**Physics.** — *Optical determination of the sphere of action of the He atoms for electrons.* By L. S. ORNSTEIN and W. ELENBAAS. Communication from the Physical Institute of the University of Utrecht.)

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The sphere of action of the *He* atom is determined from the reduction in intensity, of the heliumlines with increasing distance from a grid in a field-free space.

## § 1. *Method.*

By the measurement of the excitation function of *He* in a field-free space of cylindrical form, we observed that the light intensity decreased with increasing distance from the grid through which the electrons passed into the field-free space. It appears that this reduction originates in collisions of electrons with *He* atoms, whereby the electrons are deflected from their paths or suffer a reduction in speed. If this is the case then the mean free path of the electrons in *He* gas can be determined by measuring the intensities of the lines at different distances from the grid.

The arrangement which was used here was the same as that used in the measurement of the excitation function, with the difference, that now the observation slit of the cylinder was set vertical, whereby it was possible to project an image of the total length of this slit on the slit of the spectrograph with an achromatic lens.

In order to reduce the passage of the lines of force through the observation slit, the anode was wrapped with thin wire in front of the slit, the windings being 1 or 2 mm. apart. These windings made it much easier to obtain a sharp image of the observation slit on the slit of the spectrograph. In this manner we obtain long lines on the plate, and these lines were devided by the image of the windings in several places. Every line was photometred in several of the spaces between two windings. These windings made it easier to identify the same place on every line. In order to calculate the relation between density and intensity the method of variation of the slit width was used, with a lamp giving a continuous spectrum.

## § 2. *Measurements with a cylinder of 15 mm. length and He pressure 0.1 mm.*

If we call the intensity of the light 100 at the beginning of the space (where the electrons enter), then we find for an electron velocity of 30 and 76 Volt, respectively, the values given in Table I for distances of 2.47, 5.45, 9.05, 11.27 and 13.5 mm.

TABLE I.

| $A^\circ$ \ $x$ | 30 Volt 0 | 2.47 | 5.45 | 9.05 | 11.27 | 13.5 | 76 Volt 0 | 2.47 | 5.45 | 9.05 | 11.27 | 13.5 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5876 | 100 | 68 | 43 | 26.5 | 21.5 | 17 | 100 | 76.5 | 50.5 | 35.5 | 31.5 | 27.5 |
| 5016 | 100 | 66 | 41.5 | 30 | 24.2 | 19.1 | 100 | 73 | 51 | 35.5 | 30 | 25 |
| 4922 | 100 | 73.5 | 47 | 31 | 26.6 | 21.5 | 100 | 81.5 | 60 | 42.5 | 35 | 30.5 |
| 4713 | 100 | 71 | 42.8 | 35 | 29.8 | 24.8 | 100 | 80 | 61.5 | 46.5 | 46 | 45 |
| 4472 | 100 | 71.5 | 43 | 31.5 | 24.5 | 19.2 | 100 | 68.5 | 43.5 | 32.5 | 26 | 21.2 |
| 4438 | 100 | 70 | 43.8 | 29.7 | 24.4 | 20.6 | 100 | 70.5 | 46.5 | 36.5 | 31.5 | 29.4 |
| 4388 | 100 | 66 | 40.5 | 29 | 24.2 | 19 | 100 | 65 | 42.5 | 32 | 25 | 20.3 |
| 4026 | 100 | 63 | 40 | 28.2 | 21.5 | 17.6 | 100 | 71.5 | 49 | 35.5 | 29 | 24.5 |
| 3965 | 100 | 73.5 | 43 | 29.5 | 24.3 | 19 | 100 | 67.5 | 44 | 31 | 25.5 | 20.5 |
| 3889 | 100 | 73 | 48 | 33.2 | 26 | 21 | 100 | 74 | 52 | 39.5 | 33.7 | 28.5 |
| Mean | 100 | 69.7 | 43.3 | 30.4 | 24.7 | 20.8 | 100 | 72.8 | 50.1 | 36.7 | 31.3 | 27.3 |

In the abscence of any subsidiary phenomena, we can expect that the intensity along the observation slit falls off as $e^{-\frac{x}{\lambda}}$, where $x$ is the coordinate in the direction along the slit, and $\lambda$ is the mean free path of the electrons in helium.

