Very often direct observation has shown the existence of these dusts in drops of rain, and this is what has happened in all parts of the world since the crepuscular colorations of 1883-84. The dusts collected have a composition which usually indicates a volcanic origin. It has been shown that other volcanic eruptions have been followed by red glows in the sky; it appears to me that it may also be shown that they have been followed by abundant rains. The eruptions which have been referred to are those of the Skaptar Joekull, in Iceland, in the beginning of May 1783; of a new volcano, since disappeared, in the Sicilian Sea early in July 1831; Cotopaxi, in America, in 1856; Vesuvius in 1862. These eruptions were followed by colorations; I add that they were followed by rains which exceeded the mean. The following, in millimetres, are the monthly heights of rain collected on the terrace of the Paris Observatory; the second line is the monthly mean of from twenty to thirty years:—

	May	June	July	Aug.	Sept.	
1783	62	86	43	75	51	
Means	47	49	86	47	42	
	Oct.	Nov.	Dec.	Jan. 1832		
1831	52	76	36	35		
Means	41	47	34	34		
	April	May	June	July	Aug.	Sept.
1856	51	117	49	54	54	60
Means	37	53	54	55	45	48
	Aug.	Sept.	Oct	Nov.	Dec.	
1862	52	51	73	17	42	
Means	45	48	51	36	35	

EXPERIMENTS ON THE PASSAGE OF ELECTRICITY THROUGH GASES—SKETCH OF A THEORY[1]

THE passage of electricity through gases has of late years become a very favourite subject for experimental investigation. A large number of facts have thus been accumulated, and it becomes of importance to see whether these facts throw any light on the theoretical notions which we have based on other branches of electrical inquiry.

If we have two bodies at a different electrical potential separated by a layer of air, we might imagine the air in contact with the bodies to become electrified, then move on, impelled by the electric forces, and re-establish equilibrium by giving up their charges. The passage of electricity through gases would then be similar to the diffusion of heat. But, however natural such a view would be, it is impossible to maintain it in the face of experimental facts. The experiments which I shall bring before you to-day seem to me to support, on the contrary, the idea that the passage of electricity through a gas resembles the phenomenon studied by Helmholtz under the name of electrolytic convection.

I shall avoid as much as possible all suppositions and hypotheses which cannot be put to the test of experiment; but it seems necessary to start with some assumption in order to avoid too great a vagueness in the subsequent explanations. The assumption which I shall make is this: In a gas the passage of electricity from one molecule to another is always accompanied by an interchange of the atoms composing the molecule. I shall also try to prove that many facts are easily explained by the assumption that the molecules are broken up at the negative pole.

If, in a vacuum-tube of the ordinary form, the discharge is passed at a pressure of about one millimetre, a luminosity is seen round the negative pole which is called the negative glow. A luminous tongue projects from the end of the positive pole, which I shall call the positive part of the discharge, without meaning to imply that it is charged with positive electricity. The positive part of the discharge and the negative glow are separated by a non-luminous space, which I shall call "the dark interval." The glow itself is divided into three layers, the thickness of which increases with decreasing density. Closely surrounding the electrode itself, we have in the first place a luminous layer, which on new electrodes is of a golden colour. The spectroscope shows the presence of sodium and hydrogen; the sodium is due to foreign matter deposited on the electrode, and the hydrogen is expelled by the action of the heat out of the electrode by which it had been absorbed. When the electrodes have been in use for some time, the golden colour disappears, and the spectrum belonging to the gas used is seen. The second layer is known by the name of the dark space. The third layer is the glow proper.

The theory which I shall endeavour to establish is this: That within the first layer the gaseous molecules are decomposed, that their negative parts are projected with great velocity through the dark space, that this velocity is gradually reduced by impacts within the glow, and that in the positive part of discharge the discharge takes place by diffusion except when stratifications appear.

