The Electrical Properties of Gases—IV.*

Which Enable Important Problems in Physics To Be Studied

By Sir J. J. Thomson, O.M., P.R.S.

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IN opening the fifth lecture of his course on the above subject, at the Royal Institution, Sir J. J. Thomson, O.M., P.R.S., recalled that on the last occasion he had discussed the relationship between the potential required to produce a spark and the width of the gap and the pressure of the intervening gas. He had pointed out that this potential depended solely on the quantity of gas present between the electrodes, so that so long as the product of the gaseous pressure and the width of the gap was constant the potential needed to produce a spark was also constant. It was a matter of indifference whether the length of the spark gap was small and the pressure great or the distance large and the pressure small. Hence, while in general the potential needed increased with the length of the spark, there was nevertheless a limit beyond which it was (with the gas at constant pressure) more difficult to get a short spark than a long one, and with very short gaps it became almost impossible to get a discharge at all. He proposed, on the present occasion, to explain some principles on which this peculiarity of the spark discharge might have been foreseen.

Consider, he continued, what was the condition essential for electricity to pass through a gas. This, as he had pointed out in a previous lecture, was a supply of negative and positive particles derived from the gas itself. By the action of rays of various kinds such particles could be liberated in a gas, but in the case now under consideration the gas, in order to conduct electricity, must manage to produce these ions for itself without the aid of some external agent. This the gas was able to do with the help of such a residue of negative particles as might naturally exist in the gas. Thus any such negative particle in the gas would, under the influence of the electric field, acquire velocity and energy. It would, moreover, sooner or later collide with a molecule of the gas, and if the energy it had acquired exceeded a certain limit the shock of the collision would split up the molecule into positive and negative ions. Being still under the influence of the field the original negative particle would again acquire velocity and energy sufficient to split up another molecule of the gas, and at the same time the negative particle it had liberated from the first molecule it encountered would act like its parent, and also acquire sufficient energy from the field to split up any molecule it met. The original negative particle in this way continually "bred" new negative particles on its course through the gas. In some cases it did this at a uniform rate, and each negative particle liberated at each encounter would act similarly, so that the number of these particles increased according to the compound interest law. Hence if A_0 denoted the number of particles originally present and a unity plus "the rate of interest," the number present after the lapse of the time t was given by the formula $A = A_0 e^{at}$. The rate at which these negative particles increased was, therefore, very great.

Something more than this was, however, needed to maintain the conductivity of the gas and to make the discharge self-sustaining. Under the influence of the field all the negative particles would be gradually swept away from the cathode, leaving nothing there to make the gas conductive by fresh ionization. Hence other means of ionization were necessary. This agent need not, however, be a powerful one in comparison with the negative particle. Thus suppose that each negative particle produced a new negative particle for each millimeter of its travel along the field. In a traverse of 3 mm. each would, by the formula already given, have raised its progeny to e^3, or, in round numbers, to 20. In 6 mm. the number would be 20×20 = 400, and in 15 mm. the number would be over 3,000,000. Each of these 3,000,000 negative particles would be accompanied by its corresponding positive ion. But to keep the system going it was only necessary to replace the single original negative particle, or, in other words, the 3,000,000 positive particles were only called upon to ionize one molecule of the gas. The discharge would, accordingly, be self-sustained even if the chance of ionization being affected at a single encounter between a molecule and a positive particle was almost infinitesimal.

Small as was the demand made, however, it had to be satisfied, but it need not necessarily be met by ionizing action on the part of the positive particles. He was, Sir Joseph Thomson continued, by no means sure that the part played by these positive ions had not been overrated, and that the maintenance of the discharge might not quite possibly be due to radiation resulting from the impacts of the negative particles producing a sort of Röntgen radiation, part of which would strike back to the neighborhood of the cathode. He thought the effect of this radiation had been somewhat overlooked in considering the mechanism of the discharge. Whatever the mechanism in action, it need only be feeble, since millions of agents were available. Hence from the practical standpoint the discharge might be considered as due to the fact that the negative particles were able to ionize the gas. Theoretically the positive ions came in, but so many of these were produced that they must be extraordinarily incapable if between them they were not able to produce the single negative particle required. If a traverse of 15 mm. gave 3,000,000 positive particles, one of 30 mm. would yield the square of this number, or 9×10^{12}. Hence, whenever there was so much gas between the electrodes that collisions were frequent, the criterion for a continuous discharge was that the negative particles should be able to ionize this gas. The condition might be expressed in the following fashion. Let X denote the electric force and λ the average distance between successive collisions of a negative particle with a molecule. At each collision it might be taken that the whole of the previous history of the negative particle was wiped out, and it had to start anew acquiring energy. Hence the distance λ between successive collisions must be such that the force X had time to give the particle the energy Q required to ionize the molecule. Hence

