periods of time, it now having been used for more than a year without readjustment. The temperature of the grating-room remains so constant that exposures of several hours are successfully made.

The source of light was an electric spark. A condenser of variable capacity from 0.01 to 0.06 m.f. was used in the oscillatory circuit, the spark length being about half centimeter. The use of self-induction was avoided.

The earlier experiments were made with an electromagnet giving a field of 14,000 gausses with a gap of 8 mm. A Weiss electromagnet is now in use which gives a field of 23,800 gausses for a gap of 12 mm. This is especially convenient, since it can be rotated so that the spectrum may be examined along the lines of force or at right angles to them.

At right angles to the field a nicol prism is used to separate the *p*- and *s*-components. Along the field a Fresnel rhomb and a nicol prism are used to separate the two kinds of circularly polarized components. All of these components, as well as comparison spectra, may be obtained on the same negative by means of a slit diaphragm placed on a separate holder immediately in front of the plate-holder.

SUMMARY

Some work on series spectra, which the writer hopes to publish soon, led him to suspect that certain spectral lines are in reality close doublets, and that therefore they may be expected to show a complex Zeeman effect consisting of two *p*- and four *s*-components. This is indeed found to be the case. Conversely, the writer conceived the idea, independently of other investigators, that complex Zeeman effects occur because spectral lines which give rise to more than three Zeeman components are themselves complex in structure, and that the number of components in such a parent line is exactly equal to the number of *p*-components which it shows when placed in a magnetic field.

Investigation has shown that, in the titanium spectrum between λ 5050 and λ 3230, 62 out of 67 lines of complex Zeeman effect have twice as many *s*- as *p*-components; and that at least 70 per cent of these may be reduced to symmetrical Zeeman triplets, one for each *p*-component. In each complex type the reduced triplets are all of the same interval, which varies, however, from type to type in the same manner as for ordinary Zeeman triplets. Further study led to the prediction that in certain cases there are present one or more *s*-components which should appear unpolarized when viewed parallel to the field. This has been verified experimentally.

Several important questions still remain to be solved. One is the reason for the unsymmetrical distribution of the intensities which frequently occurs in the components of the reduced triplets. Another is that of the separation of the *p*-components when the magnetic field is applied. A third is that of the abnormal Zeeman intervals. But the same fundamental cause which gives rise to ordinary abnormal Zeeman triplets is probably responsible for the abnormal intervals of the Zeeman triplets to which the complex types may be reduced.

In conclusion, the writer wishes to recognize the valuable help of Prof. Theodore Lyman, of Harvard University, under whose supervision this work has been done. His many suggestions, particularly as to the best method of presenting the subject, have been invaluable.

The Electrical Properties of Gases—II.*

Which Enable Important Problems in Physics To Be Studied

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

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III

In his opening remarks Professor Thomson said that in his last lecture he had explained the results obtained by Mr. C. T. R. Wilson in his measurements of the electrical effects of thunderstorms. It thus appeared that in quite an ordinary storm some 30 coulombs of electricity passed with each flash from the cloud to the earth. He had since been asked if this observation could be reconciled with Faraday's conclusion that the total quantity of electricity in movement in a storm was comparable with that which could be obtained from a thimbleful of matter. It might therefore be interesting to put into figures what quantity of matter would be required to furnish 30 coulombs of electricity. The charge of electricity on the hydrogen atom was, in round numbers, 1.5×10^{-19} coulombs. Hence the number of atoms required to furnish 30 coulombs would be $\frac{30}{1.5} \times 10^{19} = 20^{19}$ atoms, or 10×10^{19} hydrogen molecules. In one cubic centimeter of hydrogen at standard temperature and pressure there were 2.75×10^{19} molecules, so that $\frac{10}{2.75} = 3.64$ cubic centimeters of hydrogen would be the amount of gas required to furnish the 30 coulombs of electricity.

He did not know whether Faraday's dictum had been quoted as a taunt to the thunderstorm or as a compliment to the electrical properties of matter. It had, however, to be observed that there was a great difference in the potential of the 30 coulombs bound up in 3.78 c.c. of hydrogen molecules with an equal amount of electricity of the opposite sign, and that of the same quantity in a thundercloud some miles above its corresponding positive charge. It was not possible to produce much in the way of electrical effects with even a large charge of negative electricity if it lay closely adjacent to an equal positive charge. The sole difficulty in getting such effects was to separate the two kinds of electricity, and this required the expenditure of work.