According to the kinetic theory of gases, the molecule of mercury vapour consists of a single atom, which is incapable of vibration. Mercury has a very brilliant spectrum, which proves that the theory is incomplete in some important point. It is well known, on the other hand, that the theoretical conclusion receives support from the fact that the vapour-density of mercury vapour is anomalous. If, as is generally supposed, the molecule of the majority of gases contains two atoms, that of mercury can only contain one. If an essential part of the glow discharge is due to the breaking up of the molecules, we might expect mercury vapour to present other and much simpler phenomena than the gases with which we are generally accustomed to work. *This, indeed, is the case; for I find that, if the mercury vapour is sufficiently free from air, the discharge through it shows no negative glow, no dark spaces, and no stratifications.* At the ordinary temperature the spark does not pass through mercury vapour; but if a tube free of air, but containing mercury vapour, is heated, the discharge passes always in a continuous stream of light. It is not always quite symmetrical with respect to the two poles; and a very curious tendency of the spark is noticed, to pass at the negative pole rather from the glass out of which the electrode protrudes than from the metallic electrode itself. A brilliant sodium spectrum then appears at the point from which the spark sets out. Whenever small traces of air remain, stratifications are very apt to appear, as a mixture of air and mercury gives fine stratifications, but I have never noticed them after sufficient removal of the air.

I now pass to the description of an experiment which seems to me to be only capable of explanation by the views brought forward in this paper, and I should like therefore to consider them as crucial experiments, which have to be explained by any true theory of the discharge. As negative electrode, I use an aluminium cylinder of 5·5 cm. internal diameter and 8 cm. long. A long aluminium wire running parallel to the axis of the cylinder at a distance of about an inch formed the positive electrode. On exhaustion, the discharge at first passes as a spark in the ordinary way, but as the pressure decreases the glow gradually surrounds the whole cylinder, *with the exception of a dark strip about 2 or 3 cm. in width, directly opposite the positive wire.* The positive electrode seems, therefore, to repel the negative glow.

The following seems to me a plausible explanation of the phenomenon which I have just described. The rapid fall of potential which is observed on crossing the negative electrode suggests at once, independently of any theory that we have to deal with, the action of a condenser, for we know that no statical charge can produce a finite difference of potential at the electrode, while a double layer will produce a discontinuity. Although it may not be proved that an absolute discontinuity of potential exists at the kathode, it is yet certain that a very rapid fall occurs at that place. This is all that is necessary for the argument.

We recognise such a double layer in the case of electrolytes, but there is an essential difference in the thickness of the layer within which we must imagine that condenser action to take place. In the liquids that thickness must be very small, as is shown by the intensity of the observed polarisation currents. The positively electrified matter in every case is kept against the negative surface by a joint action of electrical and chemical forces, for it has been shown by Helmholtz that only thus can we explain a difference of potential between two bodies. It is the chemical forces which keep the electricities asunder. The gaseous molecules or atoms, however subject to their mutual encounters, and always having certain velocities, will tend to leave the surface. They are kept near the surface, however, by the electrical forces.

Suppose, now, that a positive electrode is placed near such a condenser. The resistance of the gas is so much greater than that of the metal electrode that we shall assume the whole elec-

[1] Abstract of the Bakerian Lecture. Read before the Royal Society, June 19, 1884, by Arthur Schuster, Ph.D., F.R.S.

trode to be of the same potential. The lines of force will then cut the surface at right angles, and could we assume the condenser to be infinitely thin, there would only be a normal force acting on its particles; but as the lines of force are curved, the particles not in immediate contact with the surface are acted on by a tangential force which will tend to drive them away from the positive electrode. As a steady state will only be possible when the total force is normal throughout the condenser, we arrive at the condition for the steady state that within the condenser the fall of potential must be the same for equal distances measured along the normal to the surface.

Experimental evidence speaks strongly in favour of such a conclusion. If, for instance, a thin wire is used as electrode, it is well known that the tension at the end of the wire before discharge is very much larger than anywhere else. At high pressures the discharge passes indeed from the end of the wire, but as the exhaustion proceeds, the glow gradually covers the whole wire, and the same amount of electricity flows out of equal areas situated anywhere on the wire, for the dark space which alters its width with the intensity of current is everywhere the same; this implies that the fall of potential per unit distance is the same all over the wire.

Hitherto we have only assumed a certain number of particles positively electrified in the immediate neighbourhood of the negative electrode, and we have left it altogether undecided what these particles are. But if we consider now the fact that the glow does not appear opposite the positive electrode, that is to say, that while the fall of potential is the same all over the surface the flow is stronger at some places than at others, we are driven to the conclusion that the flow does not altogether depend on the fall of potential, and we must again look for an explanation in the chemical as well as the electric forces. Wherever the fall of potential is chiefly produced by the presence of the positively electrified particles, which I now assume to be the decomposed molecules of the gas, these will help by their chemical action to decompose other molecules. Opposite the positive pole the fall of potential is principally due to nearness of that electrode; chemical forces are absent, and the molecules will not be decomposed. This is, I believe, the explanation of the dark area. And it brings with it the explanation of a large quantity of other facts, as, for instance, the one which has been so long observed and well established, that once a current is set up in the gas it requires a much smaller electromotive force to keep it going. For the discharge, according to us, will generally be introduced by a spark which must give the first supply of decomposed molecules before the continuous glow discharge can establish itself.