If we plot the mean value of the intensity of the lines on a logarithmic scale against the distance from the grid, we expect to obtain a straight line, from the inclination of which $\lambda$ can be calculated. In fig. 1 this is shown for 30 Volts. The first part of this line is straight, but at greater distances from the gird the measured intensity becomes greater than that of the extrapolated straight line ; the measured points are shown thus 0. In order to explain this we tried to apply the theory of back diffusion as it has been developed for the passage of electrons through metal foil. From this we find for the electron density at a distance $x$ from the grid :

$$E = \frac{E_0\,(1+p)}{1-p^2e^{-2\alpha\xi}}\,(1 - p\,e^{-2\alpha(\xi-x)})\,e^{-\alpha x} \quad [1])$$

$p =$ constant of back diffusion.
$\alpha =$ absorption coefficient
$\xi =$ total length.

For the part which depends on $x$ we may write:

$$e^{-\alpha x} - k\,e^{\alpha x} \text{ (where } k \text{ is } p\,e^{-2\alpha\xi}).$$

[1]) Wien, HARMS, Handb. d. Exp. Phys. **14**, 363.

From this it is clear, that the back diffusion cannot explain the deviation from the straight line, because it gives a deviation in the opposite direction.

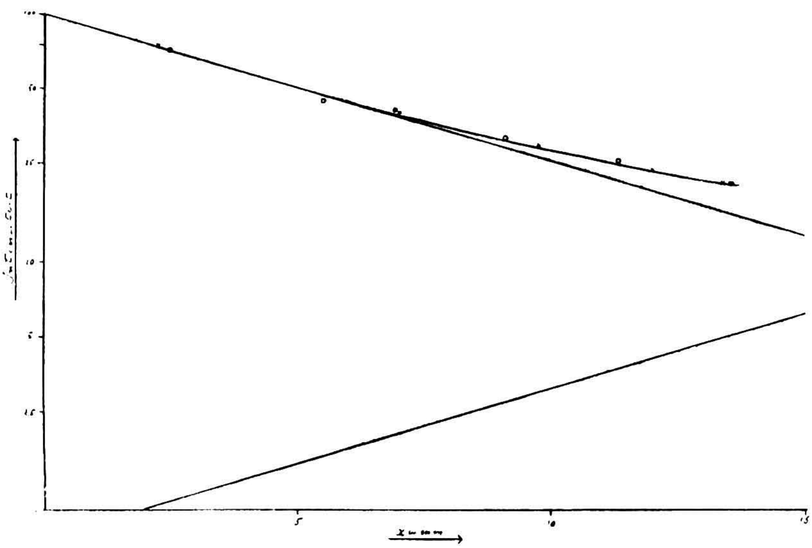

Fig. 1.

Also the assumption that a part of the electrons is scattered backwards and a part forwards cannot explain the effect.

A further possibility of explanation lies in the reflexion of electrons from the surface and within the metal (in our case *Ni*) at the end of the cylinder. For 30 Volts electrons the total reflexion is about 50 % [1]).

