Physics. — *"On the sparking-potential of argon-nitrogen mixtures"*. By Dr. G. HOLST and A. N. KOOPMANS. (Communicated by Prof. H. KAMERLINGH ONNES).

(Communicated in the meeting of September 29, 1917).

1. *Introduction.* It is well known that the so-called halfwatt-lamps are filled with a gas at a pressure of about an atmosphere in order to obviate the evaporation of the tungsten wire. In lamps with a relatively thick wire, in which the loss of heat to the gas is comparatively small as against the radiated heat, nitrogen is commonly used, whereas argon is used in lamps with thin wires as its conductivity for heat is very much smaller. The substitution of argon for nitrogen produced a new difficulty: the occurrence of electric discharges through the gas. By the addition of small quantities of nitrogen it has been possible to raise the sparking-potential by a considerable amount. [1])

Our wish to learn more of this influence of nitrogen on the sparking-potential was the origin of the present investigation. A few measurements on this subject have been made by BOUTY [2]); he also discovered the great influence of traces of admixtures.

2. *Experimental method and apparatus.* The method used by us is based on the drop of potential at the terminals of a condensor connected in parallel to the discharge tube at the moment of passage of the spark (fig. 1). The discharge tube was a large bulb of 12 cms in diameter, with two silver electrodes attached to stiff brass wires. The electrodes had a diameter of 36 mms and their distance was about 6,7 mm. [3]) The ends which were turned towards each other were spherical with a radius of 10.8 cm. A side-tube was blown to the bulb on which a quartz window was cemented. Through this window a small spark between aluminium electrodes could be

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1) A. E. G. D. R. P. 289543.

2) E. BOUTY, Journ. de Phys 4. série, 1904, p. 489, 593.

3) Owing to a displacement of the electrodes by change of pressure it was necessary to measure the distance of the electrodes each time with a kathetometer.

focussed on the kathode by means of a quartz lens in order to prevent retardation in the discharge. [1])

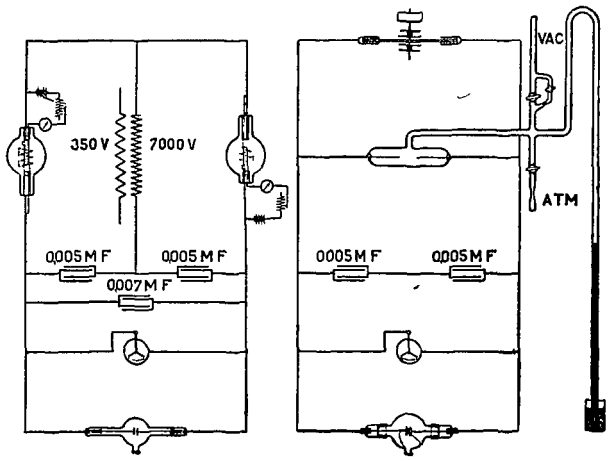

Fig. 1.

In the case of pure argon we used a discharge tube of 7 cms diameter with electrodes of 13 mms at a distance of 6,31 mm. The radius of curvature of the opposed surfaces was 7 cms; the centre of curvature coincided with the sealing places of the supply-wires, so that changes in the position of the electrodes had no influence on the distance.

The discharge tube was connected to a LANGMUIR condensation pump and to the apparatus in which the gases were kept and purified. The argon-nitrogen mixtures were prepared from fractionated argon and nitrogen [2]): the composition was determined by means of a baroscope. The last remaining traces of oxygen were burnt out by means of a glowing tungsten wire. The gases were freed from water-vapour, mercury-vapour and carbon dioxide by means of cooling tubes in liquid oxygen. Pure argon was prepared in a potassium-cell according to GEHLHOFF [3]); the smaller discharge-tube was used in this case in order not to use too much gas. The pressure in the discharge-space was measured with a mercury gauge; every now and then we used a MAC LEOD gauge. The potential was

[1]) E. WARBURG, Ann. d Phys. (62), 385, 1897. When an arc between iron electrodes was used, irregular results were obtained, probably in consequence of an effect of the heat.

[2]) Our thanks are due to Mr. H. FILIPPO Jzn. for the preparation of the mixtures.

[3]) We made use of the same large potassium-cell as was used by Dr. L. HAMBURGER (Diss. Delft 1917).

measured with an electrometer according to WULF [1]), which could be used up to 40000 Volts. It was calibrated with a compensation-apparatus according to BROOKS. The ratio between the various measuring ranges was checked with a sparking-gap between needle-points.