I may for the sake of clearness once more mention shortly the principal points of the argument.

The rapid fall of potential in the neighbourhood of the negative electrode renders the presence of positively electrified particles in its neighbourhood necessary.

If the distance through which the condenser action takes place is sensible, the positively electrified particles will be acted upon by a neighbouring positive electrode.

A steady state will be established in which the fall of potential along the normal from the surface will be everywhere the same.

As however the flow is stronger away from the positive electrode, we must conclude that other forces besides electrical forces determine the flow.

It is natural to assume that these are chemical forces: that, in other words, the positively electrified particles are the decomposed molecules, which by their presence assist the decomposition of others, and therefore the formation of the current.

Unless a flaw is detected in this line of argument, I think that the conclusion must be granted, namely, that the decomposition of the molecules at the negative electrode is essential to the formation of the glow discharge. This is really all that I endeavour to support in this paper. The rest can only be settled by further experiments. And amongst the rest I count also the primary cause which originally produces the decomposition of molecules at one pole rather than at another. It is possibly due to an electromotive force of contact between the gas and the electrodes which tends to make the gas electronegative.

The gaseous molecules, then, according to our theory, are decomposed at the negative pole. Their negative constituents can follow the electric action, and as the fall of potential in the immediate neighbourhood of the pole is very rapid, the atoms will leave the pole with considerable velocity. That the region of the dark space is filled with matter projected from the negative pole follows almost conclusively from the experiments of Goldstein and Crookes, and is also shown in a most striking way by an experiment due to Hittorf. If a tube contains two parallel wire electrodes at a distance of say a quarter of an inch, the discharge will at high pressure pass in the usual way from electrode to electrode, but at very low pressures the discharge from the positive pole goes away from the negative. The results can be shortly expressed by saying that, as far as the positive pole is concerned, the inner boundary of the dark space forms the negative electrode. If the dark space is small and does not reach to the positive pole, the discharge passes from the latter towards the negative pole, but as soon as the dark space extends beyond the positive pole, the positive part of the discharge goes towards the nearest point of the dark space that is straight away from the negative pole.

We have then two closely adjoining, almost overlapping parts, in which the discharge is in opposite directions, and this could not be unless electricity is carried by matter which can, owing to its inertia and high velocity, move against the electric forces. To my mind this experiment proves conclusively that the negative electricity is bound to matter projected with high velocity away from the negative pole.

Goldstein has shown that when a thin pencil of the negative glow belonging to one electrode passes close to another the pencil is deflected. According to our view, such a pencil would be formed by a succession of negatively charged particles projected in nearly the same direction away from the negative electrode; as these particles pass by another kathode, they are naturally deflected out of their path by the electric forces. Goldstein has shown that if the current is equally divided between the two kathodes, the deflection is independent of the intensity of the current, the pressure, and the nature of the gas. This is exactly what ought to happen according to our theory, for strengthening the current at one kathode means, as will presently appear, increasing the velocity of the particles. The square of the velocity will increase in the same ratio as the total fall of potential in the neighbourhood of the negative pole; as the particles pass the other kathode, the forces from it are increased in the same ratio as the square of the velocity with which they are moving, and consequently the path will remain the same. Similarly all the other experimental facts established by Goldstein can be easily explained.

The most conclusive proof of the view adopted in this paper would be found in the demonstration that the amount of electricity carried by each particle was always the same, whatever the current. I propose to test this fact in the following way:—It was found by Hittorf that the particles proceeding from the negative electrode, and projected at right angles to the lines of force in a magnetic field are bent round in a circle. This is as it should be, and I calculate that the radius of the circle ought to vary as $\sqrt{F/e}$, where F is the total fall of potential within the region in which the particles acquire their velocity, and e is the amount of electricity carried by each particle. As the current increases, it is shown by Hittorf that F increases; and I find that at the same time the diameter of the ring in the magnetic field increases. If this diameter varies as the square root of F, it would be proved that e must be constant as it is in electrolysis. At present we can only say that the average amount of electricity carried by the particles must increase less rapidly than the fall of potential. If e varies at all, we should expect it to vary proportionally to the fall of potential in the neighbourhood of the negative electrode, and in that case the diameter of the ring would be independent of the current, which it is not.

