomic hydrogen, can not easily be studied. The alkali metal atoms are in structure similar to hydrogen and the results of measurements on them may be interpreted by the theoretical discussions of the absorption coefficient for electrons in hydrogen.

Apparatus

The apparatus and method employed in this experiment are the same as previously used for the determination of the absorption coefficient in other substances.[1,2] Fig. 1 shows a cross-section of the apparatus. The source of electrons was a 3 mil tungsten filament, F, in the center of a cylinder, C, 7 mm in diameter. A longitudinal slit in the cylinder, S_c, 0.2 mm wide and 5 mm high, let through a fine beam of electrons. This beam passed through a series of slits arranged on a circle 15 mm in radius. The last slit, S_5, was 1 mm wide and 10 mm high. The other slits were 2 mm wide and 10 mm high. The apparatus was made of tantalum as this metal is non-magnetic and does not alloy or react with the alkali metal vapors.

A large pair of Helmholtz coils neutralized the earth's magnetic field. The magnetic field required for bending the electrons in the circular path was produced by a solenoid whose axis was perpendicular to the plane of the apparatus shown in Fig. 1.

[1] R. B. Brode, Phys. Rev. **25**, 636 (1925).

[2] R. B. Brode, Proc. Roy. Soc. August (1929). The same apparatus as used here is described in more detail in this paper.

The apparatus was enclosed in a Pyrex bulb to which a tube for holding the alkali metal was attached. The tube and the bulb were heated by separate furnaces so that the temperature of the bulb could be maintained above that of the tube. The electrical heating wires of the furnaces were wound so that there was no magnetic field resulting from the heating current. The temperature of the bulb and tube was measured by thermocouples attached to copper cylinders which were in close contact with the glass. The thermocouples were calibrated by comparison with a Bureau of Standards certificated thermocouple.

The Pyrex bulb and apparatus were evacuated and baked at 500°C for several hours. Any residual gas in the metal was driven out by heating the metal parts by an induction furnace to a bright yellow. The metal to be studied was prepared in vacuum by heating the purified salt of the metal

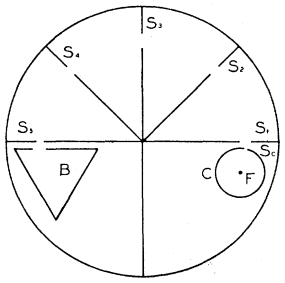

Fig. 1. Diagram of apparatus.

with metallic calcium. Some of the metal thus formed was distilled slowly into the tube attached to the bulb. The apparatus was then sealed off from the pumps. The completeness of the evacuation was shown by the constancy of the results obtained over a period of several weeks. After the measurements were completed with one metal the tube was washed out with dilute HCl and distilled water and then the evacuation process repeated.

The pressure of the metal vapor in the apparatus was determined from the vapor pressure of the metal at the temperature of the tube corrected for thermal effusion between the tube and the bulb. The uncertainty in the absolute magnitude of the values of the absorption coefficients is due almost entirely to the inaccurate values of the vapor pressure constants. The values given by different observers for these constants result in values of the absorption coefficient differing by as much as 2 or 3 fold. The values used here are those given in the International Critical Tables.[3]

Method

The absorption coefficient is determined by use of the equation $I = I_0 e^{-\alpha x p}$ where I_0 is the initial electron current in the beam, I the current at the end of the path x, p the pressure and α the absorption coefficient at unit pressure. It is not possible to measure I_0 under the same conditions as I is measured. For this reason the total emission of electrons through the slit in the cylinder

[3] International Critical Tables, Vol. III, p. 205.

has been used as proportional to I_0. By taking observations at two different pressures the factor of proportionality relating the total emission and the initial current in the beam can be eliminated and the value of α computed. From several determinations, each at a different pressure, identical values of α were obtained. This was found to be true even at velocities corresponding to less than 1 volt accelerating potential.

The velocity of the electrons was determined by the magnetic field used to bend the beam through the slits. Using accelerating potentials between 100 and 400 volts, where the contact e.m.f. was negligible, a linear relation was found between the square root of the potential and the current producing the magnetic field. When plotted, the straight line resulting from this linear relation passed through the origin.

Most of the measurements were made with the filament coated with the alkali metal and emitting at a low temperature. When the filament was heated hot enough to drive off the alkali metal there was a large change in the contact e.m.f. By using the magnetic field to determine the velocity, identical values of the absorption coefficient were obtained at corresponding velocities from both filaments. Because of the very large absorption coefficients for low velocity electrons the pressure of the vapor had to be maintained at about 10^{-5} mm of Hg. The coating of potassium and sodium on the filament could not be maintained when the filament was heated hot enough to give a suitable current for measurements at the lowest velocities. When possible, measurements were made with both types of filament.

