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ABSORPTION COEFFICIENT OF HELIUM FOR ITS OWN RADIATION

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Abstract

The absorption coefficient of helium for its own radiation in the extreme ultra-violet was measured for various pressures. In the range of pressure from 0.016 to 0.040 mm Hg the mass absorption coefficient was found to be 1.24×10^7. For lower pressures the mass absorption coefficient increases rapidly with decrease in pressure.

Introduction

THE coefficient of absorption of gases for their own radiation is a subject of great importance in atomic theory. It is related both to the lack of sharpness of spectral lines and to the duration of the excited state of the atom. For a theoretical discussion of this subject reference may be made to an article of A. E. Milne.[1] Other recent contributions are by Hughes and Poindexter[2] (the determination of the absorption coefficient of helium) and by Goos and Meyer[3] on the resonance radiation of mercury.

The object of our experiments was to determine the absorption coefficient of helium for its own line $1S-2P$ of wave-length 584.4A.

Lyman[4] found that when the helium spectrum is excited by a continuous current discharge the line $1S-2P$ is by far the strongest shown on the plate. In addition to this line, only the principal series lines $1S-mP$ are strongly excited. If therefore we produce radiation in helium by electronic bombardment at a voltage lower than the excitation potential of the line $1S-3P$, we can expect that practically all the radiation will have the wave-length 584.4A. There is a further advantage in working with low voltage excitation since, even in the absence of any definite information on the subject, it is to be expected that spectral lines excited by low voltage electronic bombardment in a gas at low pressure will be sharp. This is of some importance because it is well known that absorption of resonance radiation varies greatly over the range of wave-lengths usually called a spectral line.

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[1] A. E. Milne, Phil. Mag. **47**, 209 (1924).

[2] Hughes and Poindexter, Phys. Rev. **23**, 769 (1924).

[3] Goos and Meyer, Zeits. f. Physik **35**, 803 (1926).

[4] Lyman, Astrophys. J. **60**, 1 (1924).

APPARATUS AND METHOD

The method was essentially the following: Radiation was allowed to pass through a tube filled with helium and to fall on a nickel disk connected to a sensitive electrometer. The photo-electric current was measured by noting the time necessary for a given electrometer deflection and the intensity of radiation was assumed to be proportional to this current. The gas was then pumped out and the photo-electric current measured again. The ratio of the two currents was assumed to be equal to the ratio of the respective intensities of radiation. Although it is true that the photo-electric sensitivity of nickel may vary with pressure of gas, the fact that the ratios obtained under certain conditions were independent of the heat treatment of the nickel disk in vacuum shows that the variation is small.

Let d be the length of the absorption tube and I_2 and I_1 the respective photo-electric currents, then the linear absorption coefficient α can be computed from the relation

$$\alpha=(1/d)\log_e(I_2/I_1) \tag{1}$$

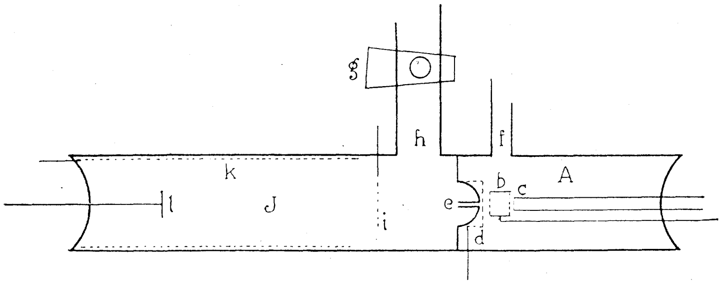

Fig. 1. Diagram of apparatus.