The theory which I advocate involves the existence of a polarisation, and it might be considered a difficulty that no polarisation currents have with certainty been observed in gases. I believe the difficulty only to be apparent, for the experiments prove that the fall of potential near the negative pole, though rapid, is not sudden, so that the layer within which the condenser action takes place is very much thicker in gases than in liquids. The capacity of the condenser is therefore smaller, and though the total fall of potential in the gas may even be stronger than in the liquid, the polarisation currents might escape observation.

With regard to the positive part of the discharge it will be sufficient here to mention that stratifications are principally observed in mixtures of gases or in compound gases, and that in the intervals between two stratifications the discharge is very likely carried as through the dark space at the negative electrode, while in the stratifications recombination of the decomposed atoms takes place.

An interesting law has been proved by Hittorf and E. Wiedemann in the case of the unstratified discharge. Hittorf shows that the fall of potential is the same in the positive part for the same tube whatever the current. This means that the energy dissipated is proportional to the current, and not to the square of the current as in a liquid. In the latter form the proposition had previously been proved by E. Wiedemann, who has shown that the total quantity of heat generated is proportional to the total quantity of electricity which has passed through the tube, whether in a few strong sparks or many weaker ones.

These experiments seem to point to the fact that once the original velocity of the particles at the regular pole has been reduced the velocity becomes independent of the strength of the current, that is to say, that in the positive part of the current greater intensity only means a greater number of particles taking place in the discharge.

The paper also contains spectroscopic evidence as to the state of dissociation in a vacuum tube, especially in the negative glow.

The question as to how the electricity passes from the electrode to the gas is not discussed, nor is it possible at present to decide, should the theory prove true, whether the polarity of the atoms in the molecule depends on the way in which these are combined, or whether that atom takes positive polarity which happens to be nearest the negative electrode as the molecule approaches it.

In conclusion some novel influence of the magnet on the negative glow is described, and it is shown that two different effects have to be clearly distinguished. The first is an effect of the magnet on the discharge when that discharge is established, and has been sufficiently well investigated. But the second effect depends on the question from what part of the negative electrode the discharge sets out. With respect to this question we meet with many contradictory and inaccurate statements. If at any place the magnet tends to throw the glow together the temperature will be raised, and owing to this fact the current will be strengthened, which again raises the temperature. It may thus happen that a slight cause can induce the current to pass almost exclusively from one part of the negative electrode. For a detailed description the reader is referred to the paper itself and the illustrations accompanying it.

UNIVERSITY AND EDUCATIONAL INTELLIGENCE

MR. ANDREW GRAY, M.A., assistant to Sir William Thomson in the Natural Philosophy department of the University of Glasgow, has been appointed to the Chair of Physics in North Wales University College. Dr. J. J. Dobbie, M.A., formerly "Clark" Fellow in Natural Science, has been elected to the Chair of Chemistry and Geology.

THE following is a list of prizes, scholarships, associateships, &c., awarded at the Normal School of Science and Royal School of Mines, South Kensington, June 1884:—First Year Scholarships: Albert G. Hadcock; Fred. Carrodus; William C. Rowden; Thomas Rose. Second Year Scholarships:—George Gibbens; Isaac T. Walls. "Edward Forbes" Medal and prize of books for biology, Thomas Johnson; "Murchison" Medal and prize of books for geology, Martin F. Woodward; "Tyndall" prize of books for physics, course 1, Isaac T. Walls; "De la Beche" Medal for mining, Herbert W. Hughes; "Bessemer" Medal, with prize of books from Prof. Chandler Roberts for metallurgy, (1) Percy Bosworth-Smith, (2) William F. Grace; "Hodgkinson" prizes for chemistry, (1st, books, &c.) George T. Holloway; (2nd) Stephen J. Elliott and William P. Wynne. Associateships in Normal School of Science: chemistry, 1st class, George T. Holloway, William P. Wynne, and Elizabeth Healey; physics, 1st class, Benjamin Illingworth and Alfred Howard; biology, 2nd class, and geology 2nd class, Joseph Lomas. Associateships in Royal School of Mines: mining, 1st class, Herbert W. Hughes; mining, 2nd class, and metallurgy, 1st class, George H. Schröder; metallurgy, 1st class, Percy Bosworth-Smith, Alfred Sutton, Henry G. Graves, and Harry J. Chaney; metallurgy, 2nd class, William F. Fremersdorf and Erskine H. B. Stephenson.