$$X = \frac{Q}{\lambda}$$

If V denoted the potential difference between the electrodes and d the distance between them, we had $V = Xd$.

Moreover, λ, the distance between successive encounters, was inversely proportional to the pressure of the gas, so that

$$V = \frac{Qd}{\lambda}$$

$$\text{or } V \propto Qdp$$

and was therefore constant when $p\,d$ was constant.

He had shown how easy it was to get up into millions of ionizing collisions. Conversely, by halving the pressure or the distance between the electrodes, the number of ions produced might be reduced from a million to a thousand. On again halving the pressure or the distance, the number would fall to a little over thirty. Halving again would reduce the number to less than six. In that case the task set the positive particles of producing the single negative ion was very different from what it was when there were millions of them available for the job. To get a discharge in such conditions it might be necessary to increase X, the electric force, to quite abnormal values before a self-sustaining discharge could be realized.

By still further reductions of the pressure the collisions with the molecules might be so few that but one negative particle out of a thousand would ionize a molecule and produce a positive particle. To maintain the flow in such case, this single positive particle would have to produce 1,000 negative ones in order to keep up the supply. Hence a stage must be reached when the discharge would fail—too few positive particles being produced to maintain the necessary supply of negative ones. It was easy to see, therefore, that at very high vacua a high potential difference would be required.

Similarly, if the pressure were high, the path λ between successive collisions became very short, and a high potential difference would again be necessary to produce a discharge. It followed, therefore, that the graph representing the voltage necessary to maintain a spark at different pressures would have the general form indicated in Fig. 1, and that at some point this potential would have a minimum value. In the case of air this minimum value was, roughly, 300 volts, and the product Pd corresponding to this minimum potential was approximately 7, when P was measured in millimeters of mercury and the distance d was expressed in millimeters. At this minimum potential the distance between the electrodes was about fifteen times the mean free path of the molecules, so that when the discharge was passing very freely a negative particle would have about fifteen collisions in passing from one electrode to the other. These collisions might be associated with the production of a sort of Rontgen radiation instrumental in producing the additional ionization, which was necessary to maintain a steady discharge.

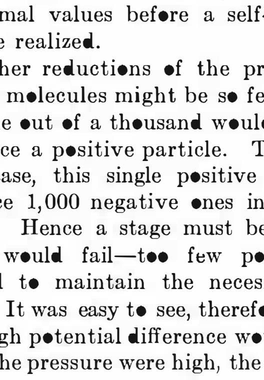
Fig. 1.

Ordinary cathode rays, the lecturer continued, caused glass to phosphoresce, and so did the radiation to which he referred. This new radiation, however, caused glass to phosphoresce a dark olive-green color, quite distinct from the yellowish-green phosphorescence produced by the cathode rays. The new radiation could, moreover, be refracted through white fluorite, and was no doubt a form of light well up in the Schumann region of the spectrum. It had very great powers of ionization, and the speaker thought it quite possible that the additional ionization required to maintain the discharge was produced by this soft type of Röntgen radiation.

It might be noted that luminous radiation might also be produced by the impact of negative particles with the molecules of the gas in a discharge tube. This the speaker demonstrated with a tube in which the cathode was a hot filament of wire supporting a speck of lime, which, in these conditions, emitted a large quantity of negative particles. These acquired velocity in passing through the electric field which was established between the two electrodes of the tube, and the energy given them could be varied by altering the potential difference between these two electrodes. The lecturer showed that with 40 volts' difference of potential the gas in the tube was not rendered luminous by its collisions with the cathode particles, but that with 80 volts the luminosity was quite distinct. The change, he said, took place quite abruptly on the attainment of a certain definite voltage, which was that at which the moving particles acquired sufficient energy to ionize the gas.

