XXV. On the admissibility of the assumption of a solar electric potential, and its importance for the explanation of terrestrial phenomena

Werner Siemens

To cite this article: Werner Siemens (1883) XXV. On the admissibility of the assumption of a solar electric potential, and its importance for the explanation of terrestrial phenomena , Philosophical Magazine Series 5, 16:99, 161-181, DOI: [10.1080/14786448308627415](https://doi.org/10.1080/14786448308627415)

To link to this article: <http://dx.doi.org/10.1080/14786448308627415>

Published online: 28 Apr 2009.

Submit your article to this journal [↗](#)

Article views: 2

View related articles [↗](#)

THE
LONDON, EDINBURGH, AND DUBLIN
PHILOSOPHICAL MAGAZINE
AND
JOURNAL OF SCIENCE.

—◆—
[FIFTH SERIES.]

SEPTEMBER 1883.

XXV. *On the Admissibility of the Assumption of a Solar Electric Potential, and its Importance for the Explanation of Terrestrial Phenomena.* By WERNER SIEMENS*.

MY brother, Sir William Siemens, in his memoir "On the Conservation of Solar Energy," has set up the hypothesis that the sun possesses a high electric potential, which possibly produces the phenomenon of the zodiacal light. He accounts for the rise and maintenance of this electric potential by friction of the matter which, according to his theory, having been dissociated by the light- and heat-rays emitted from the sun, flows in from cosmical space to its polar regions. This would, after condensation had set in, again undergo combustion and then flow towards the sun's equator. In doing this it would be electrified by friction with the rotating body of the sun, and then be afresh diffused in cosmical space, in its electrified state, by the centrifugal force of the rotation.

If this much-controverted theory be admitted as correct, it follows that the phenomenon in question is really similar to the electrization (described by me†) of the apex of the pyramid of Cheops by the whirling dust-clouds of the desert. We could then assume that the body of the sun, supposed conductive and insulated by the sea of flame enveloping it, the

* Translated from a separate impression, communicated by Sir Charles Siemens, from the *Sitzungsberichte der königlich preussischen Akademie der Wissenschaften zu Berlin*, 1883, XXVI.

† Pogg. Ann. cix. p. 355, 1860.

photosphere, keeps one of the electricities which have been separated by the friction, while the other is spread by convection in cosmical space. As it must then be also assumed that this convection extends far beyond the orbits of the planets, the body of the sun must be regarded as having an electric potential with respect to these and acting distributively upon them. I will not enter further upon the controversy respecting the admissibility of the theory in question. I do not fail to perceive the weight of many of the reasons which have been brought to bear against it; but I am of the opinion that the possibility of the assumption of a solar electric potential, given by the theory, tells much in its favour, since some of the most important terrestrial phenomena would find in it an explanation, which has hitherto been sought in vain, and since, on the other hand, in the present position of physical knowledge the finding of any other explanation of the presence of a solar electric potential will scarcely be possible. For, up to the present time, no process is known to us in which only one electricity is called forth. We know only separations of the two electricities; and although, according to all expectation, with the intensely powerful mechanical and chemical actions which are set up at the surface of the sun's body, such separations take place on a very large scale, they must be again compensated by conduction within the same; and even if there were a lasting separation of the two electricities in the body of the sun, action at a distance of one of them could not possibly take place. So long, therefore, as no new and at present quite unknown facts appear, my brother's convection theory remains inseparable from the assumption of a solar electric potential.

I must not, however, omit briefly to go into the weightiest objection to this theory, urged against it by MM. Faye and Hirn. It is that the invariability of the periods of revolution of the planets about the sun logically excludes the admission that space is filled with matter—that astronomical observations unconditionally demand the assumption that cosmical space is an absolute vacuum, since, with the prodigious velocity of the motion of the planets, even the most highly rarefied atmosphere must bring about a measurable diminution of the planetary velocities, and consequently a shortening of their periods. This would be true, on the hypothesis that the atmosphere of cosmical space is at relative rest. But this cannot be the case if the circulation assumed by my brother really takes place. It must be assumed that the sun's atmosphere has approximately the same rotation-period as the body of the sun. Any difference in the velocities of rotation,

