strains of dielectrics—all the main phenomena of static electricity admit of explanation on the basis of hollow vortices in the ether. Moreover, the theory is applicable to chemical valency and to Faraday's law of electrolysis. It places Faraday's ideal lines of force on a basis of reality, and it adds one more nail to the coffin of the material theory of electricity which it is to be hoped has now been safely buried.

DURING a thunderstorm which lately burst over Barcelona, the captive balloon in the Exhibition was struck by a lightning-flash and destroyed. The connecting-rope was probably of wire.

THE lightning-conductor discussion at the Bath meeting of the British Association has raised the question of the oscillatory character of the Leyden jar discharge. This was suggested by Helmholtz, in 1852, as an explanation of the fact observed by Faraday, that when electrolysis of water took place through a Leyden jar discharge passing through it, the gases at each electrode were mixed H and O. It was proved by Thomson, in 1853, that if self-induction existed in the discharging circuit it must occur, and the oscillations were actually observed by Feddersen. The fact that needles and iron bars are magnetized militates rather against the theory, but Prof. Ewing (*Electrician*, October 5, p. 712) suggests that oscillations in which the period lengthens while their amplitude decays would account for magnetization in layers.

MOLECULAR PHYSICS: AN ATTEMPT AT A COMPREHENSIVE DYNAMICAL TREATMENT OF PHYSICAL AND CHEMICAL FORCES.[1]

III.

PART II.—ELECTRICITY AND MAGNETISM.

§ 12. *Electrostatic Attraction.*

THOMSON'S investigations, considered in § 1 (August 23, p. 404), rest on the assumption that the diameter of a molecule or atom is indefinitely small in comparison with the wave-length of the light, and therefore the conclusions do not hold good for light-vibrations of such small wave-length as to be comparable with the molecular diameters. The consideration of vibrations of this kind shows that they give rise to what are called electrical phenomena.

These vibrations, like the former, will affect the internal energy of the molecules, and the molecules will also have critical periods with respect to them. But instead of assuming, as before, that within a finite but very short interval, only one wave impinges upon a molecule, it must now be assumed that an indefinitely large number of waves impinge upon the molecule at the same time, and that the effect of these waves is of a constant character. Suppose a sphere of a diameter differing only by an indefinitely small amount from that of a molecule, to be separated from the ether, and let vibrations of short wave-length impinge upon it from a fixed point, P. The first step will be to determine the energy, due to these vibrations, of the ether within the sphere.

Let r_0 be the least and r_1 the greatest distance of P from the spherical surface. The energy will be inversely proportional to the square of the distance, so that, where κ is a constant, the energy of the vibrating ether within the sphere will be—

$$\int_{r_0}^{r_1} \frac{\kappa dr}{r^2} = \kappa\left(\frac{1}{r_0} - \frac{1}{r_1}\right) = \frac{\kappa\delta}{r^2},$$

where $\delta = r_1 - r_0$, and r lies between r_0 and r_1.

Now consider a finite space bounded by spherical surfaces of radii R_0 and R, having their common centre at P, and by a cone with its vertex at P, and suppose it to be filled with spheres of diameters indefinitely near to those of molecules; then a finite number of concentric spherical surfaces may be inserted between the two bounding spheres, at distances equal to the diameter of a molecule. The number of small spheres between any pair of these spherical surfaces will be proportional to the spherical surface included within the cone, so that, if $d\sigma^i$ is the element of surface of the sphere of radius R_i, the total energy of the ether within the space considered will be proportional to—

$$\frac{\delta}{R_0^2}\int d\sigma_0 + \frac{\delta}{R_1^2}\int d\sigma_1 + \ . \ . \ . \ .$$

If, however, we assume that the small spheres are not sufficiently numerous to completely fill the space, but that they may all be arranged along a circular arc of radius R, then R_i^2 in these denominators must be replaced by R_i, so that, writing dR for δ, we find for the total energy—

$$\sum \frac{\delta}{R_i}\int d\sigma_i = \int_{R_0}^{R} \frac{dR}{R}\int d\sigma = \iiint \frac{dx\,dy\,dz}{R},$$

where $dx\,dy\,dz$ represents an element of volume in the most general form. We therefore obtain the following important result:—

If a portion of space infinitely large in proportion to the diameter of a molecule contains a number of spheres of the size of a molecule, so sparsely scattered that they can all be arranged on a surface within the space, then the total energy of the ether within all these spheres will be the same as if the space were completely occupied by the spheres, and the energy of each element of space were inversely proportional to the first power of the distance of the element from the point P.