It was possible from Wilson's observations to find out upon what area of cloud the flash drew for the 30 coulombs it carried to earth. We knew how much electricity was required per square centimeter of surface to furnish an electric force strong enough to produce a spark. This amount was $\frac{8}{3} \times 10^{-9}$ coulombs, which therefore represented the charge on a square centimeter just before the flash. The area required to provide 30 coulombs was accordingly $\frac{30 \times 3}{8} \times 10^{9}$, or, roughly, 10^{10} sq. cm. = 1 sq. kilometer.

A peculiarity of the phenomenon was that the whole quantity came down in a single thread. The diameter of the flash was unknown, but was certainly not very large, and with this concentration of energy in a discharge of small cross-section it was easy to understand that enormous mechanical effects might be produced. These were, in fact, the speaker continued, considerable even with small-scale apparatus. This he demonstrated by placing a glass bulb, about 1½ inches in diameter, filled with water between the two terminals of a large Wimshurst electrical machine, which were some 10 inches apart. On operating the machine the bulb was shattered to pieces by the spark.

He wished, the lecturer proceeded, to consider next a very interesting problem, a satisfactory solution of which had not even been approached till within the last few years. What, in short, was the mechanism involved in a thunderstorm? and how did Nature work to produce this huge electrical machine capable of giving sparks six or seven miles long? How was the energy accumulated? In reply, he might say that for long there had been little doubt as to an essential part being played by water. It was not actually necessary that rain must occur at the same place as the lightning, but there must be rain or heavy clouds in the neighborhood. All theories of the thunderstorm looked to rain or clouds as in some way the origin of the storm. Lenard was the first to throw light on certain properties of water which were now believed to play a leading part in the generation of thunder-storms. Lenard found that whenever there was splashing of water electrification resulted, the two electricities being separated. This effect the lecturer showed by directing from a Goudie sprayer a very fine spray of water on the plate of an electroscope. The immediate divergence of the leaves showed that the plate was electrified by the spray. The charge on the plate was positive, but the air around the spray was negatively electrified. This experiment, the speaker continued, provided the essence of the modern view as to the production of thunderstorms.

It had long been known that there was something abnormal in the electrical conditions at the foot of a waterfall, which was in fact the source of some electrical disturbance, but the matter was not thrashed out until Lenard investigated it and showed that the water was positively electrified and the air negatively. He further showed that this electrification was extraordinarily sensitive to minute traces of impurity in the water. These might change not merely the amount of the electrification, but even its sign. Thus a trace of methy-violet too small for its presence to be detected by the eye would greatly affect the amount of electrification produced by a spray. This was, the speaker said, the more notable, since the coloration produced by methy-violet was so intense that it was frequently used for tracing out the flow of underground streams. This sensitiveness of the spray to impurities was discovered by Lenard, who found it impossible to repeat at Bonn experiments he had successfully made at Heidelberg, where the water supply was much purer.

Later experiments had carried the matter further and established a point which was fundamental in the theory of the thunderstorm. It had, in fact, been shown that whenever a drop of water split up, whilst still suspended in the air, the water of the drop was positively electrified and the surrounding air negatively electrified. Hence any process by which big drops were broken up into little ones, whether by clashing against each other or in other ways, constituted a potential source of electricity. It had been shown that if the surface of pure water was increased an electrical effect was produced. This was accounted for by the view that in its normal state a water surface covered itself with a coating of negative electricity which tended to stop the emission of further negative particles from the interior. If the surface were increased there would be nothing to stop negative particles coming out from the water to form a new coating. In this process some escaped and rendered the surrounding air negative, whilst the water became positively charged by the loss of these negative particles.

This electrification produced by the breaking up of a jet of water into a fine spray the speaker illustrated further by a very striking experiment. A fine jet of water was led through an orifice in the centre of a tin bath and rose vertically some 6 feet or 8 feet into the air before it broke up and fell back into the bath. In normal conditions the spray was so fine that the sound made was barely perceptible, but on bringing near the jet an ebonite rod electrified by friction the drops immediately became bigger, producing a very audible patter as they fell into the basin below. The jet, moreover, rose higher into the air before breaking up. In still another experiment the shadow of two jets of steam was thrown on to a screen, and it was shown that the shadows became much darker when a wire at the center of the orifices from which the steam escaped was coupled up to an induction coil.