brought about by the powerful ascending and descending currents in the sun's atmosphere which must arise from the combustion of the elements cooled by expansion and the cooling of the burnt outermost layers of the photosphere by radiation, will continually be equalized again by friction against each other of the parts of the sun's atmosphere rotating with different velocities. About the height of this atmosphere rotating equally with the sun's body nothing is yet known. According to Ritter's calculations*, indeed, the density of the solar atmosphere diminishes very quickly (following the sudden alteration of the adiabatic curve) in the region of the photosphere, in which the supply of heat from combustion considerably retards the diminution of temperature corresponding to the progressive rarefaction; but we do not yet know the limit of rarefaction up to which Mariotte and Gay-Lussac's law holds good. If, however, the atmosphere reaches the limit at which the force of attraction and the centrifugal force counterbalance each other, every material molecule passing beyond this must henceforth revolve round the sun like a planet. If new particles of the mass were constantly arriving at and entering this limit, a progressive condensation of matter would of necessity take place and a ring be formed here, which would rotate round the sun in accordance with Kepler's laws. Presupposing, however, the continuity of the sun's atmosphere, this ring-formation cannot occur, since the mutual friction of the strata of gas continues even beyond the surface of equilibrium, and consequently those which are already in planetary motion are subjected to an acceleration. The result must be that with the increase of velocity the distance of each of these microplanets from the sun is perpetually increasing; consequently the constant outflow from the solar atmosphere into cosmical space, assumed by my brother, must actually take place. And it can only take place in the zone of the sun's equator, since here at equal distance from the centre the centrifugal force is the greatest. It must also be admitted that the density of this atmosphere, everywhere rotating in accordance with Kepler's laws, in the plane of the sun's equator remains constant up to great distances from the sun, since the solar gravitation is throughout equilibrated by the velocity of revolution. In the directions perpendicular to that plane, on the contrary, the density must decrease, since the solar attraction diminishes as the distance from the plane of the sun's equator increases.

It follows from this consideration that a material current emanating from the sun coincident with the phenomenon of the

* Wied. *Ann.* v. p. 405, 1878.

zodiacal light must have everywhere the period of revolution that planets would have at the distance in question from the sun. A resistance experienced by planets from the material parts of interplanetary space, moving nearly uniformly with them round the sun, is therefore out of the question. Only a resistance (here negligible) must take place in consequence of the inclination of their ecliptic to the plane of the sun's equator, to which the observed lessening of this angle of inclination may perhaps be traced. The satellites, too, in revolving round their planets, must experience a resistance from the atmosphere of cosmical space; while the extreme limit of the atmosphere of the planets, rotating with them, must undergo a frictional resistance. With respect to the moon M. Hirn is perhaps right in maintaining that, the celestial bodies moving with such prodigious velocity, even the most rarefied resisting medium would sweep away their atmospheres.

Numerous observations make it highly probable that cosmical space, at least within the region of the solar system, is filled with combustible matter. This also indirectly tells very decidedly for my brother's hypothesis that the products of combustion, in a state of extreme rarefaction and at very low temperature, are again dissociated by the sun's rays. The objection which has been made, that the work of dissociation would absorb the energy of the luminous rays and thereby render cosmical space opaque, could be set aside by supposing that the work of dissociation is done by the invisible chemically acting rays only. But it can also be assumed that, in the course of the ages, the work of dissociation is already accomplished, and that now only the chemically combined mass continually emanating from the sun is still to be dissociated by his rays, for which only a part of the light-energy would be expended.

Without the hypothesis of dissociation it would be difficult to explain why cosmical space is not filled, like the earth's atmosphere, essentially with oxygen, nitrogen, and aqueous vapour. It cannot be assumed that the composition of the body of the sun is essentially different from that of the earth, if both have come out of the same rotating nebulous mass, since to suppose a separation of matter in the gaseous state according to specific gravity is inadmissible. Hence, at least in the solar system, the electronegative substances must everywhere predominate; and it is to be assumed that even the cold burnt-up sun in the future will be surrounded by an atmosphere containing an excess of oxygen. But if cosmical space is filled with highly rarefied dissociated products of combustion, these must become subject to the attraction of

the sun wherever they are not, as in the vicinity of the equatorial plane, withdrawn from that attraction by planetary revolution. Hence a constant inflow of dissociated matter to the sun must take place, especially in the polar regions, where there is a total absence of centrifugal force, as my brother supposes. If the mass of the sun, as may well be assumed, remains invariably the same, this means that a state of equilibrium has entered, in which just as much burnt matter flows out from the sun's equatorial zone as is again conveyed by attraction, in a state of dissociation, to its polar regions. Then the flow from the pole to the equator, as well as the proved lower angular velocity of rotation of the gaseous mass of the sun in its higher latitudes, would consequently follow.