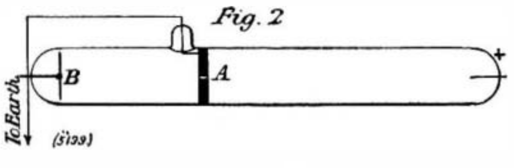
Fig. 2

The visible radiation thus produced had, however, itself no power to ionize the gas, but with higher voltages the soft Röntgen radiation referred to above was also emitted, and this was able to produce ions, an effect which had not hitherto been taken into account.

The ordinary kind of discharge could be explained if the field were of uniform strength from electrode to electrode, and the graph representing the electric force at each point was then a straight line parallel to the base. There were, however, cases in which the electric force was not uniform throughout the tube, and in that case the appearance of the discharge was also not uniform. This effect was observed over a certain range of pressures only, and with certain gases. At fairly high pressures the luminosity of the positive column was uniform from end to end. If, however, the pressure were continuously lowered a stage was ultimately reached when the column broke up into a series of detached portions of luminosity, separated from each other by dark spaces. If, however, the pressure were still further lowered these striations disappeared and the luminosity became uniform again.

This the lecturer demonstrated with a discharge tube in which the pressure was varied by absorbing the residual gases with charcoal cooled in liquid air. The effect was, the lecturer showed, also dependent on the diameter of the tube, so that with a tube consisting of a wide and narrow portion in series with each other the striae were much closer together and more difficult to produce in the narrow portion than in the wide.

The lecturer next showed what was, he stated, a somewhat paradoxical experiment, in which the complete phenomena of the discharge in a vacuum tube were obtained with no difference of potential between the electrodes. The apparatus used is represented in Fig. 2. It consisted of a long tube with a positive electrode at one end as indicated; while there was a cathode at A with a hole in it and a third electrode at B. The two

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*From a report in *Engineering*.

terminals A and B' were connected together by a wire, which was earthed. Hence both A and B were at the same potential. On establishing a discharge between A and the positive electrode, however, the whole of the phenomena of the discharge were repeated in the left-hand extension of the tube between A and B. There were the negative glows, the dark spaces and the positive column, which showed striations. This result was obtained although A and B were at the same potential. The effect originated, the lecturer said, in the passage of positive particles through the hole in A, and he showed that it disappeared entirely if the direction of the current was reversed. The electric force averaged over the space between A and B was zero. At some points in the interval it was opposed to the current, while at others it favored it.

This experiment served to emphasize a most important point. In dealing with a discharge at low pressures we had not to deal so much with the value of the force at a particular point as with its average value over a considerable distance comparable with the mean free path of the particles. In order to produce ionization the particles must have acquired a certain velocity, and if the path were very short, so that the force might be taken as uniform over its length, we had the relation; energy acquired = force × distance. If, however, the path were some centimeters long and the force variable from point to point, it was necessary to average it over the whole path, so that we had to deal not with its value at particular points, but with its integral over a considerable distance. Hence the requisite energy might be acquired even if over part of the path traversed the force acting on the particle was negative.

Professor Thomson stated that he had himself measured the distribution of the force in the neighborhood of the striations. The convex side of a striation was turned towards the cathode of the tube, and he had found that just in front of the convex side of the luminous patch the force was negative; that is to say, it was tending to move the particles in the wrong direction. It then increased very rapidly as the striation was more closely approached, and rose to a considerable positive value. It then fell off again quite slowly to a negative value, and the cycle was repeated at the succeeding striation. All up the steep portion of the curve of electric force there was, the lecturer stated, a great preponderance of negative particles, while on the reverse slope of the curve of force the positive particles preponderated.

To map out the state of the electric force in the neighborhood of the striations he had employed a fine stream of cathode particles shot across the discharge tube and falling upon a glass screen, where they produced a spot of phosphorescence. He had used for discharge tube the vacuum over the mercury in a very long barometer tube. The two electrodes were connected together by a sheet of glass, and the whole unit, thus formed, was floated on the mercury. By altering the level of the latter a striation could be moved up past the fine cross-stream of cathode particles, and the state of the field traversed by these was shown by the displacement of the phosphorescent spot on the glass. In cases in which the pressure in the discharge tube was too high to permit of cathode rays being produced, he had taken advantage of the fact that to produce a very short spark a big E.M.F. was required. He had, therefore, enclosed the cathode in a capillary tube, so that there was not room for the production of an ordinary spark, and cathode rays were obtained instead.

