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But when the galvanometer-arm is closed during the next 60° , the current through the galvanometer is in the opposite direction, for it is represented by the area EFG; thus R_d would appear less than R_c .

These experiments were made in the New Physical Laboratory of the Owens College, Manchester: where, in order to complete the research, I hope to be able to investigate the relations between the magnitude and phase of the "bismuth E.M.F." and the field-strength; also to investigate the whole effect at the temperature of liquid air.

XXVIII. Note on the Spark-discharge.

By SIEGFR. GUGGENHEIMER, *Ph.D.**

THE interest in the phenomena accompanying the spark-discharge in gases has been revived recently by a discussion between Mr. Swyngedauw† and Prof. Warburg‡. The complete discordance between the opinions of these authors led me to undertake the experiments described below with the view eventually to decide the question at issue. I may at once say that the result of my experiments and theoretical considerations is to confirm the views of Prof. Warburg.

1. The fact that the spark-potential is independent of the nature of the radiation employed to shorten the time of retardation (Warburg's *Verzögerung*) made it seem probable that this potential depends upon the momentary state, *i. e.* upon the degree of ionization of the gas. Therefore it was to be expected that the "Verzögerung" would also be destroyed, or at least shortened, if, instead of using direct radiation, we introduce a sufficient number of ions in the space containing the sparking system. The experiments confirmed this expectation.

2. In the sides of a brass tube 20 cm. long and 3 cm. interior diameter were fitted two ebonite plugs facing one another. Through each of these plugs passed a brass wire terminated inside the tube by a brass ball of 7 mm. diameter.

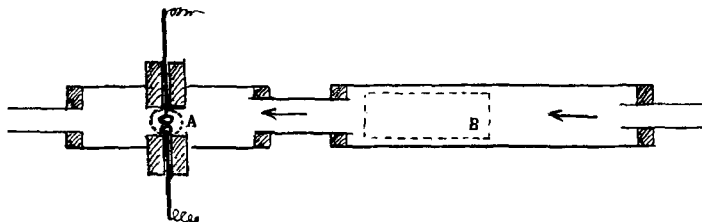
* Communicated by Prof. J. J. Thomson, F.R.S.

† R. Swyngedauw, *Journ. de Phys.* ix. p. 488 (1900); Bichat & Swyngedauw, *Rapports of the Paris Congress*, iii. p. 164 (1900).

‡ E. Warburg, *Verhandlungen der Deutsch. Phys. Gesell.* ii. p. 212 (1900).

Opposite these electrodes was an aluminium window over which a brass cover could be placed. One end of the tube was connected to a U-tube filled with calcium chloride and thence to a wash-bottle containing concentrated sulphuric acid. The other end of the tube was connected by means of a glass tube (from 8 mm. to 2 cm. diameter and 10 cm. length) to a second brass tube of 20 cm. length, and of the same diameter

Fig. 1.



as the first one. This second tube was connected at the other end by means of a U-tube containing calcium chloride to a blowpipe. In the side of this brass tube was an opening 8 cm. long and 2 cm. broad, which was closed by thin aluminium-foil.

One part of the electric circuit comprised the one pole of a Wimshurst machine, the inner coating of a leyden-jar, one of the spherical electrodes, and the indicating portion of a Braun electrometer; the other part of the circuit consisted of the other pole of the Wimshurst, the outer coating of the leyden-jar, the other sphere, and the cage of the electrometer, and was generally put to earth.

The observations were carried out in the following order:— (1) The discharge-potential was measured without exposing the sparking system to radiation, and without introducing ions into the tube A. Then (2) from an X-ray bulb placed near the aluminium window of the tube B, strong X-rays entered B, and the ions thus produced were driven by a strong current of air into the tube A, and the potential was measured whilst this operation went on. (3) A third measurement was then made whilst X-rays fell directly through the aluminium window in A upon the electrodes. The current of air was also blown through the apparatus during the operations 1 and 3. Sheets of lead protected A when B was exposed to radiation.

I give below the results of two particularly striking series of experiments.

Distance of the spheres (roughly) = 1 mm.
Potential V in Volts.

	V.	V.	V.
Without radiation	4500	5500	5500
Radiation in B	3500	3500	3500
„ A	3500	3400	3200
Distance of spheres (roughly) = 2·1 mm.			
Without radiation	7500	8000	8000
Radiation in B	6000	5500	5800
„ A	6000	6100	5900

I am compelled to observe that the observations do not always give such concordant results for the cases of the radiation in B and A as shown in the above tables. If the electrodes are not freshly polished, and if the radiation in B is not strong enough (so that fewer ions are produced), then the results obtained are of the type shown by the following table :—

Distance of the spheres = 2·1 mm.

