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Physics. — "*The ionisation of argon*". By G. HOLST and A. N. KOOPMANS. (Communicated by Prof. H. KAMERLINGH ONNES).

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1. FRANCK and HERTZ[1]) have pointed out the fact that the conduction of electricity does not take place in the same way in all gases. They divide the gases into two groups: 1st those, in which an electron moving through the gas hardly loses any energy by a non-ionising impact and 2nd gases, in which the energy of the electron is lost for the greater part or totally by each impact. To the first group especially the rare gases belong. FRANCK and HERTZ made themselves a series of measurements with these gases and also gave a theory of the conduction of electricity by them. They principally investigated helium. In the following we shall mention the results of some measurements with argon.

Until now only determinations of GILL and PIDDUCK[2]) existed on this subject. A former investigation on the spark potential of argon has taught us[3]) however, that the results of these physicists are not quite right, probably by a slight impurity of their argon. This is probably the reason why the typical behaviour of the argon was not pronounced in their measurements.

2. We have again determined the connexion between current and tension in argon. Our apparatus had been constructed in the same way as that of GILL and PIDDUCK (fig. 1). It consisted of a condensor, in which the variations in the plate-distance could be measured. In the anode a series of holes had been bored through which by means of a quartz lens ultraviolet light of a mercury lamp could be concentrated upon the zinc cathode, in order to liberate electrons from it foto-electrically. By means of a micrometer screw the cathode could be moved up and down. The whole apparatus had been fused into a glass tube with a quartz window to let the ultraviolet light through.

1) Verh. D. phys. Ges. (15), 34, 929, 1913 en (16), 12, 1914.

2) Phil. Mag. (16), 280, 1908 en (23), 837, 1912.

3) Versl. Kon. Ak. v. Wet. (26), 1027, 1917.

The intensity of the current in the condensor was determined from the time which a binant electrometer of DOLEZALEK needed, to

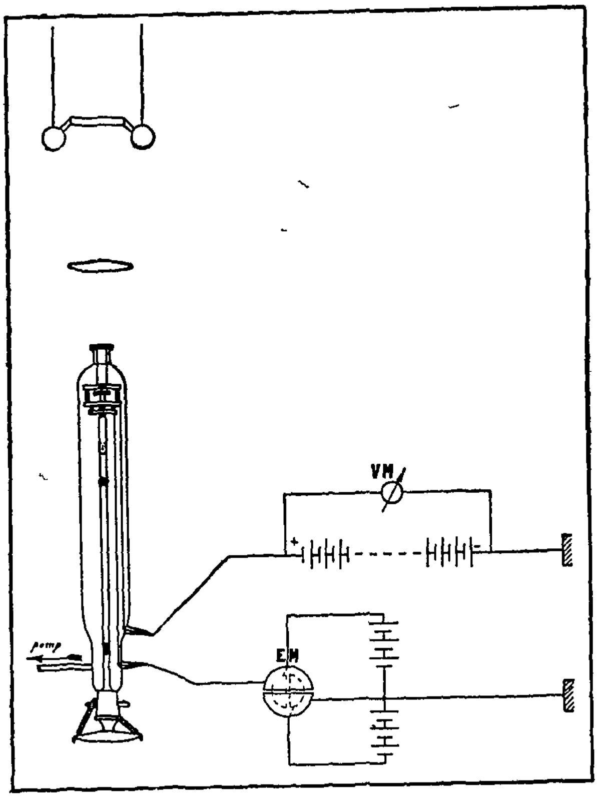

Fig. 1.

be charged. The tension was supplied by a battery of small piles and controlled with an electrometer of WULFF. All conductors, the discharge tube, and the electrometer were protected by tin-foil in order to prevent electro-static disturbances.

The argon was purified according to the method of GEHLHOFF. During the measurement there always was found a small impurity, probably due to gases from the ebonite, by which the condensor was isolated. The pressure increased about by 0.00080 mm. in 24 hours.

The quartz lamp was fed by a battery. After some time the radiation proved to be satisfactorily constant, which was controlled by a thermo-pile.

3. We have made measurements on the relation between current and tension for a constant distance of the condensor plates and on the relation between current and plate distance for a constant intensity of the field.

