The Electrical Properties of Gases—V.*

Which Enable Important Problems in Physics To Be Studied

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

CONCLUDED FROM SCIENTIFIC AMERICAN SUPPLEMENT No. 2170, PAGE 70, AUGUST 4, 1917

IN this last lecture of his course on the above subject Sir Joseph proposed, he said, to consider the application of some of the results demonstrated on previous occasions to certain important questions in general physics. Of these, the first was, What was responsible for the luminosity of gases? He had shown that in a discharge tube the luminosity varied from point to point, so that in some parts there was an absence of light, while other parts were bright. These variations in the luminous appearances ought to give some information as to what influenced the emission of light from gases. The theory of striations showed that in certain parts of the tubes in which they appeared there was no ionization of the gas present. The operation of ionization consisted in splitting up the molecules of a gas into negative and positive residues, and it might be that the production of light was the result of ionization. If so, two questions arose. In the first place, was ionization a necessary condition for luminosity? or, in other words, when we get light, did we also always have ionization? There was ample evidence that ionization had certainly a good deal to do with luminosity, as he had shown in an experiment (previously reported) in which electrons produced from a hot wire were squirted through a gas. In this case, unless the speed of the electrons was increased beyond a certain definite limit no visible radiation was emitted by the gas. When, however, the speed of the electron exceeded a certain critical value, the gas became luminous and concurrently the strength of the current went up, which was evidence of ionization of the gas. There was thus undoubtedly a close correspondence between ionization and luminosity. Admitting this close association between the two, the question remained as to whether ionization was essential.

The evidence showed that there were cases in which luminosity was not attended by ionization. In this connection it was important to bear in mind that it was very much easier to detect ionization than luminosity. The tests for ionization were of extraordinary delicacy, as was indicated by the fact that it was possible to detect four or five ions in a cubic centimeter of gas containing some 2.75×10^{19} molecules. If this ionization were accompanied by radiation the energy of this was far too small to be detected by the eye or by the longest possible exposure of a photographic plate. The tests for ionization were, therefore, so delicate that it was possible to say with confidence that some few cases were known in which we had luminosity without ionization. One of the most interesting of these was afforded by iodine vapor, which phosphoresced when exposed to the action of ultra-violet light. Tests for ionization when the gas was thus emitting light showed no conductivity. Nevertheless it had been found that, if not actually ionized, some progress had been made toward such a condition, as the vapor was more easily ionized when phosphorescing than when in its natural condition.

Anthrane vapors, and those of some other compounds characterized by the presence of the benzene ring, fluoresced under the action of ultra-violet light, and here, again, there was no ionization. These cases seemed to be exceptional, but were perhaps only apparently so, the luminosity being due to a process very similar in kind to ionization, which consisted essentially in the separation of an electron from an atom of the gas or vapor. It was, however, possible to imagine cases in which the shift of the electron was not sufficient to take it outside of the sphere of action of the atom.

The electrons might be looked on as the mortar binding together two atoms of a molecule. The suggestion therefore arose that the luminosity unaccompanied by ionization was due not to the ejection of an electron, but to its transference from one position in the molecule to another. In chemical language this would correspond to an alteration in the bonds connecting the atoms together. Thus two atoms doubly linked in the normal state, as $\bullet = \bullet$, might be altered so as to be singly linked thus, $-\bullet - \bullet-$. We would thus get a movement of an electron of the same kind as in complete ionization. But this movement would be wholly intra-atomic or intra-molecular. He thought that some action of this kind was responsible for phosphorescence.

In certain cold flames, again, there were no traces of ionization, but there might be a sort of quasi-ionization, giving similar results in the matter of light emission.

Again, there were many cases of ionization unaccompanied by any visible production of light. An instance

of this was afforded when gases were ionized by Röntgen rays. This might be due to the difficulty of detecting light. Summing up, it might be said that there was certainly a close connection between ionization and luminosity, but it would be going too far to say that complete ionization was essential to the production of light.

In any case ionization was never permanent. The missing electron was, sooner or later, always replaced, and a point of interest arose as to at what state of the process between the loss and the replacement of an electron was luminosity produced. Was it when the electron returned or when it was ejected? The study of striations threw no light on this matter, but there was independent evidence which indicated that it was the return of an electron to the atom which gave rise to luminosity.