Now suppose these spheres to be replaced by molecules with a similar scattered distribution, then the vibrations corresponding to their critical periods will increase their energy, while vibrations of different period will traverse the space unaltered, and therefore the molecules may still be regarded as specially susceptible to certain vibrations of very short period, just as in the case of luminous vibrations. Let KR^{-1} be the energy of the ether within the space occupied by the molecules, then the ponderable portions of the molecules will have their energy increased by an amount θKR^{-1}, where θ is a proper fraction—that is to say, a force varying inversely as the square of the distance will act on the ponderable molecules.

Now, it was shown in § 1 that for comparatively slow molecular motions the ether behaves like a perfect fluid, and therefore it follows from the principles of hydrodynamics that the molecules must move in the direction in which the energy of the surrounding ether diminishes most rapidly—that is, towards P; for the increase in the energy of a molecule as it approaches P must be accompanied by a decrease in the energy of the ether surrounding it.

It therefore follows that the vibrations of very short wave-length proceeding from P will have the same effect as if P had a charge of electricity, which suggests that electrostatic phenomena may be due simply to these vibrations in the ether, and it will be found that further investigation confirms this conclusion For the sake of brevity, the internal energy of a molecule due to vibrations of the short wave-length here considered will henceforth be called electrical energy, and a molecule will be said to be electrically excited when its electrical energy differs from zero. The demonstration given in § 5 (p. 407), that there is a maximum value for the possible internal energy of a molecule, will apply also to the present case, so that there will be a maximum possible value of the electrical energy of a molecule, depending upon the values of the constants which determine its internal constitution. This result leads to the following proposition:—

Two electrically excited particles will attract each other when the electrical energy of either one of them is, under the existing circumstances, susceptible of further increase. In the opposite case there will be repulsion.[1]

The truth of the latter portion of the preceding proposition is easily seen, for if two equally excited particles, or two excited to the maximum amount, were to approach each other, the energy of the intervening ether would increase in the direction of motion, for the ether at a point in the neighbourhood of one of the particles would receive an increase of energy from the approach of the other, while there could be no absorption of energy by the molecule. This would, however, be in contradiction with the law of hydrodynamics according to which the motion takes place in the direction of decreasing energy.[2]

[1] A Paper read before the Physico-Economic Society of Königsberg, by Prof. F. Lindemann, on April 5, 1888. Continued from p. 461.

[1] The action of electrified glass and sealing-wax on each other and on pith-balls is easily explained from this. The difference between positive and negative electricity being merely relative, appears, too, to remove a good many difficulties in the explanation of electrostatic phenomena.

[2] We therefore assume the truth of Maxwell's theory that light-vibrations exert a pressure in the direction of propagation ("Electricity and Magnetism," § 792); this will only be modified when the vibrations are absorbed by the ponderable molecules.

To determine exactly the conditions for attraction and repulsion respectively, let M be the electrical energy, at unit distance, of a vibration proceeding from P, then the energy at the distance R is MR^{-1}, as far as its effect on a molecule is concerned. Suppose a portion, ϵMR^{-1}, of this to be absorbed where ϵ is a proper fraction, then the repulsive force will be proportional to the negative differential coefficients of $(1-\epsilon)MR^{-1}$, and there will be at the same time an attractive force proportional to the differential coefficient of ϵMR^{-1}. The total repulsive force will therefore be proportional to $(1-2\epsilon)MR^{-2}$; its maximum value will be attained for $\epsilon = 0$; it will be zero for $\epsilon = \frac{1}{2}$: it will be attractive for $\epsilon > \frac{1}{2}$, and the attractive force will reach its maximum value for $\epsilon = 1$—that is to say, when the whole of the energy is absorbed. This may take place when the two attracting or repelling particles are of the same substance. The expressions for these forces contain, in addition to R, a factor M depending only on the attracting particle, and a factor $1-2\epsilon$ depending only on the attracted particle. In the same way the second particle will exert upon the first P a force proportional to $(1-2\eta)NR^{-2}$, where η depends only on the first particle, and N only on the second. The electrostatic potential of the mutual action will therefore be—