The foregoing experiments showed that condensation was promoted and larger drops formed by the electrification. The application of these considerations to thunderstorms which he was about to make would, the speaker said, be found, for the most part, set forth at length by Dr. Simpson in vol. ccix of the Philosophical Transactions of the Royal Society.

In the first place everyone must have noticed that raindrops never approached in size the dimensions of the largest hailstones. All sorts of statements were to be found as to sizes attained at times by the latter. The lecturer had himself found in one meteorological paper a statement that certain hailstones were as large as oranges or melons. Taking the most moderate estimate of the size of a melon, nothing even approaching such a figure was attained by a raindrop. The size of the latter had, in fact, a sharply defined maximum value, the diameter, very rarely, if ever, exceeding 5.5 mm.

The actual diameter was difficult to measure, but the evidence was strong that there was this definite limit of size. In short, if a big drop began to fall through air it was flattened into a more or less disk-like form by the resistance experienced. It thus exposed a large surface very liable to disturbances, which differed from point to point. These caused the break up of the drop, with the result that even a drop of 5.5 mm. diameter could not exist for more than a few seconds. Every time a drop broke up electrification was produced, each drop acting as a little electrical machine. In the case of hail there was no instability produced by an increase in size, and hence large hailstones were possible.

Before a thunderstorm there was somewhere or other a strong upward current of moisture-laden air. As this rose it got cooled, so that the moisture was deposited in drops. Unless these drops exceeded a certain size they would be borne up with the rising current of air. Suppose, however, that they were such a size as to be just supported, falling down just as fast as the current carried them up. If they got any bigger than this by further condensation they would fall, and in doing so

*From a report in *Engineering*.

break up into smaller drops. In this process the surrounding air would be negatively charged, and this charge would ultimately be transferred to the smaller droplets or spray formed on the break up of the big drops, while the larger residues would be positively charged. The small droplets, with their negative charges, were then carried up with the ascending current of air, which was unable to move the heavy larger drops. The two charges were thus separated, all the positively charged drops remaining at the bottom of the cloud, while the light negatively charged spray was carried up by the current against the attraction of the positive charges left behind. The result was that the bottom of a thundercloud bore a strong positive charge, while the negative electricity was carried up to the top of the cloud. Between the two a very strong field was established, and this field, it would be seen, was the outcome of the peculiar property possessed by water of setting free electricity whenever a drop broke up. The strength of the field increased as further charges were liberated, until finally a spark passed from the top to the bottom of the cloud.

If there was a horizontal current of air at the top of the cloud the charges would be separated horizontally as well as vertically, and in that case the strong field would be established between each part of the cloud and the earth immediately below it. The discharge would then take place from the cloud to the earth.

Summing up, it would be seen that the process of producing a thunderstorm commenced on the breaking up of large drops of rain into smaller drops and fine spray. The latter picked up negative charges from the surrounding air, and the work of separating this spray from the positively charged drops was effected by air currents. If these were wholly vertical the discharge took place within the cloud, but if at the top of the cloud a horizontal wind was experienced, the top and bottom of the cloud were separated horizontally, and a field established between each component and the earth below. The flash in that case passed from the cloud to the earth.

In the foregoing explanation he had, Sir Joseph proceeded, utilized but one of the various ways in which drops and spray acquired charges. In violent storms however, the drops might knock against each other, and we might then get the effect of a little induction machine. Thus consider a drop in the electric field between the top and bottom of the thundercloud. By induction the top of the drop would be positively charged and the bottom negatively, and the drop would, moreover, elongate under the stress thus produced. If, then, the bottom of this drop were knocked off as the result of a collision, and was forthwith carried up by the air current, the arrangement would be the exact equivalent of an induction electrical machine.

If the views above set forth were correct we should have a patch of cloud constituted at the bottom of large positively charged drops. If, then, the upward current failed, these big drops would fall as the very heavy rain which was so frequent a concomitant of a thunderstorm, and these big drops should be positively charged. A great many experiments had been made to determine the kind of charge carried down by the raindrops which fell during a thunderstorm. The experiment was not an easy one, since if the drops were allowed to splash they would liberate negative electricity. There was, nevertheless, evidence that although the rain was sometimes positively charged and sometimes negatively, yet the heavy rain was always positively charged. Sometimes fine showers followed the heavy rain, and in this case the fine drops were negatively electrified.