Bruche[4] has criticised this simplification of Ramsauer's method as not being capable of results comparable in accuracy with the two-chamber method. The single-chamber method which he uses and describes as "qualitative" can not be expected to give accurate results as the initial current is not measured and any change in the number of photoelectrons emitted due to the introduction of the gas is neglected. The careful study made in the experiments described here, of the relation between the pressure and the resulting values of the absorption coefficient, shows that the simplified method is capable of giving quantitative results throughout the entire range of velocities studied. The two-chamber method employed by Ramsauer and Bruche uses a path about 15 mm long defined by slits 1 mm wide and 10 mm high. The absorption coefficient depends on the length of path and the limiting angle through which an electron can be deflected and still reach the last chamber. Curves with a disagreement in magnitude of 10 to 20 percent, with agreement in form, are described by Bruche as being in contradiction. With measurements of this type not made with the same apparatus some disagreement is to be expected due to a different geometry of the path.

Measurements

The metal was first brought to a temperature giving a suitable pressure while the apparatus was maintained at from 10° to 20° C higher so as to avoid

[4] E. Bruche, Ann. d. Physik **81**, 557 (1926); **83**, 1097 (1927).

condensation on the seals. The accelerating potential was applied between the filament and the cylinder and then the magnetic field varied until a maximum of current was observed by the galvanometer connected to the box B. This maximum was quite sharp at all except the lowest velocities. At low pressure and at velocities corresponding to over 100 volts, more than half of the electrons leaving the cylinder arrived at the box B. The current leaving the slit in the cylinder and that arriving at the box B were measured by galvanometers of a sensitivity of about 10^{-11} amperes per division. In most cases the currents were of the order of 10^{-9} amperes. The two

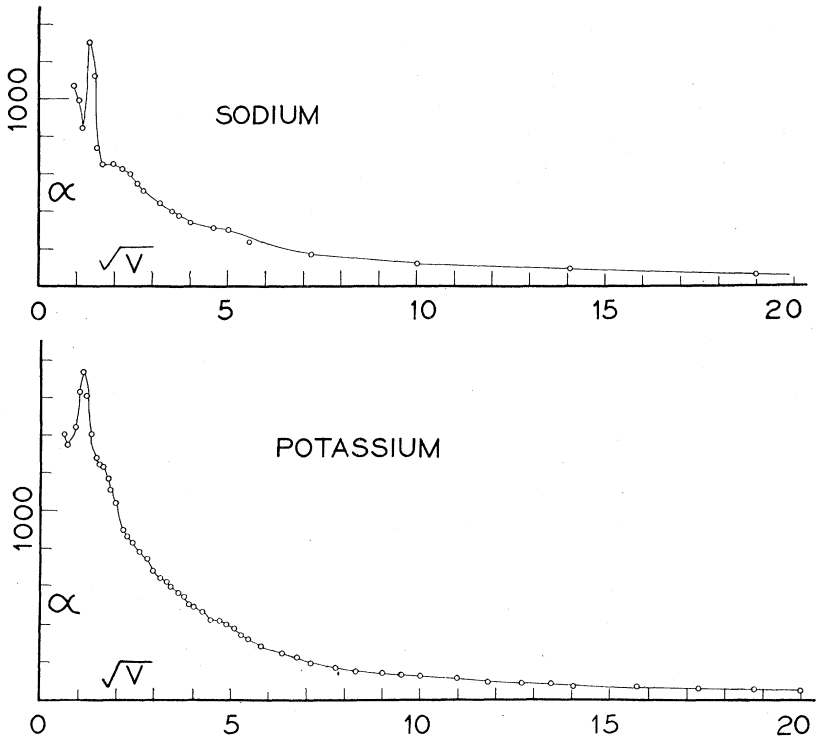

Fig. 2. The absorption coefficient α for electrons in sodium and potassium as a function of the velocity of the electrons.

galvanometer readings, the magnetic field current, the accelerating potential and the temperature of both furnaces were recorded. At each reading the zero points of the galvanometers were observed in order to allow for leakage currents. The efficiency of the guard rings was shown by the fact that with an accelerating potential of 400 volts and with sodium vapor in the apparatus at 300°C only small leakage currents were observed.