The condensers were glass tubes 1 metre in length and 8 cms in diameter which were silvered both on the inside and outside. At the ends and at the bottom the glass was locally thickened in order to prevent the spark piercing the glass [2]). They were blown for us in PHILIPS' glass-factory [3]). Their capacity was about 0,005 of a micro-farad. When rectified alternating current was used (see below), an additional condenser of 0,007 m.F. had to be connected up in parallel in order to obtain a sufficiently constant potential. With the higher potentials the condensers were charged with a Wimshurst machine. In order to make the charging take place very slowly, a discharge-tube with pointed electrodes was put in parallel to the machine. The air-pressure in this tube could be varied. During the measurements air was slowly admitted. Hereby the tension at the pointed electrodes was gradually raised. As soon as the sparking potential in the discharge-tube which is filled with the mixture is reached and passed, the discharge takes place and the potential falls to a smaller value. The highest reading of the electrometer was taken.

With the smaller tensions this arrangement was not found satisfactory. For this reason we used in this case for charging the condensers a 7000 volt-transformer with rectifiers joined up as described by GREINACHER [4]). Instead of cells of the GRAETZ-pattern we used thermo-ionic rectifiers of our own manufacture, so called kenotrons [5]). By a regulation of the heating current any charging-speed desired could be obtained.

In all our experiments we have taken care that electrostatic disturbances were kept down as low as possible.

3. *Measurements.* The apparatus were first checked by a series of determinations of the sparking-potentials in air. The air was freed of carbon dioxide and water vapour.

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1) TH WULF, Phys. Zeitschr. (11), 1090, 1910.

2) J. MÓSCICKI. E. T. Z 1904, 527.

3) Our thanks are due to Mr. P. J. SCHOONENBERG, who superintended the manufacture of the condensers.

4) H. GREINACHER, Phys. Zeitschr. (15), 412, 1914.

5) J. LANGMUIR, Electrician 1915. LXXV, 240.
A. W. HULL, Electrician 1916. LXXVII, 220.

These observations are put together in table 1; p stands for the pressure in mms mercury, S for the distance of the electrodes in cms.

Our results lie within the limits of those obtained by other observers and differ but little from the values given in the

TABLE 1

Sparking-potentials in dry, CO_2-free air.

$pS\frac{288}{273+t}$	Potential in Volts	$pS\frac{288}{273+t}$	Potential in Volts	$pS\frac{288}{273+t}$	Potential in Volts	$pS\frac{288}{273+t}$	Potential in Volts
496.4	21300	301.6	13683	122.9	6657	7.83	1017
465.8	19931	264.3	12428	97.6	5587	3.80	687
441 0	18893	267.7	12335	71.6	4303	3.06	640
412.0	17851	235.2	11140	52.2	3427	3.16	616
403.6	17367	207.7	10134	40.9	2911		
338.7	15018	165.6	8374	24.8	1998		

"Standardization rules of the A. I E. E." [1]) for the sparking potentials between spheres of a diameter of 62.5 mms (compare fig. 2).

In figs 3—5 our observations on argon, nitrogen and mixtures of argon and nitrogen are plotted. Table 2 contains the results of our measurements.

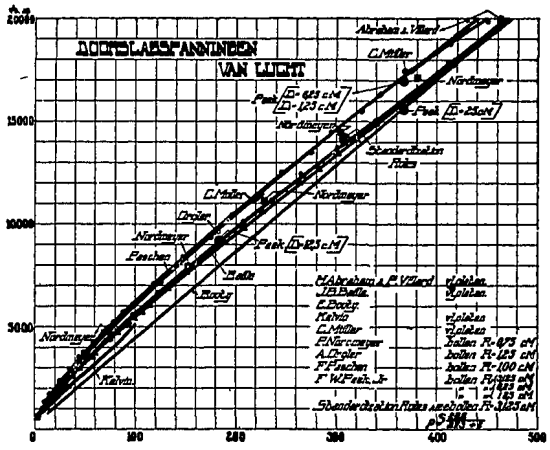

Fig. 2.

[1]) Standardization rules, Edition of July, 1, 1915, p. 50.

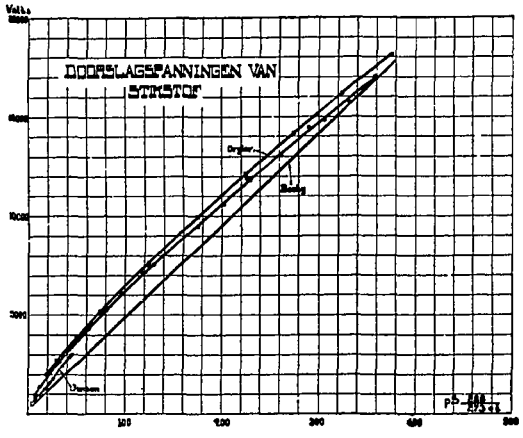

Fig. 3.