Although, however, this gives the possibility of the production of a solar electric potential by friction and continual removal from the sun of the parts charged with one of the electricities, yet the mechanism of this electrification still remains very obscure. The light of the sun proceeds from a sea of flame which, according to Ritter's beautiful calculations, must have a thickness of about 25 kilometres. Whether a flame of burning gases of this thickness will still transmit much of the heat- and light-rays from a hotter source of emission, how much of them it will absorb or, like a layer of cloud, will reflect, we cannot know. I have recently * shown that gases heated to from 1500° to 2000° C. still appear perfectly dark, while even at a lower temperature they emit the more slowly vibrating heat-rays. Whether gases become self-luminous on being raised to a much higher temperature has not yet been determined by experiment. As, however, a small flame in a brighter light casts a shadow, it seems unlikely that many of the light- and heat-rays from the deeper and hotter strata of the sun can traverse the huge photosphere. The observed temperature and light of the sun are then phenomena originating essentially in the chemical action that goes on in the solar atmosphere. This requires that that atmosphere ascending in a state of dissociation and at the same time cooled by increase of volume, shall begin to burn when the limit of the temperature of dissociation for the respective compound is passed, and that this combustion shall continue until the loss of heat by expansion is equal to the heat liberated by combustion. The apparent temperature of the sun will hence be approximately the dissociation-temperature of those compounds which have the highest chemical heat-equivalent, consequently of water, the elements of which will burn at the greatest altitude, while the masses which are heavier and at the same time

* *Sitzungsb. der Akad. der Wiss., Wied. Ann.* xviii. pp. 311-316, 1883.

possess a higher temperature of dissociation are already ignited in lower regions. In order to keep going this upward motion of the dissociated elements, the final products of the combustion must return to the main body of the sun. As Faye, Ritter, and others have shown, this takes place, first, because those products possess greater specific gravity than the unburnt gases, and, secondly, in consequence of the cooling of the higher strata of the photosphere by radiation of heat and light. This disturbs the adiabatic equilibrium of the over- and underlying strata of gases, and compels the higher, having become relatively heavier, to return in descending currents to the solar depths. The reason that these descending currents become visible as sun-spots only in middle solar latitudes is that there only are the conditions present for a rotating motion of the descending current, by which a vertical direction is given to it. The funnel-shaped diminution of the diameter of a sun-spot is the result of the great diminution of volume effected by the rapidly increasing pressure. The interior of the funnel must be relatively dark, since there the formation of luminous flame fails, as the temperature must be lower by the amount of the heat of dissociation than that of the surrounding unburnt solar substance, and perhaps products of condensation already occur, which act as a screen in keeping back the radiation of the more brightly luminous deeper strata of the sun. On the other hand, it is not improbable that the high-blazing faculæ consist of bubbles of hydrogen and oxygen in the proportion to form explosive gas, or of coal-gas mixed in the right proportion with oxygen, which, in consequence of their less specific gravity and greater liberation of heat in combustion, bursting through the penumbra and the photosphere, soar aloft, and, the elements of luminous flame being absent, transmit in part the rays of the hotter deeper layers of the sun. The enormous velocity of the coruscations of many faculæ, scarcely admissible as a mechanical effect, might then find its explanation in this radiation from the solar depths. My brother, in a recently published supplement to his theory of the sun, assumes that the main body of the sun itself may not be hotter than about 3000°C. , since at a higher temperature the chemical rays would be the predominant ones, and at a very much higher temperature the sun would actually cease to give light. This might be true if the photosphere did not as a screen keep back the hotter rays of the sun's body, as it probably does. In fact, from analogies to the observations we cannot draw any safe conclusion as to whether a body heated to hundreds of thousands or millions of degrees would still be luminous. Only rays of so minute a wave-