He had, the lecturer continued, made some experiments not very long ago which threw light on this point. He was investigating the production of ionization by a form of radiation intermediate between ordinary Röntgen rays and ordinary light. These "soft Röntgen rays" were produced by the impingement on solid particles of electrons moving at different speeds. It turned out that no radiation whatever was produced until the energy given to these electrons exceeded that due to a fall through some 15 volts to 20 volts. At this limit a small amount of these soft radiations was emitted, which increased as the voltage was raised. The type, however, varied very little even when the fall was changed from 20 volts up to 100 volts or 200 volts. Through all this range by far the greater part of the radiation produced was of the same type as that produced by the 20-volt drop. It was not wholly of this type, since there was an admixture with other constituent radiations which increased with the energy given to the electrons, but nevertheless, the major proportion of the total remained unchanged in character in spite of the large increase in voltage. A point was, however, at length reached in which a further addition to the energy of the electrons led to the emission of a different type of radiation, which in its turn persisted through a considerable range of voltage. As before, there were stray constituents depending upon the energy supply.

These peculiarities were easily explainable if the radiation was due to the replacement of a lost electron. The energy involved in this would be always the same, whatever the speed of the electrons which had effected the original ionization. With a certain energy the colliding particles electrons would be detached from one position in the atom, but to knock off other electrons from other positions the energy would have to be increased. There was thus reason for believing that in the main luminosity resulted from the return of an electron to the positive residue of an atom.

It was possible to have several types of positive residues. Positive rays, for example, were found consisting of atoms carrying one charge, and also of atoms carrying two positive charges. Thus, if an electron returned to an atom which had only one positive charge the result might well be different than when it returned to an atom showing two positive charges. Indeed, Stark had been able to distinguish certain spectral lines as due to residues having one positive charge and others as due to doubly-charged residues. This fact was connected with some extraordinary changes in the color of certain gases when the character of the discharge through them was altered. A notable instance was afforded by argon. A tube charged with this gas emitted light of a purplish color when the discharge through it was derived from an ordinary induction coil; but when Leyden jars were included in the circuit the light was of a bright, steel blue color. Hence by altering the conditions of the discharge it was possible to change the type of luminosity given out. The difference might be due to there being a great preponderance of singly-charged residues in the one case and of doubly-charged residues in the other.

Although the luminosity was due to the return of an electron to the atom, previous ionization was essential. More energy was required to ionize one kind of atom than another. Hence in a mixture one kind might be excited to luminous emission and not the other.

This the lecturer illustrated by placing a bulb, filled with a mixture of hydrogen and chlorine, as secondary to a coil traversed by very rapidly alternating currents. The hydrogen was, he stated, more easily ionized than the chlorine, and the green light from the latter gas was accordingly only visible near the surface of the bulb,

where the field was very strong. The inner layers showed only the red of hydrogen, as in these inner regions the negative particles did not acquire sufficient energy from the field to ionize the chlorine.

Summing up to produce luminosity it was necessary in general to have positively electrified atoms to which electrons could return. There was one method known, the lecturer continued, by which it was possible to obtain such positively electrified particles in great number. It would be a complicated matter to use discharge tubes filled with potassium or sodium vapors; but a large supply of positively charged atoms of these elements could be obtained by coating the positive electrode of a tube with a paste made up out of their iodides or other similar salts. When the discharge passed the positive electrode got hot and the salts evaporated, and a stream of positively electrified ions was obtained, which had very considerable luminosity.

A point of some difficulty arose in attributing luminosity to the return of an electron. There was reason to believe that the hydrogen atom had only one electron, since in positive ray analysis no hydrogen atom was ever found to have less than one electron. How was it, then, that from this single positive residue and this single electron that we got the complicated hydrogen spectrum. He did not refer here to the second spectrum of hydrogen, with its almost infinite complication, but to the ordinary spectrum as represented by the Balmer series of lines. It would be natural to expect that from a combination of one electron with one positive particle symmetrically placed, but one spectral line should result, but actually there was a practically infinite number.