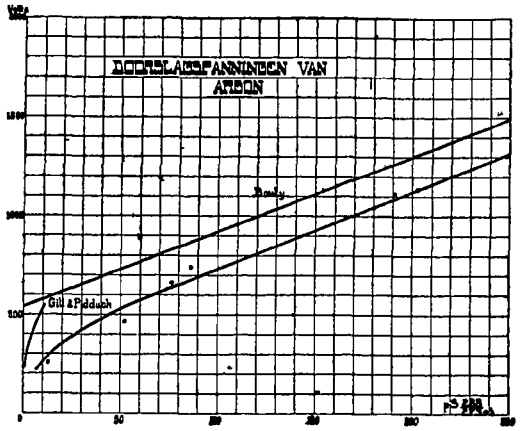

Fig. 4.

The figures found for nitrogen lie in between the potentials determined by ORGLER [1]) and the values found by BOUTY for the "champ critique", a quantity which is practically identical with the sparking-potential. [2]) (See fig. 3).

At lower pressures JENSEN [3]) has also made some measurements. Supposing his measurements were also made at 15°, his results are lower than ours; but the temperature is not mentioned by him.

Pure argon has been investigated by BOUTY [4]) and at low pressures

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1) A. ORGLER, Ann. d Phys. 1900, 1, 159.
2) E. BOUTY, Journ. de Phys. 4. série III. 1904, 489, 593.
3) J. C. JENSEN, Phys. Rev. Vol. VIII, 433, 1916.
4) E. BOUTY, Ann. de Chim. et de Phys. 8. série. Tome 23 (1911) p. 1.

by GILL and PIDDUCK [1]). We found a lower value for the potential at which the discharge occurs. (See fig. 4). The direction of our curve is practically the same as BOUTY's curve at high pressures. As the direction of this curve according to BOUTY is a test of the purity of the argon, and the curve given in the figure corresponds to BOUTY's purest sample we may conclude that our argon satisfied very high demands. Similarly to BOUTY we found it exceedingly difficult to obtain series of observations which give properly corresponding results, as small quantities of gas — probably liberated from the electrodes by the sparks — raised the sparking-potentials considerably. We found it therefore necessary to purify the argon anew for the determination of each point.

TABLE 2.

Sparking-potentials for argon, nitrogen and mixtures of argon and nitrogen.

Pure nitrogen.

$pS\frac{288}{273+t}$	Potential in Volts	$pS\frac{288}{273+t}$	Potential in Volts	$pS\frac{288}{273+t}$	Potential in Volts	$pS\frac{288}{273+t}$	Potential in Volts
358.02	17033	229.78	11771	118.45	7162	22.53	2074
346.12	16460	226.05	11870	97.68	6052	12.97	1377
330.50	15799	202.91	10561	80.20	5248	8.16	954
306.13	14868	175.40	9459	63.32	4313		
290.54	14430	130.38	7548	47.96	3577		
261.03	13057	125.95	7402	32.93	2717		

Argon-nitrogen mixture 80.9 % N. 19.1 % A.

$pS\frac{288}{273+t}$	Potential in Volts	$pS\frac{288}{273+t}$	Potential in Volts	$pS\frac{288}{273+t}$	Potential in Volts	$pS\frac{288}{273+t}$	Potential in Volts
386.39	15963	232.84	10401	129.50	6692	53.80	3442
336.27	14270	199.82	9320	102 40	5714	38.79	2731
271.20	11741	163 23	7894	68.57	4117	27.18	2143
						13.88	1342

[1]) E. W. B. GILL and F. B. PIDDUCK, Phil. Mag. (6) 16, p. 280, 1908; 23, p. 837, 1912.

TABLE 2.

Argon-nitrogen mixture 44,6 % N. 55,4 % A.

$pS\frac{288}{273+t}$	Potential in Volts	$pS\frac{288}{273+t}$	Potential in Volts	$pS\frac{288}{273+t}$	Potential in Volts	$pS\frac{288}{273+t}$	Potential in Volts
333.65	11283	201.78	7522	89.36	3988	17.57	1264
315.78	10899	196.82	7355	62.13	3058	11.15	927
293.93	10234	167.65	6538	52.35	2664	4.96	190
274.36	9669	134.99	5499	41.26	2224		
247.81	8954	121.30	5031	31.78	1892		
223.52	8253	103.45	4472	25.41	1637		

Argon-nitrogen mixture 22.3 % N. 77.7 % A.