length might emanate from it that they would be incapable of performing any chemical work! The apparently dark nucleus of the sun-spots might then be accounted for thus:—The flameless products of combustion, relatively cooled by commencing dissociation, returning to the sun, remain transparent and permit the deeper layers of the sun, too highly heated for luminous radiation, to radiate through them. The violet colour of the nuclei of the sun-spots would tell in favour of this. For attainable temperatures, it is true, the law holds good that, besides the rapid undulations of the æther corresponding to the higher temperature, the entire scale of the slower undulations comes in also; but whether it is or is not different with temperatures so enormously higher cannot, at all events, be known.

It was necessary to enter somewhat more into particulars respecting the constitution of the main body of the sun and its light- and heat-radiating envelope, in order to get a foundation for an answer to the question whether, with the present extent of our knowledge, the hypothesis of a solar electric potential appears admissible. As I have already insisted, its conception is only possible if a separation of the two electricities goes on at the sun's surface and if one of the separated electricities is simultaneously conducted away. As flame is a good conductor of electricity, the entire photosphere and the penumbra (which probably take part in the process of combustion) may be regarded as a conducting mantle enveloping the hotter body of the sun. As, further, flames have, like points, the property of transmitting electricity to their surroundings (here, therefore, to their gaseous combustion-products), the photosphere must be continually discharged by a partial outflow of the products of combustion into cosmical space. If, therefore, the photosphere were insulated from the deeper body of the sun not yet included in the combustion, the latter, if it should be regarded as a conductor of electricity, could be charged with electricity by friction or chemical processes taking place between the conducting body of the sun and the photosphere. The question whether hot gases are conductors of electricity, even when no flames appear in them, has not yet been decided by direct experiments. That gases, like all bodies, become conductors of electricity when the dielectric polarization of their molecules has reached its maximum, and that this maximum diminishes proportionally with the rarefaction of the gases, consequently also with their heating reckoned from absolute zero, I have already shown, when describing my ozone-apparatus, in the year 1857*. Accordingly conductors are

* Pogg. *Ann.* cii. p. 66.

distinguished from nonconductors only by the maximum of polarization of the former being vanishingly small. That in very highly heated gases the maximum of polarization would become, as in metallic conductors, vanishingly small, can scarcely be admitted. Direct experiments on the dielectric properties of highly heated flameless gases are not known to me; but the phenomena of the electric spark, as well as the luminous appearances in the ozone-apparatus and Geissler tubes, and the beautiful experiments of Hittorf*, can be explained even without assuming that highly heated conduct differently from cold gases of equal density. Hence the high temperature of the solar gases appears at present to be no obstacle to ascribing to them insulating properties. Indeed their maximum of polarization will, in correspondence with the density of the sun's atmosphere, be greater than that of our cold atmospheric air, notwithstanding their elevated temperature.

Very different relations, however, may appear on the appearance of the critical state at greater depths in the sun. For the electrical property of the critical state we have neither experiments nor analogies: hence we can assume that the interior of the sun is also a metallically conducting mass—that is, having a vanishingly small polarization-maximum. The surface of this mass of the sun in the critical state might then have an electric potential. The question, however, would have to be taken into consideration whether the conducting photosphere might not on the face turned towards the interior of the sun become electric by distribution, so that the sun with its enveloping photosphere would form a

* M. Hittorf, in a communication in vol. xix. of Wiedemann's *Annalen*, p. 73, says that what I communicated to the Academy on the 9th November, 1882, viz. that gases at temperatures from 1500° to 2000° C. still appear perfectly dark if they are quite flameless, and that the luminosity of gases on the passing through them of an electric current is a similar process to the shining of a flame that separates no solid components, had been previously made known by himself and others. I willingly grant this with respect to the nonluminosity of hot gases; but I made no claim to priority in this communication: I believe, however, that I first proved by experiment that gases so highly heated actually appear perfectly dark, although the hot layer of air be over a metre thick and the eye has been rendered in the highest degree sensitive by complete darkness. Hittorf's experiments proved only that hot gases are relatively dark. As to the conductivity of gases, assumed by Faraday for high tensions, in my paper above cited, about 25 years older, I already set up the general law according to which the conductivity of gases commences. To this I might also refer M. Eilhard Wiedemann, who claims priority for his explanation of gases becoming luminous on an electric current passing through them as a result of dielectric polarization.