$$-\frac{(1-2\epsilon)(1-2\eta)MN}{R} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (28)$$

M and N measure the electricity radiated from the two particles respectively—that is to say, the excess of the internal electrical excitation of the two particles over that of the surrounding ether. This excess may be negative, and therefore two unelectrified particles may repel each other (when $\epsilon = 0$, $\eta = 0$) provided the surrounding medium is excited. The next step would be to determine the further motion of an attracted or repelled electrified particle, but since electricity in motion behaves quite differently from electricity at rest, as will be shown to follow from the author's theory, the consideration of this problem must be postponed, but it may be noted here that an attracted particle can only continue to approach the attracting particle so long as its maximum energy has not been attained. They may therefore either continue to approach until they come into contact, or may cease to approach at a certain critical distance. The latter possibility does not seem allowable according to experience, and in fact is found to be excluded when the motion is more fully considered, and the author merely mentions it in this place to call attention to its relation to the objections brought by von Helmholtz against Weber's theory.

Attempts have already been made to explain Newtonian gravitation from electrostatic actions.[1] The attempt to explain gravitation in this manner derives additional interest from the author's theory of electrostatic action, according to which the earth receives from the sun's rays, not only heat and light, but also electrical energy.

The theory of planetary motion should be capable of being derived from the laws of electro-dynamics, and the author's theory may therefore possibly prove of great value for the explanation of the phenomena of terrestrial magnetism, of meteorology, and may perhaps also throw some light upon the nature of comets.

§ 13. *Electro-dynamic Potential of Two Currents.*

Electrostatic action may be compared, according to the author's theory, with heat radiation, since both series of phenomena are due to the transference of energy from the ether to ponderable molecules. Similarly, heat conduction may be compared with electrical conduction. A body will be defined as a conductor when its molecules, in virtue of specially favourable values of its critical periods and other constants, are so sensitive to electrical energy as to easily absorb the maximum amount of internal energy, after which the centres of gravity of the molecule will begin to execute exceedingly small vibrations, which will be transmitted from molecule to molecule, accompanied by an absorption of electrical energy by each molecule, in exactly the same way that the molecules become luminous by the absorption of energy in the form of heat vibrations. Conduction, then, will take place by electrostatic radiation from molecule to molecule.[1] Those substances, on the other hand, in which the molecules absorb with difficulty the maximum amount of electrical energy, or in which internal electrical vibrations are only excited with difficulty, will be non-conductors.

[1] By Mossotti, for example, in 1836; see Zöllner's "Wissenschaftliche Abhandlungen," vol. ii. p. 417 (Leipzig, 1878). On p. 16 *et seq.*, various hypotheses regarding action at a distance are collected together, but the author states that he does not agree with Zöllner's criticisms on them. See also Maxwell's "Electricity and Magnetism," Articles 37, 59, *et seq.*, and 846 *et seq.*

The energy of an electrical vibration is inversely proportional to the square of the period of vibration, and therefore to the square of the wave-length, λ. A very good conductor (and these alone are considered in electro-dynamics) must have a very large number of critical wave-lengths lying so close together that their sum may be represented by a definite integral. Let λ_1 be the smallest, and λ_2 the greatest, of the electrical wave-lengths to be considered in any given case, then the internal electrical energy of the molecule will be proportional to

$$\int_{\lambda_1}^{\lambda_2}\frac{d\lambda}{\lambda^2} = \frac{1}{\lambda_1} - \frac{1}{\lambda_2} = \frac{\lambda_2 - \lambda_1}{\lambda^{1^2}},$$

where λ^1 is a value of λ lying between λ_1 and λ_2. Owing to the number of critical wave-lengths being necessarily very large, $\lambda_2 - \lambda_1$ will be a finite quantity in comparison with λ^1. We therefore arrive at the conclusion that the total internal electrical energy of a molecule of a good conductor is inversely proportional to a certain mean critical wave-length λ^1.