$pS\frac{288}{273+t}$	Potential in Volts	$pS\frac{288}{273+t}$	Potential in Volts	$pS\frac{288}{273+t}$	Potential in Volts	$pS\frac{288}{273+t}$	Potential in Volts
379.24	10131	270.25	7841	159 60	5340	89.35	3420
364.50	9879	261.62	7752	150.86	5020	72.81	2924
337.16	9313	235.35	7041	124.54	4348	41.36	1907
301.63	8577	192.52	6006	118.11	4189	24.14	1378
296.68	8392	186.38	5938	98.91	3635	16.30	1064

Argon-nitrogen mixture 11,2 % N 88,8 % A.

$pS\frac{288}{273+t}$	Potential in Volts	$pS\frac{288}{273+t}$	Potential in Volts	$pS\frac{288}{273+t}$	Potential in Volts	$pS\frac{288}{273+t}$	Potential in Volts
394.33	7922	251.31	5469	132.34	3243	39.07	1405
320.96	6667	232.64	5227	114.39	3017	21.52	965
296.51	6294	191.53	4482	97.65	2801		
292.47	6213	162.77	4021	62.06	2005		

Argon-nitrogen mixture 6,6 % N 93,4 % A.

$pS\frac{288}{273+t}$	Potential in Volts	$pS\frac{288}{273+t}$	Potential in Volts	$pS\frac{288}{273+t}$	Potential in Volts	$pS\frac{288}{273+t}$	Potential in Volts
373.67	6248	259.41	4733	132.27	2813	58.54	1642
341.92	5774	227.85	4211	112.63	2517	46.19	1326
306.66	5298	198.20	3798	98.09	2336	29.16	888
282.54	4972	164.74	3368	79.00	1988		

Pure argon.

$pS\frac{288}{273+t}$	Potential in Volts	$pS\frac{288}{273+t}$	Potential in Volts	$pS\frac{288}{273+t}$	Potential in Volts	$pS\frac{288}{273+t}$	Potential in Volts
202.48	1138	86.23	740	63.34	678	12.85	255
190.57	1113	76.44	660	52.25	466		

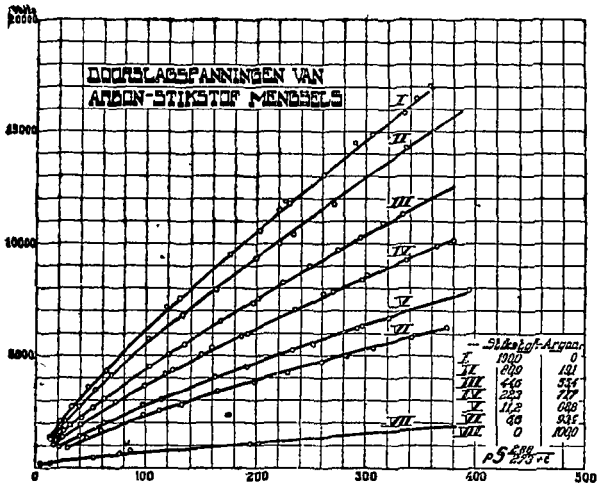

Fig. 5.

Our results on argon, nitrogen and the mixtures are combined in figs 5 and 6. Fig. 6 shows the large influence of small admixtures of nitrogen on the sparking-potential, especially at the higher pressures. Qualitatively our measurements on mixtures agree with those of Bouty.

4. *Discussion of the results.* The exceedingly low sparking-potential for argon can be made intelligible by TOWNSEND's theory. [1]) According