One view advanced amounted to this: that there were practically an infinite number of kinds of hydrogen atoms. It was, in fact, quite possible to make up an infinite number of neutral atoms consisting of a positive particle in equilibrium with a negative one. Such an equilibrium showed that there must be a repulsive force to keep the two apart. One way of providing for this was to attribute the repulsion to centrifugal force, and by suitably altering the speed it was possible to get, on this hypothesis, a hydrogen atom of any size. This, however, did more than was required, since in that case the series of lines would merge into a continuous spectrum. Something more was necessary. Those acquainted with hydro-mechanics would know that in a vortex ring in a liquid the speed of a particle was governed by the relation $v r = \text{constant}$, where v denoted the speed and r the radius of the path. This held wherever might be the center enclosed. If, however, two centers of vorticity were enclosed the value of $v r$ would be doubled, and if three centers were enclosed it would be tripled. Assuming the repulsion of the electron in a hydrogen atom to be due to centrifugal force, the value of this force was $\frac{v^2}{r}$, which might be written as $\frac{v^2 r^2}{r^3}$. For

equilibrium in its orbit this force must balance the attraction between the electron and the positive charge. Hence, if $v r$ represented circulation round a vortex ring the electron would be in equilibrium near in if it enclosed one center, but if it enclosed three it must be farther out. Hence possible positions varied by jumps.

This represented one way of regarding the origin of the hydrogen spectrum, but it was not in accord with chemistry, since the amount of energy required to ionize the atom would differ with the different positions of the electron. The chemical properties depended upon the energy required to separate the electron from its atom, and hence on the view above explained we ought to find that some hydrogen atoms were more electro-negative than others. So far there was no evidence in support of this. It had, however, to be borne in mind that much yet remained to be discovered, and that such a difference would not be found unless specially looked for. It was, therefore, quite possible that if chemists set themselves to investigate this point confirmatory evidence might be forthcoming. At the present time, however, the theory just explained was not backed up by any chemical evidence.

There was, however, another way of regarding the matter. The field of force between the electron and the positive charge might be represented by lines of force stretching from one to the other.

If we regarded these as having a material existence and shot an electron between them at a high speed they would be disturbed, and we might thus get vibrations of the lines of force independent of the electron to which

*From a report in Engineering.

they were attached. In this way we might derive a very complicated spectrum from a system consisting of but one positive and one negative particle.

Coming next to the structure of the atom, the lecturer said he would consider first the characteristic Röntgen radiations which would be derived from atoms. These Röntgen rays were an extreme case of light rays, and were just as characteristic of a particular atom as was its ordinary spectrum. These Röntgen-ray spectra were, however, of such simplicity that the laws which governed them sprang out in a way which was not possible with such entangled sets of lines as formed the luminous spectra.

Mr. Mosley (whose death on active service had been so great a loss to science) had shown that the frequency of the characteristic Röntgen radiation from any element was proportional to the square of the "atomic number." This atomic number must be distinguished from the atomic weight. It denoted merely the order in which the elements came when arranged according to their atomic weights. Thus the atomic number of hydrogen was 1, that of helium 2, of lithium 3, and so on. Theory indicated that the atomic number was proportional to the number of free electrons in the atom. In formulating his law Mosley had to suppose that two elements still remained to be discovered.

The connection between the atomic number and the atomic weight was of extreme interest. The most characteristic feature of the list of atomic weights was their tendency to approximate to whole numbers, although the differences were appreciable in some cases. In the case of the smaller atomic weights the difference was nevertheless astonishingly small, and it was quite out of the question that it could be a mere matter of chance. We were for this and other reasons led to believe that the atom was built up of a number of positively charged units, each having a weight equal to that of the hydrogen atom, combined together. The positive charge in the atom was proportional to the number of these units and hence to the atomic weight. We knew, however, that the number of free electrons was not equal to the atomic weight but to the atomic number.

How did the positive units stick together? It was not legitimate to suppose that the law of the forces between charges so closely adjacent was the same as when they were separated by considerable distances. Still, whatever the law governing it, the repulsion existed, and some sort of cement was required to keep the charges together, and this was provided by a certain number of electrons mixed up with the positively charged units. These had to be brought down to the center of the atom from the exterior, thus reducing the number of free electrons below that of the positive charges.