In this way he had found that the force might be actually negative on the cathode side of a striation, provided the pressure was quite low. At higher pressures it did not become actually negative, but fell much below its average value.

How were stable striae possible? Suppose we started with a particle moving slowly in a region where the force was very low. Its energy would then for a certain distance be too small to produce ionization, and the tube would therefore show a dark patch. As the particle proceeded, however, it ultimately acquired a velocity sufficient to ionize the gas, producing thereby positive particles which moved so slowly that they might, as a first approximation, be regarded as at rest.

These positive particles remaining nearly stationary, while the negative ones moved on, counterbalanced somewhat the negative charge, but the field went on increasing until a point of the tube was reached where the number of positive particles present was equal to the negative particles there present. At this point the graph of the electric force became horizontal and then fell, since a negative particle having passed through this point would be attracted back by the positive charges left behind it. The rate of ionization did not, however, begin to fall off at the same time as the field, since the position in which the electric force attained its maximum value was not the same as that in which its integral over a certain distance became a maximum, so that the energy of the negative particles still continued to increase for some time. Ultimately, however, it fell below the ionization point, and the particle had then to pass through a portion of the tube in which there was again nothing but negative ions; but as it was approaching a region where the positive particles were again in excess, it acquired velocity afresh and the cycle was again repeated. The alternations of brightness characteristic of striation were in this way produced. To obtain them it was necessary that the drop of potential from center to center of two striae should be less than would be required if the force were uniform over the whole distance.[1]

In conclusion the lecturer stated that the condition in which the total fall of potential required for the transport of the ions between two points was less with a non-uniform force than with a uniform one, held only between certain limits of pressure.

[*To Be Continued*]

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[1] [As a mechanical analogy we would suggest the case of a gravity railway. It is known that the path of quickest descent between two points at different levels is not a straight line but a cycloid, and if passengers were to be transported between two such points the capacity of the line, or the number of passengers carried over it in a given time, would be greater if the line were laid out to the path of quickest descent than as a uniform gradient.—Editor *Engineering.*]

Removal of Stains in the Laundry*

As a rule, the washing process, as carried out in the laundry, easily removes most of the stains from the goods. Hence, it is only in exceptional cases that a laundry worker must resort to special chemicals to remove them. It is, however, good policy to be prepared to use regular spotting agents for the removal of any obstinate stains, for a little attention paid to the removal of such stains will pay well. I have frequently sent to the laundry collars which were spotted with ink or color, and generally I have had them returned minus the dirt but still stained. It is such a simple matter to remove stains of this character, and the number received is so small, that it is a shame not to make an effort to eradicate them.

In order to simplify the classification of stains, I have divided them into two groups, which I have called "oil or fat stains" and "color stains." Stains of the first group are caused by lubricating oils, food greases, tar, paint, varnish, etc., and are characterized by perfect insolubility in water. In order to treat stains of this description satisfactorily, it is necessary to make use of chemicals in which they are soluble. The so-called organic solvents do the work perfectly. Color stains are due to highly colored fruit juices, inks and dyes. These stains are frequently met with and are very noticeable. In order to eradicate these stains it is necessary to destroy the color, for which purpose the so-called "bleach spotters" are used.

There have been stain removers on the market for which the claim is made that they will remove any spot from any fabric. That one chemical or mixture of chemicals can eradicate successfully all stains is out of the question, and even if such a product were possible, it would be more expensive than taking the proper chemical for each case. The following six solutions will take care of all the stains which are met with in the laundry. It is possible to get down to only six solutions by considering the fact that the washing process in itself removes a great many stains.

ORGANIC SOLVENTS

Aniline oil, commercial strength.
Ether, commercial strength.
Carbon tetrachloride, commercial strength.

BLEACH OR DISCHARGE AGENTS

Hydrosulphite, conc., powder form.
Hypochlorite of soda, 2 degrees Tw.
Oxalic acid, 5 per cent solution.