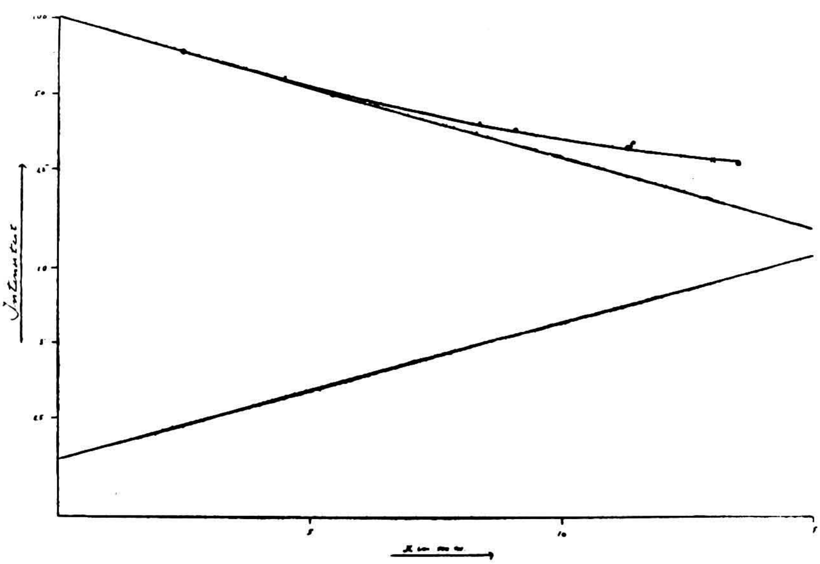

Fig. 2.

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1) Wien, HARMS, Handb. d. Exp. Phys. **14**, 342.

We assume thus that the secondary current from the end of the cylinder is half that of the incident current, and that this electron current is reduced in the same way as the primary current.

If we now add the densities of the original and reflected currents we find the points which are shown in fig. 1 by crosses. As is seen, these crosses lie on the experimental curve.

In fig. 2 the same is shown for 76 Volt. Here we must assume a reflexion of 80 %, which is in good agreement with previous experiments. The current density therefore falls off on account of collisions with *He* atoms in exponential form. From the straight line of Fig. 1 we find for the mean free path for 30 Volt electrons in helium at a pressure of 0.1 mm.

$$\lambda_{30} = 0.72 \text{ cM.}$$

and from the straight line in fig. 2

$$\lambda_{76} = 0.78 \text{ cM.}$$

The fact that the mean free path for 76 Volt electrons is greater than that for 30 Volt electrons agrees with the experiments of RAMSAUER.

### § 3. *Measurements with a cylinder of 35 mm. length and a He pressure 0.1 mm.*

In order to test further whether the deviation from the straight line is due to reflexion of the electrons, measurements were made with a longer anode cylinder. The pressure was again 0.1 mm.

One can expect that in this experiment the deviation of experimental curve from the straight line is first to be seen at greater values of the abscissa (it should appear at about the same distance from the end of the cylinder).

The result for 30 Volt electrons is shown in fig. 3 (here the mean value of different lines is again used). We see here that the points lie on a straight line to within 20 mm. from the grid. This shows thus that the deviation from the straight line is indeed not dependent on the action of the gas, but on the dimensions of the cylinder.

At the beginning of the cylinder a noteworthy effect is to be seen. The intensity of the lines first increases and then falls off exponentially. This fact can be explained if one assumes that a diffusion of the field takes place through the grid. At the beginning of the cylinder the electrons have a smaller velocity than that of 30 Volts, and therefore have a smaller probability of causing excitation. As is shown in a former publication, the excitation function of the lines falls off rapidly under 30 Volts. If we assume that the diffusion of the field has a value 4 Volts then this effect is explained. We can test this explanation by an experiment with 36 Volts electrons. Because the excitation curves does not increase for all lines from 32 to 36 Volts this effect, if we take a mean over all the lines, must no longer be observed, and this is actually the case.