A mathematical investigation of the conditions of the stability of such a nucleus was for the present almost impossible, but if we studied the list of the atomic weights certain rules were apparent. Confining attention to elements with atomic weights under 40, which were these most accurately known, it was to be noted that if the atomic weight were divided by 4, the residue was always either zero or 3. There were but two exceptions to this rule, viz.: beryllium, with an atomic weight of 9, and nitrogen, of which the atomic weight was 14. With numbers given at random there ought to be as many with one remainder as with any other, but the data showed that the elements could be divided into two types, with which the remainders, after dividing the atomic weights by 4, were zero and 3 respectively. This law would result if we supposed that the number of electrons going to produce stability of the nucleus must be an even number and at least one-half the number of positive charges they bound together. If we tried to build up the elements on this rule with one positive charge no electron cement was necessary, and we thus had hydrogen with one positive unit. With two positive units we should require by the proposed rule at least one-half the number of cementing electrons, but the half of two was an odd number, and we had, accordingly, no element of atomic weight 2. In the case of three nuclei we must have at least one-half the number of nuclear electrons; that was to say, in this case, two, which was an even number, and an element of atomic weight 3 was, therefore, possible. It would be remembered that in the course of his positive-ray analyses he had very frequently found particles with an apparent atomic weight of 3. It would, however, be very difficult to get chemical evidence of the existence of this body, since two of the positive charges were neutralized by the central electrons, and the electrical field produced would be indistinguishable from that of hydrogen. It was this field which determined the chemical properties of the atom, and hence an element of atomic weight 3 would be very elusive to chemical tests. Its constitution would be identical with that of hydrogen and, in fact, he had in the past considered his find as H_3 . It would seem, however, that an element of this atomic

weight might possibly exist, differing from hydrogen only in other than chemical properties. Coming to a nucleus of four, this, by the rule, would be stable with two nuclear electrons, as half of four was an even number. We had accordingly helium, which was known to have two free electrons. With five positive charges at the center of the atom, the number of cementing electrons could not be three, as this was an odd number. Four was a possible number, but in that case the chemical properties would be identical with those of hydrogen, and such an element was not known to exist. With six positive charges we could not have three cementing electrons, since the three was odd, and with four the element having but two free electrons would not be distinguishable chemically from helium. With seven, four cementing electrons would serve, and we got lithium. With eight, there was a gap, no element of this atomic weight being known, while beryllium, with atomic weight 9, should not exist. Nitrogen provided the only other anomaly. With ten we could not have five bonding electrons, as five was an odd number, and an element of atomic weight 10 was unknown. With eleven, we got six bound electrons and five free ones, corresponding to boron, and twelve positive units gave us carbon. Proceeding in this way it was possible to account for all the elements up to atomic weight 40, with the two exceptions already stated.

Above this limit the same principle could be applied, but more negative charges than one-half the total of positive ones were needed as cement. In fact, a discontinuity appeared with calcium, after which the positive charges required four more than half their number of electrons mixed with them to hold them together. Later on further critical stages became evident at which the binding electrons had to be in still greater excess over the figure of one-half the positive units. The elements located where one flight ended and the next began had properties of an interesting character. There were long series throughout which the law governing the number of bonding electrons was constant, and then came points of discontinuity at which a fresh series commenced.

In work of this kind it was important to take the atomic weight as proportional to that of hydrogen. Chemists preferred to refer the atomic weights to oxygen, as being more convenient for their purposes. Taking hydrogen as the basis, it would be found that with very few exceptions the atomic weight was always less than the nearest whole number. To this rule silicon and chlorine provided the only exceptions. It was known that mass was not constant, but depended on the amount of energy represented. If we had systems built up with positive and negative particles which required a large amount of energy to pull apart, the mass of the system would not be the same as that of its constituents when separated from each other, but would be slightly more than in the latter case. In actual atoms the mass was slightly in defect. The amount of the change in mass could be calculated by the rule that if a mass equal to the missing quantity were set to move with the velocity of light the kinetic energy represented would be equal to the work required to bring the constituents of the atom together again. With the exception of silicon and chlorine, the mass of the atom was always just a little less than the sum of its constituents. This fact indicated that work must have been done in pushing the constituents together. The amount of this could be estimated by the difference between the atomic weight and the nearest whole number. The amount thus determined represented a greater amount of energy than had yet been found in the particles emitted by radio-active bodies. There was thus a great store of energy in the interior of ordinary atoms.