As for the lighting, Wilson had found that sometimes it carried to earth a positive charge and at other times a negative one. This was quite in agreement with the view which attributed a discharge to earth to the drifting apart horizontally of the top and bottom of a thundercloud. The whole phenomenon was, it would be seen, due to the action of a kind of wind and water mill. Both water and wind were essential, the wind being necessary to carry the spray above the large drops or to knock the latter together, or to break them up if too big.

One remarkable effect sometimes seen had not been touched on in the foregoing theory. This was the thunderbolt or globular lightning. For his own part he had, Sir Joseph went on, never seen it himself, but there were a great many records of such experiences, constituting overwhelming evidence as to the occurrence of the phenomenon. In some cases a luminous ball was seen slowly falling to earth, disappearing when it reached the ground. In some statements this disappearance was said to be accompanied by a loud bang. So far this effect had not been satisfactorily explained. Another effect recorded was the running along the ground of a sort of luminous football. This might be merely a brush discharge over a line of metal piping under the surface of the ground, and was quite distinct from the globular lightning described in other records, which fell slowly from sky to earth.

What seemed to the speaker the most probable explanation was that this globular discharge differed in kind from the flash. The latter had, to begin with, to ionize the gas through which it passed, and it left its track in a conductive condition. An immediately succeeding discharge would therefore meet with quite different conditions, the track having been already prepared for it by the flash. The current in this discharge would, accordingly, not reach the same intensity as in the flash, but be more analogous to a continuous discharge.

To illustrate the resultant difference the lecturer took a discharge tube, and passed through it an intermittent current of such a periodicity that the ionization produced by one discharge had disappeared before the next followed. Each discharge had therefore to prepare its own track. In these circumstances the appearance of the tube was uniform from top to bottom, no one point being more luminous than another. A current of much higher frequency was next passed through the same tube, and in this case there were marked differences in the appearance of the glow, striae, or alternate patches of brightness and darkness, being very visible in the upper part of the tube. The difference was due, the lecturer stated, to the fact that in this second experiment the effects of one discharge had not died away before the next came.

Globular lightning, in his view, was accordingly a slow continuous discharge, with the peculiarity that the luminosity was concentrated into a ball. It was, moreover, possible to produce a discharge tube in which the luminosity was concentrated into a ball, and this ball could be caused to travel up and down the tube. This experiment the lecturer showed with a vertical discharge tube fitted with a Wehnelt cathode. By suitably adjusting the resistances in the same circuit with the tube, the discharge took the form stated, and was caused to shift up or down the tube at will.

This was the closest analogy he could find in the laboratory. He had, however, never himself seen the phenomenon of globular lightning, but the records left no doubt as to its existence, though the evidence was less satisfactory as to its ultimate disappearance with a loud explosion, or that it got into rooms and blew the windows out when it burst. The sulfurous smell, also recorded, appeared quite likely, being attributable to the formation of oxide of nitrogen. Those who had the fortune to see it should note the rate of fall and whether the globular discharge followed immediately after a flash. It need not necessarily follow the same path as the flash, since the ionized channel produced by the latter might be drifted some way off by the wind.

[*To be continued*]

The Compression of the Earth's Crust in Cooling

The principal cause of the elevation of continents and mountains has been ascribed by geologists to a state of horizontal compression of the earth's crust under which it frequently gives way, the strata being then folded into a shorter length in the neighborhood of the point where the weakness has been shown. Such a compression appears to be the only mechanism that has been suggested to be qualitatively capable of producing the observed results. The cause of the compression itself is, however, very uncertain. The contraction hypothesis is the most satisfactory of those that have been offered, but grave doubts have frequently been expressed about its quantitative adequacy. Previous estimates by G. H. Darwin and Davison rested on Kelvin's theory of the cooling of the earth. From radioactivity considerations, however, it has been shown that so much heat is actually being generated within the earth's crust, that if the same amount per unit volume were being produced throughout the mass, the temperature gradient at the surface would be 300 times its actual value, and the earth would be getting hotter instead of colder. There are many objections to this view, and it seems that the amount of radio-active matter per unit volume must decrease so rapidly with depth that the total is insufficient to supply more than about three-fourths of the present loss of heat from the surface. From a review of the evidence obtained by several different lines of investigation, Holmes has found that the observational data can be satisfied exceedingly well if the age of the earth be taken to be about sixteen hundred million years, and if the rate of liberation of heat per unit of volume decrease exponentially with the depth. The interval of time concerned is so much greater than that found by Kelvin that his theory of cooling requires to be revised so as to take into account our most recently acquired data, and at the same time the contraction theory, which depends on it, needs similar revision. This is the principal object of the present paper.