If we now make the assumption that the electrified particles are moving relatively to each other with a given velocity, their mutual electrostatic action will be modified in the same manner as if the wave-length of the electrical vibration proceeding from each of them were increased or diminished by an amount $\Delta\lambda$. Let c be the velocity of light, and ρ the relative velocity of the two electrified particles, in the direction of the line joining them, then we know that $\Delta\lambda = \lambda\rho/c$. Let r be the initial distance between the particles, and $E/r\lambda = M/r$ the initial electrostatic potential of one due to the presence of the other, then during the motion it will be—

$$\frac{E}{r(\lambda + \Delta\lambda)} = \frac{E}{r\lambda\left(1 + \frac{\rho}{c}\right)} = \frac{M}{r}\left(1 - \frac{\rho}{c} + \frac{\rho^2}{c^2} - \ldots\ldots\right).$$

Let ds be the element of length of the first conductor, and ds' that of the second, and let θ and θ' be the angles which they make with the joining line, then—

$$\rho = \frac{ds}{dt}\cos\theta - \frac{ds'}{dt}\cos\theta' \quad . \quad . \quad . \quad . \quad . \quad . \quad (29)$$

To determine the mutual action of the two current elements, each element must be assumed to consist of a pair of molecules, one of which has transmitted electrical energy to the other without having itself received a fresh supply, an assumption in complete accordance with the representation of a molecule as consisting of a series of distinct shells, and which takes the place of the assumption usually made that at each moment the quantities of positive and negative electricity on every current-element are equal. The two original elements will repel each other if the internal energy is electrically excited to an equal extent, or to the maximum amount possible in each. In order to fix the ideas this may be assumed to be the case in what follows.

Let 1, 2, represent the two molecules of the element ds, and 1', 2', those of ds', then the mutual potential of the two elements will be represented by the sum—

$$P_{22'} + P_{12'} + P_{1'2} + P_{11'};$$

where P_{ik} represents the mutual potential of two molecules i and k. The author takes the potential such that its positive differential coefficient in any direction is equal to the component of force in that direction, and therefore we have—

$$P_{22'} = -\frac{M}{r}\left(1 - \frac{\rho}{c} + \frac{\rho^2}{c^2} \ldots\right) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (30)$$

$$P_{12'} = \frac{M}{r\left(1 + \frac{ds}{dt}\frac{\cos\theta}{c}\right)} = \frac{M}{r}\left(1 - \frac{ds}{dt}\frac{\cos\theta}{c} + \left(\frac{ds}{dt}\frac{\cos\theta}{c}\right)^2 - \ldots\right) \ldots (31)$$

$$P_{1'2} = \frac{M}{r\left(1 - \frac{ds'}{dt}\frac{\cos\theta'}{c}\right)} = \frac{M}{r}\left(1 + \frac{ds'}{dt}\frac{\cos\theta'}{c} + \left(\frac{ds'}{dt}\frac{\cos\theta'}{c}\right)^2 + \ldots\right) \ldots (32)$$

$$P_{11'} = -\frac{M}{r} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (33)$$

[1] Kundt has recently shown that heat conduction is probably effected in a similar manner (*Sitzungsberichte der Berliner Akademie*, 1888, p. 271).

The constant M, according to (28), depends on the two current elements, and measures the electrical energy of the medium between them.