Since no material is known, which transmits radiation of the short wave-length investigated, it was necessary to introduce the radiation into the absorption tube through a fine capillary. The details of construction of the tube will be apparent from Fig. 1. In part A, electrons from the tungsten filament c (0.18 mm diameter) were accelerated by means of a suitable voltage applied to the nickel cylinder b (2 cm in diameter and 2 cm long). These electrons excited radiation inside the cylinder by collision with helium atoms. A fine nickel gauze d (mesh 70) was kept at -14 volts with respect to the negative end of the filament in order to prevent electrons from reaching the absorption tube J. Radiation passed into the absorption tube through a capillary tube e (1 mm in diameter and 1.2 cm long). A nickel disk l (18 mm diameter) was connected to the electrometer which served for measuring the intensity of radiation. The collecting electrode *k* was kept at +10 volts. A grid of tungsten wire *i*, kept at −18 volts, collected any positive ions that might be present.

The absorption tube *J* was connected by glass tubing of large diameter with a set of mercury vapor diffusion pumps. A large bore stop-cock *g* made it possible to change the pressure in *J*. The high pressure side of the mercury vapor pumps was in turn connected with *A*. Three liquid air traps with charcoal at the bottom were placed between the pumps and *A* to insure the purity of helium when it was circulated. A liquid air trap and a tube with charcoal immersed in liquid air was also interposed between *g* and *J*. This is not shown in the diagram. The whole apparatus could be evacuated by another set of mercury vapor pumps backed by a Cenco oil pump.

The electrometer used in the experiments was of the Compton type. With 96 volts on the needle it had a sensitivity of 4400–9000 scale divisions per volt, depending on adjustment. The scale distance was 1.4 meters. As it was unnecessary to know the sensitivity it was tested only occasionally and used for computing the order of magnitude of the photo-electric currents obtained.

The tube was baked for several hours before readings were taken and the nickel cylinder *b* and disk *l* were out-gassed by means of an induction furnace. The helium was purified in a tube with charcoal immersed in liquid air before being admitted to the apparatus. A series of readings was then taken at various pressures.

The measurement of the absorption coefficient itself consisted mainly in the following procedure. Stop-cock *g* being kept closed, the radiation was excited in *A* and the photo-electric current to *l* was measured. Under these conditions the pressure in *A* and *J* was the same. Consequently, radiation leaving the capillary was partially absorbed before reaching *l*. Stop-cock *g* was then opened and the photo-electric current measured again. With the arrangement of apparatus that was used, the pressure in the absorption tube then dropped to 1/30 its former value while that in *A* remained nearly constant. Radiation leaving the capillary was therefore the same, but, as the absorption in *J* was less, the photo-electric current was greater. The linear absorption coefficient was then evaluated with the aid of Eq. (1).

As there was a drop in pressure along the capillary, the length *d* in Eq. (1) was measured from the nickel disk *l* to the mid-point of the capillary. It was found to be 16.5 cm. The correction to be added to the voltage applied to *b*, to take account of initial electron velocities and contact potential differences, was determined by plotting the voltage current curve for *b* and noting the ionization voltage. The current to *b* used in these experiments was about 10^{-3} amp. The order of magnitude of the photo-electric currents was 10^{-14} amp. The electrometer leakage current was also observed during the experiments and, whenever necessary, the measurements were corrected for this effect.

Results

The linear coefficient of absorption α divided by the pressure in the absorption tube expressed in mm Hg gives a quantity β which is obviously proportional to the mass absorption coefficient, as all measurements were taken at room temperature. The quantity β is also proportional to the contribution of individual atoms to absorption.

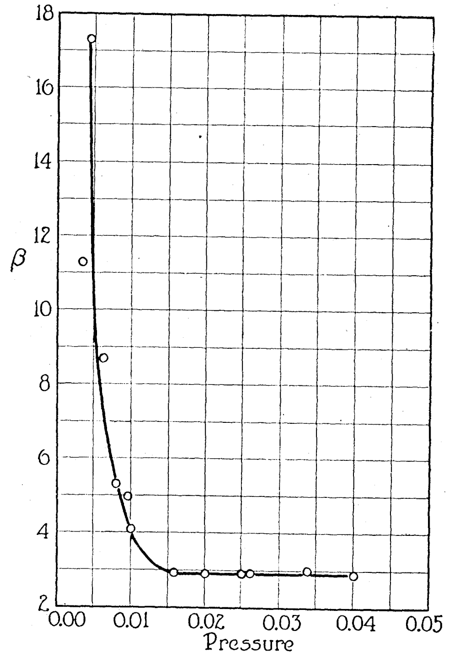

Fig. 2. Absorption coefficient as function of pressure.