SCIENTIFIC SERIALS

American Journal of Science, June.—On the tendency of rivers flowing to the north or to the south to encroach on their east or west banks respectively, by G. K. Gilbert. The author, after further study, here finally adopts the view that this tendency is sufficiently accounted for by terrestrial rotation.—Examination of Mr. Alfred R. Wallace's "Modification of the Physical Theory of Secular Changes of Climate," part ii., geological and palæontological facts in relation to Mr. Wallace's modification of the theory, by Dr. James Croll.—Description of a new fossil marsupial from the Miocene deposits of Chalk Bluffs, Colorado, by W. B. Scott. This opossum, which the author names *Didelphys pygmæa*, is intermediate in size between the *D. murina* and *D. elegans* of South America. It establishes the fact that the small insectivorous opossums now characteristic of South America existed in Miocene times in North America, and is additional evidence that the latter continent is the source from which the former received the greater part of its fauna.—On a method of obtaining autographic records of the free vibrations of a tuning-fork, and on the autographic recording of beats (five illustrations), by Alfred G. Compton.—Notes on the volcanic rocks of the Great Basin, stretching for over 400 miles from the Sierra Nevada eastwards to the western base of the Wahsatch Range, by Arnold Hague and Joseph P. Iddings. In this region the association of andesites and trachytes, or trachytes and rhyolites, is unknown, and the authors infer that trachytes occupy a far more restricted position among volcanic rocks than has hitherto been generally supposed. They also consider that the geological independence of rhyolite and trachyte is now clearly established.—Transition from the copper-bearing series to the Potsdam in the St. Croix River Basin, Wisconsin, by L. C. Wooster.—On the expression of electrical resistance in terms of a velocity, by Francis E. Nipher.—Lateral astronomical refraction, by J. M. Schaeberle. The author proposes a simple remedy for the errors in astronomical observations arising from the assumption that all atmospheric layers of the same density over any given locality are parallel to the horizon.—Description of a remarkable variety of kaolinite from the National Belle Mine, Red Mountain, Ouray County, Colorado (three illustrations), by Richard C. Hills.—The influence of convection on glaciation, by Geo. F. Becker.—Description of a new Dinichthys (*D. minor*) from the Portage Group of Western New York (two illustrations), by Eugene K. S. Ringueberg. This specimen differs in several important respects from the two Ohio species *D. Herzeri* and *D. Terrelli*, Newb.—Mineralogical notes on allanite, apatite, and tysonite (two illustrations), by Edward S. Dana.

Revue d'Anthropologie, tome vii. fasc. 2, Paris, 1884.—On the weight of the cerebellum and the hemispheres according to Broca's mode of registration, by Dr. Philippe Rey, who has been commissioned by M. Topinard to continue the comparative tables and determinations which had already served as the basis of the memoir drawn up by the latter on the weight of the brain. Bicêtre, Saint-Antoine, La Pitié, and La Salpêtrière are the sources whence Dr. Rey has derived the requisite data for his work, and his conclusions must therefore be regarded as having more of a special than a general interest, since they are exclusively based on observations of the particular classes of persons confined in these institutions.—Study of primitive peoples, as the Kaffirs, and more especially the Zulus, by Élie Reclus. This paper presents little interest or novelty for English readers, as it consists almost entirely of extracts from English travellers and missionaries, and neither opens up new sources of information nor throws any novel light on the ethnography of the nations of whom it principally treats.—On the Kalmuks, by M. Deniker. In this second part of his memoir the author, after completing his description of the anatomical and physiological characters of the Kalmuk race, which he shows to be generally brachycephalic, supplies much important information regarding their present social and political condition under the influence of Russian domination. It would appear that the people have considerable mental capacity, various young Kalmuks having taken good places in the examinations of the University of Astrakan, and officiating creditably as medical practitioners, and as directors of the hospitals which the Russians are establishing for the benefit of the tribes. The change from a nomadic to a stationary life seems, however, to have been productive of decided injury, the census of 1869 howing a diminution of 22 per cent. in the population since 1862. According to the author, this diminution principally affects females, while this census presents, moreover, the singular