In (30) $\epsilon = 0, \eta = 0$; in (31) $\epsilon = 0, \eta = 1$; in (32) $\epsilon = 1, \eta = 0$; in (33) $\epsilon = 1, \eta = 1$.[1]

Substituting for ρ its value from (29), and neglecting the second and higher powers, we find for the electro-dynamic potential of the two current elements—

$$dV = \frac{2M}{c^2} \cos\theta \cos\theta' \, ds ds' \quad . \quad . \quad . \quad . \quad . \quad (34)$$

which gives for the potential of two closed circuits—

$$V = \frac{2}{c^2} \int\int M \cos\theta \cos\theta' \, ds ds' \quad . \quad . \quad . \quad . \quad (35)$$

where M is an electrostatic constant and c the velocity of light.

In the case of closed circuits we know that the value of V remains unchanged if $\cos\theta \cos\theta'$ is replaced by $\cos(ds, ds')$, and therefore we arrive at Neumann's expression for the mutual potential of two closed circuits, namely—

$$V = \frac{2}{c^2} \int\int M \cos(ds, ds') \, ds ds' \quad . \quad . \quad . \quad . \quad . \quad (36)$$

These expressions for V have been obtained by neglecting the second and higher powers of ρ/c, $1/c \,.\, ds/dt$, and $1/c \,.\, ds'/dt$; moreover, the dependence of the energy on the wave-length was only expressed in terms of a mean value, λ'; so that the expressions are only to be considered as approximately true. It is evident that they cannot hold good if either of the quantities ρ, $\frac{ds}{dt}$, or $\frac{ds'}{dt}$ become equal to or greater than the velocity of light—that is to say, both the relative and absolute velocities of the particles must be less than that of light; and it will be shown in what follows that this limitation is of the utmost importance.[2]

§ 14. *Weber's Fundamental Law.*

von Helmholtz has investigated the mutual potential of two current elements on the assumption that it is of the form—

$$\frac{M}{c^2}\left\{(1 + \kappa)\cos(ds, ds') + (1 - \kappa)\cos\theta\cos\theta'\right\} ds ds'.$$

Putting $\kappa = -1$, this expression agrees with Weber's law and also with (34), showing that the author's theory leads to Weber's law. In fact, putting $\theta = 0$, $\theta' = \pi$, and $ds = ds' = dr/2$, and taking the sum[3] of the electrostatic and electro-dynamic potentials, we arrive at Weber's expression for the potential of the two particles, namely—

$$-\frac{M}{r}\left\{1 - \frac{1}{2c^2}\left(\frac{dr}{dt}\right)^2\right\},$$

and the author's expression for dV leads to Weber's expression for the repulsion between two particles, namely—

$$\frac{M}{r^2}\left\{1 - \frac{1}{2c^2}\left(\frac{dr}{dt}\right)^2 + \frac{r}{c^2}\frac{d^2r}{dt^2}\right\}.$$

von Helmholtz's objections against Weber's law must now be considered, and his own examples may be taken.[4]

[1] All the electric rays proceeding from 2 will not be absorbed by 1' unless (§ 12) the two conductors are of the same material; if they are of different material, ϵ and η can only approximately assume the value unity, and therefore the expression (35) will only give an approximate value of the mutual potential. From a physical point of view, it would perhaps be more reasonable to assume that the particles in the elements ds and ds' respectively, instead of being, one strongly electrified and one unelectrified, are distributed in an approximately regular manner throughout all the intermediate stages. In this case the sum of the four expressions (30)–(33) will have to be replaced by a double integral, of which this sum will be the mean value.

[2] These conditions are known experimentally to be fulfilled, for while the velocity of light is about 300,000 kilometres a second, that of electricity in wires is, according to Fizeau, Gounelle, Fröhlich, and W. Siemens, from 100,000 to 260,000 kilometres a second. See Sir W. Thomson, "Mathematical and Physical Papers," vol. ii. p. 131, and Wüllner's "Experimental Physik," vol. iv. p. 403, 4th edition. According to the author's theory, the propagation of electric waves *in vacuo* must take place with the velocity of light; but the theory would not be affected if the velocity in air were found to be different. See von Helmholtz, "Wissenschaftliche Abhandlungen," vol. ii. p. 629 *et seq*. In fact, Hertz has found this velocity to be distinctly greater than that of light (*Sitzungsberichte der Berliner Akademie*, February 1888). The increase may be due to the electrical excitation of the air particles, and their consequent repulsive action on one another. With respect to electro-dynamic determinations of the constant c, see Himstedt, *Wiedemann's Annalen*, vols. xxviii. and xxix.