In order to determine the electron-density from the intensity we must take account of this alteration of he electron velocity from 32 to 36 Volts for values of $x$ from 0 to 8 mm. (we see from fig. 3 that the diffusion takes

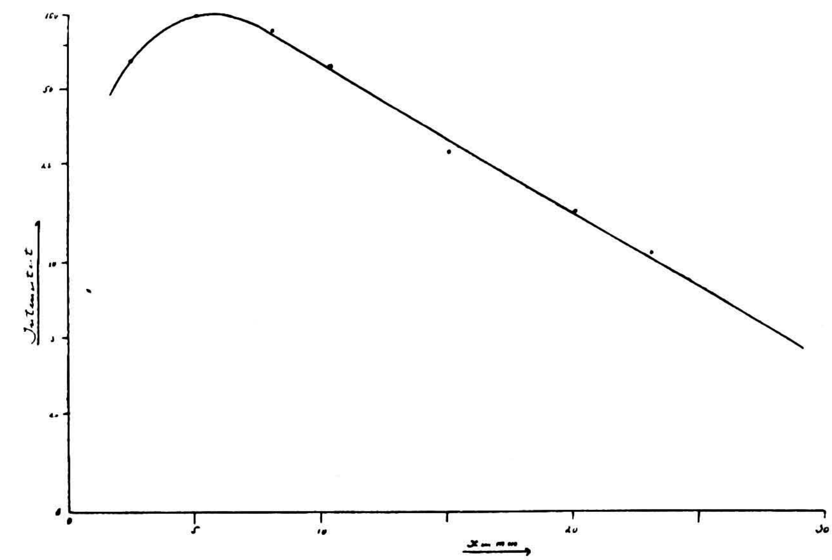

Fig. 3.

place in this region). With the aid of the determined excitation function we can correct the electron-densities.

Further we must make a second correction. Above we have determined the current-density from the intensity, by assuming a linear relation between these variables. The intensity is however, not proportional to the current-density. We must thus make a graph of the intensity and current-density (obtained by currentvariation) and so read off the current density.

Table II gives numbers for 36 Volts electrons corrected in this way. We have therefore found current densities as a function of the distance from the grid, and these must be the same for all lines. That this is not the case must be due to experimental errors. The deviation of the mean values show no relation with the character of the excited level, so that the mean value is approximately the real current-density.

In Fig. 4 this current-density is plotted as function of the distance from the grid ($x$).

From the straight line it follows that after 20 mm. the current-density is 0.058 of its original value.

The mean free path follows thus from the formula :

$$e^{-\frac{2}{\lambda}} = 0{,}058$$

$$\lambda = 0.70 \text{ cM.}$$

In order to be able to compare these values with those of RAMSAUER, we calculate from this mean free path the cross-section sum for all atoms in

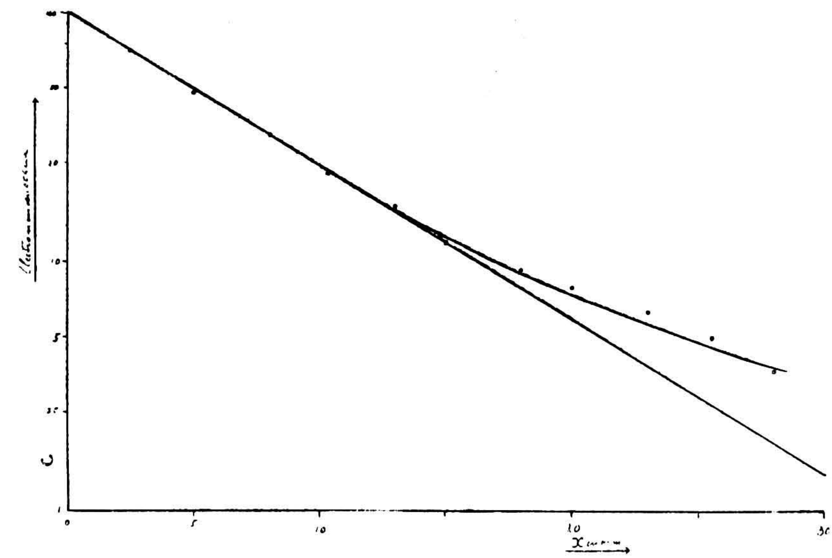

Fig. 4.