prodigiously powerful Leyden jar, by which action at a distance of the electricity of the conducting nucleus of the sun would be in a great measure excluded. This cannot be assumed at once, since the conductivity of flame has quite different causes, directly connected with the combustion-process itself, than that of conductive bodies not in chemical action ; so that an analogy between the two is hardly to be inferred with respect to their capacity for electric distribution. I have therefore made some experiments on the question whether a flame is subject to the action of induction in the same manner as other conductors ; and these experiments have confirmed the hypothesis. According to this, two flames insulated from each other can act as the coatings of a charged Leyden jar, in like manner as other conductors*. According to this it must be assumed that the seat of the sun's electricity is chiefly to be sought in the photosphere, and not in the body itself of the sun. The electric properties of flame are still very obscure, notwithstanding all the experiments hitherto made on the subject. In particular, it is not yet decisively determined whether a difference of potentials, spontaneously produced, between the different zones of the flame, especially between that where the combustion commences and that where it goes out, exists or not. If this were the case, as appears probable from some experiments by Riess and others, the cause of the sun's electricity might be sought therein, considering the prodigious dimensions of the sea of flame

* The experiment was made thus :—A ring-shaped gas-burner was insulated. On opening the cock a cylindrical flame of about 2 centim. diameter rose above it to the height of about 15 centim. The flame passed through a metallic cylinder of about 8 centim. diameter, placed so as to be insulated and to surround it concentrically. To produce conducting connexion with the flame, an insulated platinum wire, bent into a circular shape, was placed in the lower part of the flame. The charge produced between this platinum wire and the cylinder by a galvanic series of fifty Daniell cells was now measured, by means of my rapidly oscillating electromagnetic switch, with the gascock alternately nearly closed and quite open. The difference between the deflections of the mirror-galvanometer was then a measure of the capacity of the Leyden jar formed by the flame and the cylinder. The results obtained are collected in the following table :—

Number of oscillations of the switch per minute.	Difference of deflection between low and high flame.	Amount of a discharge.
310	3	96
600	6	100
700	8	115
1000	12	120

The increasing numbers of the last column show that with slow oscillations a part of the charge was lost by conduction.

surrounding the sun, and the corresponding great differences in temperature and density, since the electricity of the outer layers of the photosphere would then pass over to the products of combustion, and with them, according to my brother's theory, would in part be spread in the direction of the plane of rotation of the sun in cosmical space. Even supposing, however, that the process of electrification may have to be sought in the solar combustion itself, in the friction of the matter flowing in from cosmical space, or in other causes yet unknown, the possibility of the existence of an electric potential of the sun is given by the equatorial diffusion of solar products of combustion in cosmical space.

And this possibility rises to the rank of high probability when one considers the facility with which some difficult and hitherto unsolved problems of terrestrial phenomena can be solved with the aid of a solar electric potential. If the sun possesses a high electric potential, he must act distributively upon all the celestial bodies, consequently upon the earth also. But an accumulation of electricity upon the entire solar surface can only take place when the opposite electricity liberated is conducted away; and the only conceivable way in which it can be so conducted is by being diffused in cosmical space. The process is approximately the same as that which takes place when an insulated sphere is placed opposite to a larger charged spherical conductor. The sphere then gradually takes an opposite charge, while the same electricity is lost by dissipation in space. With the earth this dissipation of the so-called free electricity arising from the sun's distribution is, moreover, greatly favoured by the extreme rarefaction of the upper strata of air and by the ascending and descending currents of air loaded with moisture, since by these the free electricity is conveyed to the upper strata of highly rarefied air. That in this rarefied upper air electric currents take place is proved by the auroræ boreales and australes. They might be regarded as the electrical compensation taking place at the boundary of the earth's atmosphere, between the matter flowing out from the sun charged with negative electricity and the liberated positive induced electricity of the earth. This compensation must occur whenever by a change in the sun's potential that of the earth is also changed. For the restoration of equilibrium, positive or negative electricity must then flow out from the earth; consequently either a compensation must take place at the boundary of the atmosphere with the negative electricity flowing out from the sun, or this must flow to the earth. The reason that this exchange takes place preeminently in the