The biggest discrepancy in the rule that atomic weights approximated to whole numbers was found in the case of chlorine, the atomic weight of which, referred to that of hydrogen, was 35.2. [Referred to oxygen as 16 it is 35.46.] If this figure could be relied on it would mean that no work had been expended in building up the chlorine atom. He was inclined to think, however, that the real reason for the difference between chlorine and other elements was that chlorine as we knew it was mixed up with molecules of another body with identical chemical properties, but of slightly greater atomic weight. If the true figure for chlorine was 35 there would be 18 inside electrons and 17 free electrons. An atom with atomic weight 39 and with 22 nuclear electrons would also have 17 free electrons and the same chemical properties as chlorine. The addition of 3 per cent of such a body to true chlorine would account for the whole of the discrepancy. He hoped to attack this question by the positive-ray method of analysis, and to find out whether any evidence could be obtained of a chlorine with an atomic weight 4 units greater than that of ordinary chlorine.

Aircraft Testing

A GENERAL account of some of the methods of testing the performance of aeroplanes as practised by the Testing Squadron of the Royal Flying Corps was given by Captain H. T. Tizard before the Aeronautical Society.

He stated that, so far as England is concerned, the general principles of the scientific testing of aeroplanes were first laid down at the Royal Aircraft Factory. The methods of reduction adopted by the Flying Corps were based to a considerable extent on those of the R.A.F., with modifications jointly agreed upon; they have been still further modified since, and recently a joint discussion of the points at issue has led to the naval and military tests being coördinated, so that all official tests are now reduced to the same standard.

CLIMBING TEST

In order to reduce the results of a climbing test to standard atmosphere (i. e., the density of dry air at 760 mm. pressure and a temperature of 16 deg. C.) observations are required at intervals of the time from the start and of the height reached at those intervals. Here the difficulty arises that there is no instrument which records height with accuracy. The aneroid has faults partly unavoidable and partly due to those who first laid down the conditions of its manufacture. As now graduated it will give the correct height only if the atmosphere has a uniform temperature of 50 deg. F. (10 deg. C.) from the ground upward. This temperature is much too high, and only on the hottest days in summer, and even then very rarely, will the average temperature between the ground and 20,800 feet be as high as 50 deg. F. In winter or cold days the reading may be 2,000 ft. too high at 16,000 feet, the aneroid showing 16,000 feet when the real height is only 14,000 feet.

Hence a temperature correction must be applied, and on account of its magnitude it is important that observations of temperature should be made during every test. For this purpose a special thermometer is attached to a strut of the machine, well away from the fuselage and clear of any warm air coming from the engine. If the temperature is noted at the same time as the aneroid reading, both the atmospheric pressure and temperature at the point are known, and the density can be calculated or read off from curves drawn for the purpose.

The observations necessary (after noting the gross aeroplane weight and the net or useful weight carried) are therefore (1) aneroid height every 1,000 feet; (2) time from the start of the climb; and (3) temperature, with (4) air speed and (5) engine revolutions at frequent intervals. The observed times are then plotted on squared paper against the aneroid heights; and from the curve drawn through them the rate of climb at any part can be obtained (also in aneroid feet) by measuring the tangent to the curve at the point. This is done for every 1,000 feet by aneroid, and the true rate of climb is then obtained by multiplying the aneroid rate by the correction factor corresponding to the observed temperature. The time rates are then plotted afresh against standard heights, and the curve gives the rates of climb corresponding to the standard heights of 1,000 feet, 2,000 feet, 3,000 feet, etc.

At least two climbing tests, and if time permits three or more, are made of every new machine up to 16,000 feet, or more by aneroid. The final results given are the average of the tests, and represent as closely as possible the performance on a standard day, with temperature effects, up and down currents, and other errors eliminated.

SPEED TESTS

After reaching 16,000 feet, or whatever it is, the flyer's next duty is to measure the speed flying level by air-speed indicator at regular intervals of height (generally 2,000 feet) from the highest point downwards. The air speed indicator reads too low at great heights, and its readings must be corrected by dividing by the square root of the density of the air. Even the corrected speeds will be true only if there are no disturbances due to the pressure head being in close proximity to struts or wings.

Hence it is always necessary to calibrate the air speed meter, and the only way of doing this is to measure the real air speed by actual timed observations from the ground. One method is to use two camera-obscures, one of which points vertically upward and the other is set up sloping toward the vertical one. At one important testing center the cameras are a mile apart. But when a machine has to be tested quickly and low clouds or other causes prevent the camera test from being carried out, it becomes necessary to rely on measurement of speeds near the ground, the aeroplane being flown about 10 feet off the ground and timed over a measured run by two observers, one at each end of the course.