Fig. 2 gives the results of observations taken. The quantity β is here plotted against pressure. If the radiation could be regarded as monochromatic and if the probability of absorption of individual atoms did not depend on pressure or on the molecular fields of other atoms, β would be constant. From the diagram, however, it is seen that below a pressure of 0.016 mm Hg β increases rapidly with increasing pressure. In the range of pressure from 0.016 to 0.040 mm Hg β is constant within the errors of observation.

Its mean value in this range was computed from the following observations:

p:	0.040	0.034	0.026	0.025	0.020	0.020	0.016
β:	2.89	3.00	2.92	2.92	2.87	2.86	2.97

mean 2.92 ± 0.05

These values were obtained with 22 volts applied between the negative end of the filament and the nickel cylinder. As the correction to be applied varied between 0 and +0.7 volt, this is seen to be well below the excitation potential of the line $1S-3P$ which is 22.97 volts.[5]

The values of β for lower pressures are less accurate than for pressures above 0.016 mm Hg. The reasons are, first, the relatively greater correction for leakage current, and second, the increased proportion of impurities present. In general, impurities were found seriously to affect the observations and satisfactory results could only be obtained when careful precautions were taken to insure the purity of helium. This applied in particular to the necessity of eliminating mercury vapor.

Measurements were also made with bombarding voltages other than 22 volts. As the cathode was not equipotential, no exact results could be expected. It was however found that when the voltage approached the ionization voltage, the absorption coefficient decreased. At voltages below 21 volts the absorption coefficient was also much less.

Interpretation of Results

From the method of evaluating the results it follows that they give merely the difference of absorption between helium at a certain pressure and at 1/30 of that pressure. If absorption were independent of pressure it would be easy to calculate the total absorption coefficient. However, since the absorption coefficient varies with pressure the amount of the necessary correction is uncertain and therefore has not been calculated.

Radiation* entering the absorption tube has already been filtered by passing through a certain mass of gas. The increase of the absorption coefficient for low pressures shows the presence of a component for which the absorption is very strong. The fact that the absorption coefficient was found constant in a considerable range of pressure indicates that sufficiently filtered radiation would have an absorption coefficient independent of pressure. No certain conclusions could however be

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[5] Cf. Sommerfeld, Atombau 4th ed., p. 522.

* The objection might be raised that our results were due to excited helium atoms rather than radiation. Since, however, the electrometer current was very small for bombarding voltages lower than that corresponding to the line $1S-2P$ and since a constant value of the absorption coefficient hardly could have been obtained if the effect of excited atoms was appreciable, this is not believed to be the case.

drawn as the measurements could not be extended to higher pressures. It should be stressed that the radiation used was always produced with the gas at the same pressure as that for which absorption was measured.

The mass absorption coefficient of the filtered radiation was determined as $(1.24 \pm 0.02) \times 10^7$. The limits of error here given cannot be claimed to have any absolute significance, but merely indicate how closely the measurements could be repeated.

If we wish to regard the individual helium atoms as disks or spheres absorbing all incident radiation of the particular wave-length considered, the diameter of the spheres would be 1.2A. This value is of the same order of magnitude as the diameter of the electronic orbits in helium. For lower pressures however, where the coefficient of absorption is higher, the diameter of the equivalent disk or sphere by far exceeds the diameter of electronic orbits, obviously presenting difficulties for the picture of absorption of radiation given by the theory of light quanta.

We wish to express our thanks to Professor C. B. Bazzoni for advice with regard to construction of apparatus and his interest in this investigation.

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