	V.	V.	V.
Without radiation	8500	8000	8500
Radiation in B	7000	6800	7000
„ A	6000	6100	6000

Here one sees the discharge with radiation in B taking place at potentials lying between the potentials obtained for discharges without introduction of ions or without direct radiations, and the potentials measured in exposing the sparking system to direct radiation. But the potentials necessary to produce the discharge were always about 1300 to 1500 volts lower than those measured without employing any means to destroy the retardation.

3. It might be permissible to insert here a few words with a view to a theoretical explanation of these results. There are, in my opinion, mainly two points to be considered which.

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so far as I am aware, have not yet been taken into consideration in the various attempts that have been made to explain the phenomena of retardation and of the spark-discharge in general. These two points are—(1) The fact discovered by Geitel* and by C. T. R. Wilson†, that the air always contains ions, and that there is a continuous production of ions connected naturally with the re-combination of these ions. (2) The principle first established by Prof. J. J. Thomson‡, and also brought forward and strengthened by experiments executed in the Cavendish Laboratory by Prof. Townsend§, viz., the principle of the production of new ions by the collisions of negatively charged corpuscles moving under the influence of strong electromotive forces with the molecules of the gas.

A careful comparison of the results of experiments undertaken from different standpoints, shows that the electromotive force per cm. which is required to give to the negative ions a velocity such that they can produce new ions by collisions with the molecules of the gas, *is very nearly the same as the electromotive force required to produce spark-discharge in the gas at the same pressure and with the electrodes at the distance of 1 cm.*

Prof. Thomson illustrates this, in the paper mentioned above, by a small table taken from a paper by Skinner (Phil. Mag. [5] l. 1900). Here X (the potential-gradient per cm. in the positive column) means the above described minimum E.M.F., and p is the pressure. The table is as follows:—

p .	X/cm. in Volts.	$\frac{X}{p}$.
mm. 0.6	27	45
1.0	40	40
1.5	56	38

Liebig (Phil. Mag. [5] xxiv. p. 106) found the value required for a spark-discharge at a distance of 1 cm. in air

* H. Geitel, *Phys. Zeitschrift*, ii. p. 116 (1900); J. Elster & H. Geitel, *ibid.* p. 560 (1901).

† C. T. R. Wilson, *Proc. Roy. Soc.* lxviii. p. 151 (1901).

‡ J. J. Thomson, *Phil. Mag.* [5] l. p. 278 (1900); *ibid.* [6] i. p. 361 (1901).

§ J. S. Townsend, 'Nature,' August 1900; *Phil. Mag.* February and June, 1901.

at atmospheric pressure to be 31,000 volts. This gives $\frac{X}{p} = 40.8$. The fact that the values of $\frac{X}{p}$ are nearly coincident seems to entitle one to draw the above conclusion. I hoped to be able to calculate the values of $\frac{X}{p}$ for a wider range of pressures from the recent observations of Orgler*, but I was prevented from so doing as his numbers and curves do not apply for greater distances of the electrodes than 0.5 and 0.6 cm. respectively. Paschen†, also, in his well-known paper, does not give enough observations for a spark-length of 1 cm. at different pressures to enable me to calculate the values of $\frac{X}{p}$ in a sufficient number of cases.

Starting from the fact already mentioned, that even air at atmospheric pressure always contains ions, and that ions are continuously produced, it seems possible to obtain a fairly clear idea of what happens before a spark passes, as well as what happens during the spark-discharge.

If, for instance, one subjects two electrodes to slowly increasing electromotive forces, there will be formed immediately a very feeble current, as observed by Warburg and other experimenters. This current will, so long as no external agents are acting, remain constant within very wide ranges of the E.M.F.; but its intensity will increase very quickly and tend to a maximum, as soon as the E.M.F. attains the value necessary to give to the ions the velocity required to produce new ions by impact.

It seems to me that the experiments of Kreusler‡ prove this very decidedly. It ought to be observed that in all his experiments (the final ones) the electrodes were exposed to ultra-violet light, but nevertheless when he approached the discharge-potential, a change in the value of the E.M.F. of 1.7, 1.7, and 1.3 per cent. (he used Pt, Cu, and Fe electrodes) corresponded to an increase in the intensity of the current of 337.2, 243.1, and 392 per cent. The theory strongly demands that just as the spark-potentials are approximately the same, so also these last numbers ought to be the same; but it seems that here secondary circumstances of the experiments exert a certain influence.