[3] See Riemann, "Schwere, Electricität, und Magnetismus," §§ 96 and 97. It should be noted that Riemann uses c to denote the velocity of light multiplied by $\sqrt{2}$. It may also be noted that the author uses ds/dt and ds'/dt to denote the velocity of propagation of an electrical disturbance, and not directly that of a molecule.

[4] "Wissenschaftliche Abhandlungen," vol. ii. p. 636 *et seq*. The two equations which follow may be interpreted as meaning that the quantity of electricity in motion depends on r, which is in agreement with § 12.

Suppose a ponderable electrified particle of mass μ to be repelled by a stationary quantity of electricity at the origin, in the direction of the joining line r. Let a force R of the ordinary kind act on the mass μ so as to diminish r, then the differential equation of motion of the electrified particle will be—

$$\mu\frac{d^2r}{dt^2} = \frac{M}{r^2}\left\{1 - \frac{1}{2c^2}\left(\frac{dr}{dt}\right)^2 + \frac{r}{c^2}\frac{d^2r}{dt^2}\right\} + R;$$

or, putting $M = \rho\mu c^2$—

$$\mu\left(1 - \frac{\rho}{r}\right)\frac{d^2r}{dt^2} = \frac{M}{r^2}\left\{1 - \frac{1}{2c^2}\left(\frac{dr}{dt}\right)^2\right\} + R.$$

Choosing the initial circumstances, so that $t = 0$, when the velocity and the work done by R are both zero, and supposing that r then has the value $\mathfrak{r}$, the principle of conservation of energy gives—

$$\frac{1}{2}\mu\left(1 - \frac{\rho}{r}\right)\left(\frac{dr}{dt}\right)^2 = M\left(\frac{1}{\mathfrak{r}} - \frac{1}{r}\right) + \mathfrak{R},$$

where

$$\mathfrak{R} = \int_0^t R\frac{dr}{dt}dt.$$

If, now, $Rr^2 < -M$, von Helmholtz points out that the moving particle must always approach the stationary one; its velocity meanwhile increases without limit until, for a distance $r = \rho$ (the so-called critical distance, see § 12), it becomes infinite, so that a finite force can give an infinitely great velocity to a mass μ by a finite expenditure of work. This impossible result is not, however, a consequence of the author's theory, owing to the limitations stated at the end of § 13. For if the velocity $\frac{dr}{dt}$ increases without limit, it must exceed that of the velocity of light, and then Weber's law ceases to hold good.

It would be easy, by expanding the four previously-considered partial potential expressions, in terms of c/ρ, $c/ds/dt$, and $c/ds'/dt$, to obtain a law for the further motion; but there is no object in doing so, as it will be seen from what follows that this new law would again only hold up to a certain limit not far removed from the first.

In the first place, it is doubtful whether, when moving so rapidly, the ponderable molecules could traverse the ether without resistance. In the second place, the electrical energy transferred from the fixed origin to the moving particle has been assumed to be inversely proportional to the wave-length, and the latter has been regarded as varying gradually within the given limits. This was allowable for good conductors, since their molecules must be specially sensitive to electrical disturbance, and therefore have a very large number of very small critical periods. With the very great velocity assumed, the wave-lengths of the disturbances proceeding from the origin will be greatly shortened before acting on the mass μ. It will follow, therefore, that only such vibrations will cause electrical excitation which already have so great a wave-length that they will really appear as light, or ultra-violet, vibrations, and not as electrical vibrations. Now, in the case of all known substances, these critical wave-lengths do not come together in great numbers, and therefore cannot be treated as forming a continuous series.

If such rays are emitted from the origin, they can only give rise to electrical excitation by separate impulses, and will therefore only cause a slight temporary variation in the acceleration of the particle μ due to the steady action of the force R.