In fig. 2 and 3 the results of the best measurements have been represented graphically. Both curves show typical sudden changes of direction due to the augmented increase of the intensity of the current and which occur at regular distances [1]). For helium

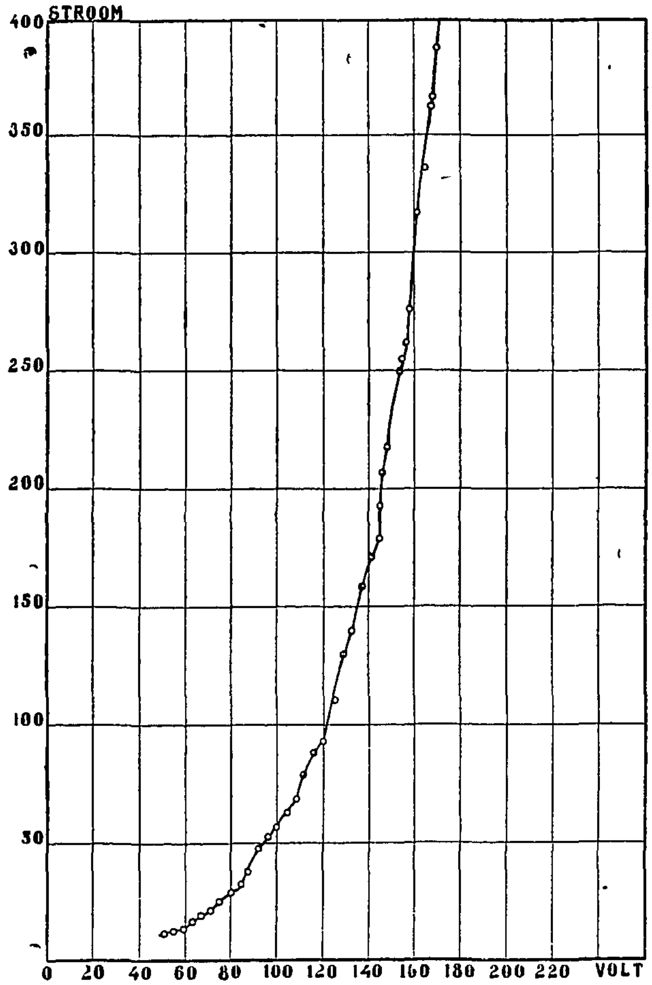

Fig. 2.

FRANCK and HERTZ have observed a similar phenomenon and proved, that these changes of direction must occur each time an electron has travelled through a potential difference equal to the ionisation potential. Our measurements give in this way for the ionisation potential of argon 12,0 Volt, which agrees satisfactorily with the value FRANCK and HERTZ found in another way. [2]) In the curve for constant field the steps are much more pronounced than in that for constant plate

1) Maximally we have observed 15 steps.

2) Later measurements by Dr. OOSTERHUIS and one of the writers proved that no real ionisation occurs at 12 Volts. The real ionising potential is about 17 Volts. So 12 Volts must be considered to be the velocity of first inelastic impact (Note added in translation).

distance and it seems extremely useful for the precise determination of the ionisation tension. This method has the advantage that it is quite independent of eventually existing contact potentials and besides, that it does not only determine the ionisation tension itself but also a series of multiples of it, so that the mean value can exactly be calculated.

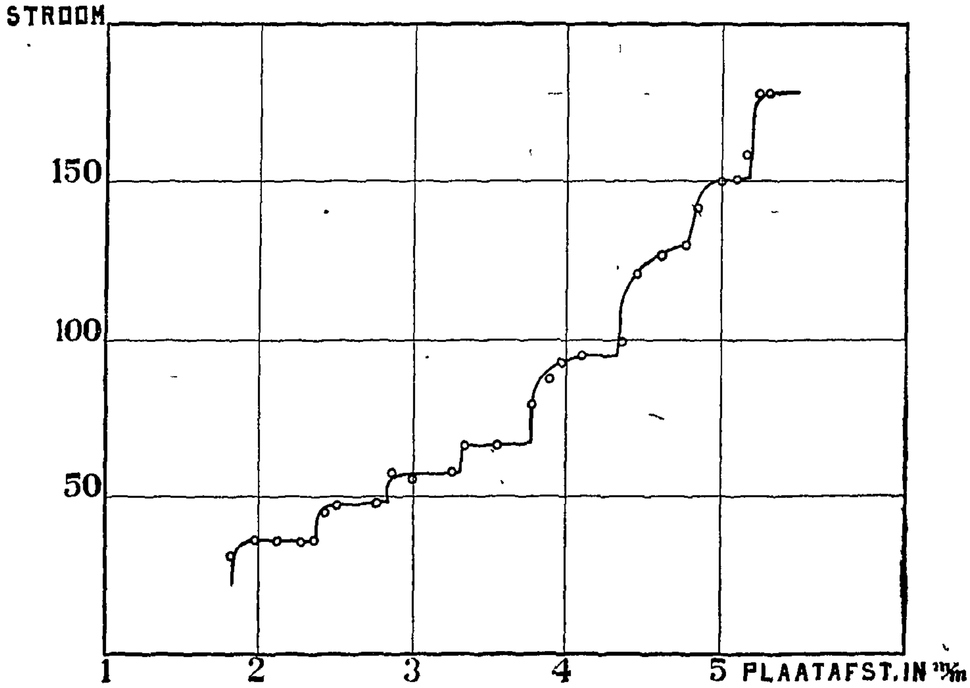

Fig. 3.