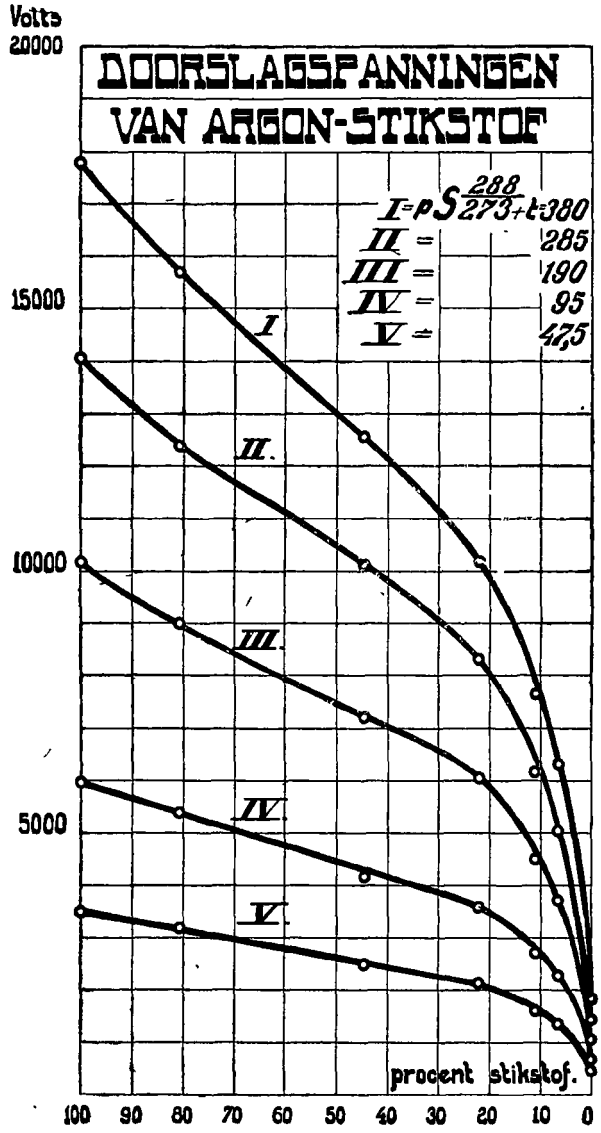

Fig. 6.

to him the distance S (in cms) between the plates at which the discharge passes with a given gas-pressure and potential-difference is given by

$$S = (\alpha - \beta) \log \left(\frac{\alpha}{\beta}\right)$$

[1]) See for instance TOWNSEND, Electricity in gases, p. 323.

where α represents the number of ionising collisions per cm. of path described in the direction of the field for a negative ion, β the same quantity for a positive ion. S will thus be large, if α is large and if β — which is always small as compared to α — does not become relatively large. Argon belongs to the so-called "elastic" gases in which the negative ions in collisions, with molecules which do not give rise to ionisation, do not lose any energy. For these gases K. T. COMPTON [1]) has recently calculated $\frac{\alpha}{p}$ (p = gas-pressure) as a function of the ionisation-potential V_0, the mean free path l and the intensity of the field per unit pressure $\frac{X}{p}$. He finds $\frac{\alpha}{p}$ much larger for the elastic gases than for the non-elastic gases. Substituting in the table given by him the values of V_0 and l for argon, neon and helium (the value of l being taken proportional to the value calculated according to the kinetic-theory) α is found largest for argon. As there is no obvious reason for assuming that β would be much larger for the elastic gases than for the non-elastic ones, the large value of α can make us foresee that the sparking-potential of argon should be particularly small.

As regards the sparking-potential of the mixtures we may again refer to a calculation of COMPTON's [2]). This calculation was not carried to the end, but it indicates, that for a mixture of an elastic and a non-elastic gas α should have about the character of α for non-elastic gases. Now nitrogen is not altogether un-elastic K. T COMPTON and J. M. BENADE [3]) have proved, that the loss of energy in a collision of an electron with a nitrogen molecule depends on the smallest distance of their respective paths, more particularly, that it is inversely proportional to the 10^{th} power of this distance. In this way the problem certainly becomes very complicated.

The other limiting case of a mixture of two completely elastic gases has been discussed by FRANCK and HERTZ [4]), although in a somewhat different connection. In that case the gas with the smaller ionisation-potential practically completely assumes the conduction. For nitrogen the ionisation-potential is considerably smaller than for argon. The part played by nitrogen will therefore be in the first place a reduction of α by its un-elastic nature, whereas on the other hand

[1]) COMPTON, Phys. Rev. (7). 517, 1916

[2]) loc. cit. p. 516.

[3]) Phys. Rev. (8) 449. 1916.

[4]) FRANCK and HERTZ, Ber. D. phys. Ges. (18) 213. 1916.

when the current passes, the nitrogen will be principally ionised. The spark will therefore show the nitrogen-spectrum. This was actually observed by BOUTY [1]) and was recently confirmed by HAMBURGER's measurements. [2])

In conclusion we wish to express our sincere thanks to Dr. G. L. F. PHILIPS for the opportunity given to us of carrying out this investigation.

Eindhoven. *Physical Laboratory of Philips's Incandescent lamp-factory.*

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[1]) BOUTY, Journ. de Phys. (1904), p. 605.

[2]) HAMBURGER, Diss. Delft 1917.