We may therefore conclude that a particle easily susceptible of electric excitation will be electrified if it is made to approach a source of light with very great velocity, and this the more readily, the higher the refrangibility of the light from the source. The requisite velocity must exceed that of light by a definite amount.

The author is not aware that this conclusion has as yet been directly verified by any experimental evidence, unless Hertz's observations of the effect of light on the electric spark[1] may be explained in this way, but it is indirectly supported by the phenomena observed in Geissler tubes, as will be shown below. Consider, moreover, the motion of the particle μ away from the origin at an equally great velocity, then electrical waves proceeding from the origin will be lengthened, and act on the particle as light waves, causing it to glow. This electric glow will first appear of a blue colour, gradually passing through the various colours of the spectrum towards the red, as the velocity further

[1] *Sitzungsberichte der Berliner Akademie*, 1887, pp. 487 and 895.

increases, and of this electric glow many instances could be cited, both in Nature and in the laboratory.

Consider, in the first place, the glow surrounding a point from which an electric discharge is taking place. By means of the electrical repulsion, the density of the air immediately surrounding the point will be so far diminished that a single air-particle will be able to traverse a sensible distance with a very great velocity, and therefore give rise to the glow. Here it is not a question of particles becoming electrically excited by radiation from the point, but of those which are electrified by actual contact with it. As soon as they have lost some of their electrical energy they will again become sensitive to electrical radiation. There must therefore be a dark space immediately surrounding the point, and outside this an electric glow, which explains a well-known phenomenon always observed in the rarefied atmosphere of a Geissler tube. The stratification can also be explained very simply, for the glow causes a diminution in velocity, for when the electrical waves from the positive electrode give rise to luminous instead of electrical vibrations in the particles of gas, the repulsion will be diminished, and therefore the velocity will gradually become less than that of light, when the particle will again become sensitive to the electrical radiation. The velocity will therefore again increase until the glow appears again, thus giving rise to a stratified appearance. The velocity in the glowing layers will naturally be greatest in the neighbourhood of the positive electrode, and here, therefore, light will be given off of all the colours corresponding to the critical periods of the gas contained in the tube, which is in accordance with observation. According to the author's theory, the electrical excitation takes place by the transference of ponderable gas molecules from the positive to the negative electrode. After they have parted with their electrical energy to the latter, they will return in an unelectrified condition to the positive electrode to which they will be attracted, and at the same time repelled from the negative electrode. There will be no dark space surrounding the negative electrode, because the particles leaving it will have little or no electrification. The velocity of the returning molecules will increase as they approach the positive electrode, so that there can be no further transformation of electrical into luminous energy. In very high vacua the velocity of the returning particles may become great enough for electrical energy to be excited in them by the red glow of the positive pole, by which their velocity will be still further increased. The velocity of the returning particles will in this case ultimately become so much greater than that of the luminous molecules moving away from the positive electrode as to cause a sensible increase in the density of the gas surrounding it. The result of this will be to prevent the formation of the positive glow, and the whole tube will become filled by the negative glow. The density in the neighbourhood of the negative electrode will therefore be diminished, and the returning molecules will leave it with still greater velocity. If both electrodes are at one end of the tube, the molecules returning towards the positive electrode will be deflected by the layer of dense gas surrounding it, against the sides of the tube, giving rise to fluorescent phenomena, as explained in § 11 (September 6, p. 461). If the complicated phenomena which have recently been observed in Geissler tubes by Crookes and Hittorf can be thus simply explained, it will afford an important confirmation of the author's theory.

These considerations may be applied to the explanation of many cosmical phenomena, such as the aurora and the light of comets. It is quite possible that the particles of a comet's tail moving with great velocity towards the sun may become electrified by means of the sun's light.