TABLE II.

| $A^\circ$ \ $x$ | 0 | 2.5 | 5 | 8 | 10.3 | 13 | 15 | 18 | 20 | 23 | 25.5 | 28 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 6678 | 100 | 64 | 45 | 32 | 23.5 | 17.4 | 13.6 | 10.8 | 9.35 | 7.65 | 6.2 | 4.7 |
| 5876 | 100 | 69 | 45 | 30 | 20 | 14.2 | 10.2 | 7.3 | 5.3 | 4.1 | 2.85 | 2.14 |
| 5016 | 100 | 66 | 43 | 23.5 | 13.5 | 9.0 | 7.2 | 5.25 | 4.05 | 3.2 | 2.2 | 1.44 |
| 4922 | 100 | 69 | 52 | 31 | 22 | 16.8 | 12.8 | 11.2 | 9.8 | 7.8 | 6.4 | 5.05 |
| 4713 | 100 | 81 | 56 | 37 | 25.5 | 17.4 | 13.3 | 11.3 | 9.1 | 7.2 | 5.6 | 4.0 |
| 4472 | 100 | 75 | 46.5 | 29.5 | 18.5 | 12.3 | 8.3 | 6.4 | 5.1 | 4.0 | 3.1 | 2.25 |
| 4438 | 100 | 71 | 50 | 34.5 | 26.7 | 20.0 | 15.1 | 12.5 | 10.9 | 9.6 | 7.55 | 5.9 |
| 4388 | 100 | 76 | 54 | 36.5 | 25.2 | 21.0 | 13.9 | 11.4 | 10.4 | 7.9 | 6.2 | 5.05 |
| 4121 | 100 | 69 | 47.5 | 36 | 28.6 | 21.0 | 14.0 | 9.75 | 7.75 | 6.35 | 4.5 | 2.65 |
| 4026 | 100 | 72 | 47 | 34 | 24 | 19.4 | 12.2 | 9.9 | 8.5 | 6.3 | 5.2 | 3.9 |
| 3965 | 100 | 71 | 48 | 30 | 22 | 17.2 | 13.3 | 9.65 | 8.80 | 7.0 | 5.6 | 4.0 |
| 3889 | 100 | 69.5 | 45 | 29 | 20.4 | 14.4 | 9.3 | 6.7 | 5.75 | 4.65 | 3.35 | 2.53 |
| Mean | 100 | 71.0 | 48.1 | 31.9 | 22.5 | 16.7 | 11.9 | 9.35 | 7.89 | 6.31 | 4.88 | 3.63 |

1 cc. of helium at 1 mm. pressure (the value "a" in the work of RAMSAUER).

The effective cross-section of an atom follows from the equation

$$\pi r^2 = \frac{1}{\lambda N}$$

where $N$ is the number of atoms in 1 cc. helium at 0.1 mm. pressure and $\lambda$ the m.f.p. at this pressure. The number of atoms in 1 cc. at 1 mm. pressure is therefore 10 $N$ and the cross-section sum of all the atoms in 1 cc. at 1 mm. pressure is thus :

$$10\,N\pi r^2 = \frac{10}{\lambda} = \frac{10}{0.7} = 14.3\,\frac{\mathrm{cM}^2}{\mathrm{cM}^3}.$$

It follows from the curves of RAMSAUER that the cross-section for this velocity is about $9\,\frac{\mathrm{cM}^2}{\mathrm{cM}^3}$.

This method can in principle also be used to determine cross-sections by electron velocities smaller than the excitation potential of the gas. One can proceed as follows :

In helium at e.g. 0.1 mm. pressure one introduces a small quantity of another gas with a smaller excitation potential. The pressure of this foreign gas must then be so small that the number of electron collisions with the foreign gas is negligible in comparison with the number of collisions with helium atoms. The electron-density is then determined by the *He* atoms and measured with the lines of the foreign gas.