The following matter relates to the removal of the various stains from white goods. There is always danger in the use of a spotter on colored goods, and this is especially true of the bleach or discharge spotters.

Oil, Grease, Tar and Paint Stains.—Stains due to lubricating oils are generally unaffected by the washing process, but they may be removed with carbon tetrachloride. Carbon tetrachloride also has the advantage that it is not inflammable. Grease stains, if due to animal fats, such as gravies, etc., are removed in the washing, animal fats in general being very easily saponfied. Tar is very difficult to remove, but the best thing to do is to rub the spot well with lard, in order to soften it, and then treat it with warm carbon tetrachloride. Paint, varnish and linseed oil stains are rapidly removed with hot aniline oil. Aniline oil will in itself leave a spot, but it may be removed with ether. Aniline oil should be kept protected from the light or it will become very brown in color, due to oxidation.

Color Stains.—Ink stains may be removed with the oxalic acid solution, followed by hypochlorite if the stain still remains. The treatment with oxalic acid is to remove the iron which is contained in most inks, while the hypochlorite rapidly bleaches any coal tar color which may be present. Stains of dyestuff are treated with hypochlorite, which removes all except a few yellows and browns. This treatment, however, is only of interest for cotton goods, woolens being turned yellow by this reagent. In point of efficiency, hydrosulphite ranks next in the removal of color stains, and is especially valuable for colored cotton and woolen goods. While hypochlorite of soda removes color stains very rapidly, it acts too efficiently to be of value for removing stains from light colored goods. As before stated, as it is not of value for wool and silk, its application is rather limited. Hydrosulphite of soda may be used on all fibers except tin-weighted silks, which it turns gray. Hydrosulphite of soda is also better suited to the removal of fruit stains, particularly those yellowish stains which appear to be fast to chlorine.

The hydrosulphite compound which is of special value for the removal of stains is the sodium compound, which readily dissolves in water without the aid of acids. One or two ounces of this product added to a load of badly-stained or gray-looking goods will whiten them considerably. To use it as a spotting agent, a little should be dissolved in warm water, immediately before use, and the solution applied to the stain in the usual manner. It is also possible to moisten the stain and apply the dry product, but this method is much harder to control. As this product loses its strength rapidly in solution, only enough should be dissolved for the job in hand.

*A. F. Musgrave in the *National Laundry Journal.*

Barometric Gradient for Discovering Unknown Seismic Zones

VARIOUS Japanese investigators have found that the barometric gradient offers a means of discovering unknown seismic zones or faults, as it was shown that the prevailing gradient at the zone at the time of an earthquake was nearly perpendicular to the seismic zone. The method was found more feasible and more accurate than that of constructing zones statistically by locating a large number of epicenters.—From a paper by A. H. PALMER on California Earthquakes during 1916, in *The Bulletin of the Seismological Soc. of Am.*

Determination of Carbon in Steel by Micrographical Examination

THE estimation of carbon in steel by measuring under the miscroscope the relative proportions of ferrite and pearlite, may be disturbed by the inequality of the distribution of carbon throughout the metal. This heterogeneity, which is not indicated by chemical analysis, may be detected by observing large surfaces with a low magnification. Errors may also arise through the ferrite and pearlite being deposited in laminated schist-like form. In this case, duplicate sections, one parallel, and the other perpendicular, to the direction of the alinement of the layers, should be examined. Variations in the fineness of the texture lead to the necessity of varying the magnification with each specimen, so as to bring the mean dimensions of the areas of ferrite and pearlite to the same scale. Samples of metal for examination must first be subjected to the same conditions of annealing, as the structure of the pearlite and its association with ferrite and cementite are largely modified by the heat treatment received. The presence of manganese and chromium, which affect the relative proportions of ferrite and pearlite, gives an illusory high value in the micrographical estimation of carbon.—Note in *Journal Society Chemical Industry* in an article by A. PORTEVIN, in *Rev. Mét.*

New Carbon Remover

MANY preparations have been put on the market for quickly removing carbon from the cylinders of gasoline engines. The latest to appear is acetol, a liquid applied by injection through the spark plug opening. It is asserted that the carbon is thus rapidly softened, and the detached material is blown out through the exhaust when the engine is restarted.