The level of no-strain is found now to be at a considerably greater depth than the older determinations gave, and at the same time the amount of compression at the surface is much increased. For both reasons the volume of crumpled rock is increased. On the basis of the exponential distribution of radio-active matter the available compression is 133 km., *i. e.*, enough to shorten every great circle of the earth by this amount. Actually, folding is not uniformly distributed over the earth, but nearly confined to certain definite lines of weakness, and in the valleys of East and Central Africa a tension is actually indicated. Some great circles thus show very little crumpling, and others are free to be folded to a greater extent than would be possible if the distribution of mountains were uniform. When a numerical estimate is made of the amount of compression required to produce the known mountain ranges, that found to be available on the contraction hypothesis appears to be quite adequate. The author gives a mathematical investigation into the effect on underground temperatures of a uniform distribution of radio-active matter through a horizontal layer, as also of other distributions of radio-active matter where the restriction is removed that the liberation of heat by such matter is assumed to be given by a special law of uniform distribution down to a particular depth and zero below. If it be assumed that throughout the process of cooling the earth preserves a state of spherical symmetry, then since the changes of temperature are not the same at all points, a state of strain must be set up consequent on the variations of volume that take place. This straining of the crust in cooling receives detailed mathematical attention. An examination of the amount of compression required to produce existing mountains is also undertaken. The author states that the elevation of a continent or a large tableland involves little crumpling within it, and no great amount at the coast so long as the slope is there gradual, so that in determining the amount of compression only the steep slopes of mountains need be considered. The theoretical and observed compressions are of the same order of magnitude; it thus seems highly probable that the contraction hypothesis is adequate to account for a very large fraction of the mountain-building that has taken place, and perhaps for the whole of it. The influence of denudation and thermal blanketing is examined at some length. An oceanic area is found to require round its margin a smaller horizontal pressure than the mean if it is to remain spherical, while a continental area requires a larger pressure. As the pressures must be equal, it follows that the earth cannot remain spherical. The only way in which this can happen is by a reduction of the radius of curvature of the crust, *i. e.*, the continents will tend to rise and similarly the ocean-bed will sink. The effect capable of being thus produced is very great. The adjustment of the figure of the earth to make the compression constant all over is not likely to be complete and the remaining part of the differential compression will be shown in extra folding in the continents, and diminished compression, or even, in extreme cases, a tension in the ocean-bed. A section of the paper is devoted to the causes of isostasy, and the author goes into the difficult problem of how the continents and ocean basins ever came to be formed. If there were no isostatic compensation, they might be attributed to crumpling by compression of a type not very different from that which produces mountain ranges. Continental areas, though varying enormously in height and shape, are fairly permanent in position and their height is really due to their being made of lighter materials than the ocean-bed. The question is to decide how the lighter materials succeeded in being collected to certain points, leaving the denser rocks exposed in other parts, and Jean's theory of Gravitational Instability, which the author considers to be the most satisfactory extant, is examined at some length. The concluding section is devoted to the effect of changes in the rotation of the earth. The truth of the theory of Tidal Evolution follows as a natural consequence of the present paper, and must, therefore, be considered with it.—A note in Science Abstracts on an article by H. Jeffreys in the *Philosophical Magazine*.

Removing Rust by Electricity

An electrolytic process of deoxidation has been patented in the United States. The object to be treated is made the cathode in an electrolyte containing phosphoric acid. In addition to its normal function of carrying the current, this acid acts as a solvent upon rust without attacking the steel or iron body beneath. It is in this last detail that its chief availability lies, since nitric, sulphuric, or hydrochloric acids would not display such moderation. Finally, the phosphoric acid is beneficial in preventing subsequent further rusting. The electrolyte is made by adding 10 parts of phosphoric acid to 90 parts of water, or by adding 10 per cent of the acid to a 10 per cent solution of sodium phosphate. A temperature between 50° and 70° C., is recommended.