The temperatures were then changed and after equilibrium was reached the measurements were repeated throughout the range of potentials used. From 5 to 8 different pressures were used with each metal. The value of α could be computed from readings of the same velocity taken at any two dif-

ferent pressures. The average of the resulting values of α was computed for each velocity and the results plotted in Figures 2, and 3. The value of α is expressed in square centimeters per cubic centimeter of vapor at a pressure of 1 mm of Hg at 0°C. The individual values of α for velocities above 4 volts differed in no case from the average by more than 10 percent. In most cases

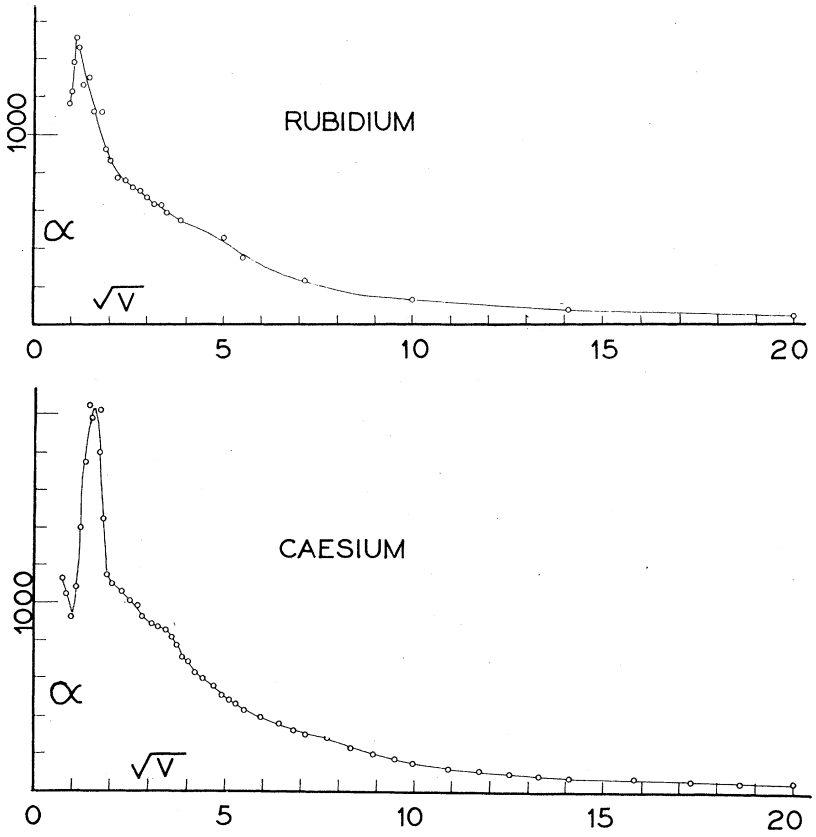

Fig. 3. The absorption coefficient α for electrons in rubidium and caesium as a function of the velocity of the electrons.

this difference could be almost completely removed by assuming that the temperature was measured in error by not more than 1/4° C. Below 4 volts the results were somewhat less consistent but never in greater deviation than 15 percent from the average value.

Discussion

The shape of the observed curves can be described as due to a curve rising monotonically with decreasing velocity to which is added a curve which begins to rise at about the first resonance potential, reaches a sharp maximum and falls rapidly in the region of the ionization potential of the alkali metal. The absorption coefficients of the alkali atoms are much larger than those for

any other materials previously measured. The effective radius of the disk within which the passing electron is deflected out of the beam is given by the relation, radius in angstroms $=0.30\,(\alpha)^{1/2}$. This radius is as large as 10 or 12 angstroms for electrons below 2 volts. Atoms of this size are consistent with the relatively large atomic volumes of the alkali atoms. By either Pauling's[5] or Hartree's[6] method of finding the electron probability distributions, there is an appreciable probability of finding the valence electron between 8 and 10 angstroms from the nucleus.

A treatment of the problem by classical mechanics in terms of the polorization of the atom by the passing electron is difficult. The time of passage is so short that the polarization may not be able to follow the electron. Another difficulty is that the passing electron enters into the same region in which the valence electron is to be found.

Two solutions have been given for the hydrogen atom by the wave mechanics. Elsasser[7] has concluded that the variation of the absorption coefficient with velocity of the electron should consist of a monotonic increase with decreasing velocity superimposed on which is another system of curves begining at the resonance potentials, rising rapidly to maxima and then decreasing with increasing velocity. Oppenheimer[8] by a more general solution has shown that neglecting the polarization effect, the absorption coefficient for electrons in monatomic hydrogen should rise monotonically with decreasing velocity. With a complete solution in which the polarization is introduced it would be reasonable to expect that a type of resonance effect would appear in the region of the critical potentials as is here actually observed.

[5] L. Pauling, Proc. Roy. Soc. **A114,** 181 (1927).
[6] D. R. Hartree, Proc. Cam. Phil. Soc. **24,** 89 and 111 (1928).
[7] W. Elsasser, Zeits. f. Physik **45,** 522 (1927).
[8] J. R. Oppenheimer, Phys. Rev. **32,** 361 (1928).