Let us assume, for instance, the intensity of such a saturation current between the two electrodes to be only $\frac{1}{100}$

* A. Orgler, *Ann. d. Physik*, i. p. 159 (1900).

† F. Paschen, *Wied. Ann.* xxxvii. p. 69 (1889).

‡ H. Kreusler, *Ver. Phys. Ges. Berlin*, 1898, p. 86, especially table, p. 91.

of the intensity of the maximum current observed by Mr. Kreusler; thus let I (intensity) be 10^{-10} ampere. Then a simple calculation by means of the formula

$$I = qe$$

gives

$$q = 2 \times 10^9 \text{ approximately,}$$

where q equals the number of ions per unit-volume. Comparing this value with Loschmidt's number, we see that only about the 10^{-11} part of the molecules become ionized. If no external ionizing agents are acting, then the transformation of the 20 ions contained in unit volume according to C. T. R. Wilson (if I is greater then, of course, there is a correspondingly greater number of ions) into about $2 \cdot 10^9$ ions must take place by collisions. The time which is necessary for this transformation is what Prof. Warburg calls the period of retardation. It is obvious that this time is considerably shortened if we produce by radiation a new set of ions whose number is large compared with the number of ions originally present, which new ions are also put in motion, thus producing still more new ions by collisions with the molecules of the gas.

It will be easily seen that the above considerations explain fairly well Prof. Jaumann's results.

The following is a new definition of Maxwell's "electric strength" of a gas based on this view of the nature of the spark-discharge:—"The electric strength of a gas at a pressure p is defined as the electric intensity required to give to the negative ions a velocity sufficient to enable them to produce other ions by collisions with the molecules of the gas." According to this view, the determinations of the spark-potential under the action of radiation made by Prof. Warburg and his pupils are to be regarded as giving the normal spark-potential, as Prof. Warburg maintains. It follows also that when working without radiation one ought to obtain the same normal potential, provided sufficient time is allowed for the electric intensity to act.

I hope soon to be able to publish further experimental results in support of these views.

The spark itself appears to amount practically to a short circuit between the electrodes. In addition to the production of ions by collisions, the following causes help to explain this:—

1. The ionization resulting from the high temperature of the spark.
2. The presence of hot metal vapour.

3. The emission of cathode rays by the cathode due to the influence of the ultra-violet light given out by the spark.

In conclusion I wish to say that my heartiest thanks are due to Prof. J. J. Thomson for the kind and liberal hospitality with which he received me at his laboratory, and for the continuous interest he has taken in my work.

Cavendish Laboratory, Cambridge.

XXIX. *The Anomalous Dispersion of Cyanin.* By Privat-docent Dr. A. PFLÜGER, *University of Bonn, Germany*.*.

IN several papers Wood† has communicated a new method of making prisms of solid cyanin, and also a repetition of the measurements of the dispersion-curve, as I made and used them several years ago for the proof of the Ketteler-Helmholtz dispersion-formula‡.

Using my photographic method, Wood finds that cyanin has a strong absorption-band in the ultra-violet, beginning at the wave-length $\lambda = 372 \mu\mu$. He says that in this part of the spectrum it makes the measurements of the refractive indices impossible, since the strong absorption prevents any impression on the photographic plate, even with a five-hours' exposure. He continues§: "Pflüger found no traces of this band, and gives values for the refractive index within its limits. It seemed at first that the reason of this might be found in the difference in the optical properties of fused cyanin and that obtained by the evaporation of an alcoholic solution, but we have found that films prepared in the same way as those by Pflüger show the band also."

My measurements of the refractive index [after the manner accurately explained ||] in this part of the spectrum were made on photographs, some taken with an exposure of 25 minutes, others with 40 minutes. The plates show plainly the double image of the iron lines used for the purpose of the measurements.

Furthermore, I have made photographs of the whole absorption-spectrum, which show plainly the absorption-band in the visible part of the spectrum, but not the faintest trace of an absorption in the ultra-violet. In these experiments the light of an iron spark passed through a quartz plate

* Communicated by the Author.

† Wood and Magnusson, *Phil. Mag.* [5] xlv. pp. 380-386; [6] i. pp. 36-45, January 1901. Wood, *Phil. Mag.* June 1901, pp. 624-627.

‡ Pflüger, *Wied. Ann.* lvi. pp. 412-432; lxv. pp. 173-228.

§ *Phil. Mag.* Jan. 1901, p. 41.

|| *Wied. Ann.* lxv. p. 199.