earth's polar regions may be that the polar air is more strongly electric, as it is continually displaced by the more strongly electrified air brought by the equatorial current in the upper regions of the atmosphere, and must therefore receive in its entire mass the electricity of the highest strata of air of the lower latitudes. Earth-currents, standing in intimate connexion with the northern and southern lights, are then to be considered a necessary consequence of the compensation of the variations of intensity of the electricity of the earth and the sun taking place preeminently in the polar regions. These compensation-currents must on their part affect the magnetic needle by their electrodynamic action.

Here, however, the question intrudes, is not the earth's magnetism itself to be considered an electrodynamic action of the electrical charge of the earth? According to the beautiful investigation instituted in Helmholtz's laboratory, under his direction, by Mr. Rowland*, it is to be regarded as demonstrated that stationary electricity mechanically moved exerts electrodynamic actions in a similar manner as an electric current. Accordingly the earth must, if its surface is charged with electricity of great density, exhibit, in consequence of its rotation, magnetic phenomena, in like manner as if electric currents encircled it, carrying round it in each latitude, during the time of a rotation, just so much electricity as the static electricity present on the respective surface-rings amounts to. What density of electricity on the earth's surface would be required, in order to produce the magnetism of the earth by its rotation, will not be difficult to practised mathematicians to calculate. As the magnetic moment of a circular current is proportional to the surface flowed round, we may foresee that, considering the dimensions of the earth, that density will not prove to be inadmissibly great. Further, with the colossal dimensions of the sun, whose surface contains 11,483 times the surface of the earth, while the distance of the sun amounts to only 22,934 earth's semidiameters, the density of the sun's electricity need be only about twice that of the earth in order to call forth the latter by electric distribution. Were the whole of the earth's surface equally charged with electricity, the magnetic pole would necessarily coincide with the pole of rotation of the earth. Since it is not so, and as, on the whole, great irregularities take place in the distribution of the earth's magnetism over its surface, the distribution of the static electricity on that surface must be irregular. This also appears probable when it is remembered that about one third of the earth's surface consists of

* *Monatsberichte der Berliner Akademie der Wissenschaften.*

continent, which mostly has a rocky bottom only thinly covered with badly conducting earth. The accumulation of the induced electricity will therefore have to be sought rather on the surface of the incandescent well-conducting interior of the earth, by the greater distance of which from the outer surface the preponderant influence of the masses of electricity in convective motion lying nearest is diminished. Whether it will be possible to deduce the existing distribution of the earth's magnetism, as well as the observed periodic and irregular disturbances of it, from this theory of the cause of the phenomenon of terrestrial magnetism, must be decided by subsequent special investigation. The daily regular disturbances might be accounted for by the fact that the density of the induced electricity on the side turned away from must be somewhat less than that on the side turned towards the sun. This unequal density of the earth's electricity depending on the position of the sun, must proceed *pari passu* with the rotation of the earth, and may therefore be the cause of the regular equatorial earth-currents discussed by Lamont. The magnetic disturbances produced by the moon may likewise find their explanation in the reaction of lunar electricity upon the distribution of the induced electricity of the earth. On the other hand, the secular alteration of the situation of the magnetic pole can, in all probability, only be referred to yet unrecognized cosmic causes.

Although this theory may still leave much unexplained, it yet affords at least the possibility of giving an explanation of the origination of the earth's magnetism fitting in with our present experience. This is not the case with any previous theory. The hypothesis of a central magnet in the interior of the earth is contradicted by the universal experience that a red heat destroys the magnetism of all bodies. Hence that hypothesis cannot be maintained without entirely losing sight of the foundation of experience. The hypothesis of a stratum of magnetic ore in the crust of the earth as the seat of terrestrial magnetism is contradicted, in the first place, by calculation, since the magnetism of such a stratum, even if it be supposed of the greatest possible thickness and magnetized to the maximum, would not suffice to produce the existing terrestrial magnetism; and, secondly, by the impossibility of finding a cause for the magnetization of that stratum of ore, since the magnetism cannot have been present from the beginning, but must have first arisen after the cooling of the earth.