4. HERTZ [1]) concluded from the experiment made by him together with FRANCK on helium, that the energy transmitted by an electron to a helium atom at a non-ionising impact has just the value it would have when the impact took place between perfectly elastic spheres with the mass of the electron resp. of the helium atom. Let us suppose now, that also in the argon the impact between an electron and an argon atom follows the law of the elastic impulse. We then find that during a non-ionising impact the electron loses a quantity of energy equal to $V = kE$, where E represents the energy of the electron and k a constant, equal to double the quotient of the mass of the electron by that of the argon atom:

$$k = 2\frac{m_e}{m_a} = \frac{2}{1844.40} = 0,000027.$$

Now we can also calculate the increase of the energy of the

[1]) Verh. D. phys. Ges. (19) 268 1917 Verg. BENADE Phys. Rev. (10) [illegible] 1917.

electron between two succeeding impacts. Let v be the velocity of the electron, λ the mean free path, then the mean value of the interval between two succeeding impacts will be $\tau = \frac{\lambda}{v}$ sec. During this time the electric field X gives to the electron the acceleration $X\frac{e}{m}$. As after each impact the electron begins again with the mean velocity zero in the direction of the electric field, it will travel over a distance $x = \frac{1}{2} X \frac{e}{m} \left(\frac{\lambda}{v}\right)^2$ in this direction [1]. The mean value of the increase T of the energy between two impacts will therefore be $T = Xe \frac{1}{2} X \frac{e}{m} \left(\frac{\lambda}{v}\right)^2$.

Evidently this increase becomes smallest when the energy $\frac{1}{2} mv^2$ itself is as great as possible. Then the loss of energy V by the impact is however also maximal and therefore also the ratio $\eta = \frac{V}{T}$.

Let us now suppose, what probably will be the case, namely that ionisation will occur, as soon as an electron receives enough energy to be ionised. Then η becomes a maximum for $\frac{1}{2} mv^2 = e V_i$; where V_i is written for the ionisation potential

$$\eta_{max} = \frac{ke\ V_i}{X^2 e^2 \frac{1}{2} \lambda^2 \frac{1}{mv^2}} = 4k \left(\frac{V_i}{\lambda X}\right)^2.$$

Now the free path of an electron in argon is $4\sqrt{2}$ times that of an argon molecule. From the data on internal friction, we can easily deduce, that λ in argon for 17° C. and a gas pressure of p mm. is equal to $\lambda = \frac{0{,}028}{p}$ cm.

The ionisation potential for argon is 12 Volt. Introducing this into the above formula we find:

$$\eta_{max} = 20 \left(\frac{p}{X}\right)^2.$$

In the measurements with constant field p was about 2 mm. and

[1]) The mean velocity in the direction of the field becomes therefore $v_x = \frac{1}{2} X \frac{e}{m} \frac{\lambda}{v}$, while HERTZ finds double the value. This must be ascribed to the integration used by H, in which the rare very long paths have a great influence. In reality, when the number of the impacts between two ionising impulses is not exceedingly great, an intermediate value will be the right one.

$X = 250$ Volt/$_{cm}$, so that η_{max} was equal to $\frac{1}{750}$. Maximally an electron loses therefore by the impact with an argon atom the $\frac{1}{750}$ part of the energy it has gained between two succeeding impacts. In this case the loss of energy may be entirely neglected and we may assume that the energy of an electron it determined only by the way it has travelled in the direction of the field viz. all electrons at the same distance from the cathode will have the same velocity.

In measurements with constant plate distance this is not at all the case. As long as the potential difference between the plates is small, the field is weak and η therefore great. In this case we must therefore always take into account the energy loss by the impacts and especially for the first steps of the current-tension-curve this influence will be considerable. For this reason measurements with a constant practically chosen field are preferable for the determination of the ionisation potential.

As to the height of the steps, according to FRANCK and HERTZ they must be in the ratio 1 : 2 : 4 etc. When we disregard the round corners the current could be represented as a function of the tension by a formula of the form $i = e N_0 2^n$, where N_0 is written for the number of the electrons emitted by the cathode and n for the greatest integer smaller than $\frac{V}{V_i}$. (V is the potential difference between the two plates).

In our measurements the ratio 2 : 1 never occurred, but 1.3 : 1 and 1.5 : 1. Doubtlessly this is due to the influence of impurities in the argon. By these the deviations are also greater in the measurements with a constant field than in those with a constant plate distance. It seems therefore to be of importance to repeat these measurements still with a purer gas. Finally we can conclude from the curves with a constant field, that nearly every impact of an electron that has travelled through 12 Volt causes ionisation. From the preceding calculation it is found, that the mean value of the path travelled by an electron with a velocity corresponding to 12 Volt between two impacts in the direction of the field is 0,001 cm. The measurements teaches however that all ionisations take place in a layer of maximally 0,004 cm., so that nearly each impact that can cause ionisation really does cause it.