The formulæ previously obtained are applicable to the determination of the motion of an electrified particle, in the case in which no proper luminous vibrations are given off from the origin, or where these may be neglected, for the equations (29) to (33) give in this case for $\frac{dr}{dt} = c$, $r = r_0$, $\mathfrak{R} = \mathfrak{R}_0$, and consequently—

$$\frac{\mu}{2}\left(1 - \frac{\rho}{r_0}\right)c^2 = M\left(\frac{1}{r} - \frac{1}{r_0}\right) + \mathfrak{R}_0.$$

Also—

$$\frac{\mu}{2}\left[\left(\frac{dr}{dt}\right)^2 - c^2\right] = -\frac{2M}{r} + \frac{M}{r_0} + \frac{Mc}{r\frac{dr}{dt}} + \mathfrak{R} - \mathfrak{R}_0.$$

And dr/dt can hence only become infinite when the positive quantity $\mathfrak{R}$ becomes infinite, or $r = 0$. von Helmholtz's objections, therefore, do not apply to this equation.

§ 15.—*Electrical Excitation.*

The foregoing theory easily explains the different methods of electrical excitation.

(1) The friction of two bodies sets their molecules into vibration, which appears in the form of heat. The resulting impacts of neighbouring molecules will most readily excite internal vibrations of the critical periods, for which they are specially sensitive. If the molecules are exceptionally sensitive to vibrations of very short periods, they will be easily electrified, the process being exactly analogous to the production of luminous vibrations by heating gases, as described in § 4 (August 23, p. 407). Electro-positive bodies will be those which are most sensitive, and these will, according to the theory, attract other less electrified bodies. In the ordinary frictional electrical machine the glass will therefore be more strongly excited than the rubber. The explanation of the collecting action of points on the prime conductor is given by the consideration that at a point the molecules are more fully exposed to the electrical radiation from the glass plate, and being electrically excited by this radiation communicate their electrification to the prime conductor by conduction, as explained in § 13.

(2) Electrification by the action of heat takes place in the same manner, and it is clear that the molecules in crystals, being regularly disposed with their axes in definite directions, will be electrified. Thermo-electrical currents are also explained. For if one of the junctions of a circuit consisting of two dissimilar metals is heated, the more sensitive metal will receive more electrical energy than the other, and give rise to a positive current. The potential difference at the junction will depend on the internal constants of the molecules in the two metals, so that we cannot expect to be able to express it by any simple general law.

(3) Electrification by simple contact of two dissimilar metals is not so easily explained if the effects of heat, pressure, and friction are excluded. It is, however, possible that the close contact of differently vibrating molecules may disturb the internal and therefore the external energy, and thus give rise to electrification. The electrification of similar metals by contact could be explained in the same way.

(4) Electrification by chemical action is completely explained by the author's theory, the production of electrical vibrations by this means being exactly analogous to the similar production of heat- and light-vibrations. Such chemical action must, in the author's opinion, play an important part in the galvanic cell, though contact electrification may also have a share in the action. The contact between copper and sulphuric acid, for example, is a very intimate one. At ordinary temperatures the molecules of both substances will be in motion. When two different molecules collide, their internal equilibrium will be destroyed, and they will therefore, according to § 8 (September 6, p. 460) form a chemical compound, provided the critical vibrations of the compound are, at the given temperature, less easily excited than those of the separate elements, which we must assume to be the case, from the strong chemical affinity which is experimentally known to exist between copper and sulphuric acid. During this process electrification will take place if the maximum internal electrical energy is less for the compound than for the constituents, exactly as hydrogen in combining with oxygen to form water produces light, and chlorine in combining with hydrogen to form hydric chloride produces heat. The electricity set free will be carried away by the copper, the latter being a good conductor. The accumulation of electricity in the copper is prevented, however, by its being used up again in forming a chemical compound with the zinc.

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(*To be continued.*)

COMPRESSIBILITY OF WATER, SALT-WATER, MERCURY, AND GLASS.[1]

THE pressures employed in the experiments ranged from 150 to 450 atmospheres, so that results given below for higher or lower pressures [and inclosed in square brackets] are extrapolated.

[1] Extracted, with the sanction of Dr. Murray, from a Report by Prof. Tait, now in type for a forthcoming volume of the *Challenger* publications.