The same might be maintained of the theory advanced after Faraday's discovery of the magnetic properties of the

oxygen of the air, that this oxygen is the seat of the earth's magnetism, if calculation had not already shown that the seat of this magnetism cannot be outside of the surface of the earth. Just as little can those theories of the earth's magnetism meet with consideration which rest upon thermo-electric currents or, as Zöllner attempted to base his, on convection-currents in the liquid interior of the earth, since in a medium conducting equally well in all directions such currents can never take place. Moreover no cause can be found for the existence of permanent regular currents of the liquid interior of the earth.

In like manner as an electric potential of the sun affords the possibility of accounting for the earth's magnetism, together with the related phenomena of the auroræ and earth-currents, it also gives a handle for the explanation of the electricity of the air and the phenomena of thunder-storms. That the earth must be charged with negative electricity was assumed already by Lamont for the explanation of the perpetually changing atmospheric electricity. His view, however, that this electric charge is to be accounted for by thermoelectric differences, is no more tenable than the view that friction-processes can generate an electric potential of the earth. Such a potential can only arise from cosmic influence and the removal of the liberated same electricity by diffusion in space, or its neutralization by the oppositely charged matter which flows out from the sun in the direction of the plane of his equator. If, however, we assume this to be the case, that consequently the earth together with the sun forms an electric accumulation-apparatus the separating dielectric of which is the atmosphere of the sun and of the earth and the interplanetary space filled with most highly rarefied matter, all the conclusions drawn by Lamont and others from the electric charge of the earth are justified. But to account for the electricity of thunder-storms, the trifling and varying electricity of the atmosphere, to which it has hitherto been attributed, does not seem sufficient. The sudden appearance of such vast masses of electricity as arrive especially in tropical storms repels the supposition that they have had their seat in the feeble electric charge of the comparatively small quantity of air that carries the thunder-clouds. The sources from which it springs must be more productive. Such a source, of inexhaustible vastness, is found in the electric charging of the earth by solar influence. When a conducting object is brought near a large sphere charged with electricity, it is subjected to the distributive action of the electricity existing on the surface of the sphere.

If the similar electricity accumulated in the part of the conductor most distant from the sphere finds a means of transmission to still more distant conductors, the first conductor becomes lastingly charged with electricity the polarity of which is the opposite of that of the sphere. But if the elevation of the conductor above the surface is but little in proportion to the diameter of the sphere, then the difference of tension between the surface of the sphere and the most distant point of the elevation can only be small. For this reason, even with a great density of the electricity on the surface of the earth no electrical repulsion can take place there, and even on mountain-tops it cannot be very noticeable. But the ratio takes another form when a sphere is charged by induction from a distant electrical sphere. The lines of force which, according to Faraday's molecular-distribution theory, go from the charging to the charged sphere from which the electricity is carried away, meet the latter everywhere almost perpendicularly and, with a great distance between the influencing spheres acting upon each other in proportion to the diameters of the spheres, in almost equal number on the side turned towards the distributing sphere and on that turned away from it. If now an insulated conductive screen that covers a part of the surface of the influenced sphere be brought near the latter, if it be thin it will not become perceptibly electric. But as soon as the screen is touched so as to conduct away its electricity, it takes the opposite electricity to that of the sphere, while the like electricity is carried away. The behaviour is the reverse of this when the screen is conductively connected with the sphere; the screen then forms part of the surface of the sphere and receives its electric charge, while the part of the surface under the screen becomes nonelectric. Now the thunder-clouds appear in the character of such screens upon the surface of the earth. If such a screen of cloud be imagined included in the formation over a part of the earth's surface, it will remain unaffected by the earth's electricity so long as the conductive particles of water are insulated and at a considerable distance from one another. Hence mist and light clouds will not become electric. But as soon as the mist has so far condensed that its conductive parts come into contact with one another, or the distance between them becomes so small that electricity of very slight tension can overleap the intervals, the cloud is subjected to the distribution process. This can be initiated by its being put into conducting connexion with clouds situated in very elevated regions by ascending cloud vortices. This conductively connected cloud is then electrified in its lower part with the

contrary electricity to that of the earth, while the upper part is electrified similarly to the latter. But a dense conductive bank of clouds may in one or more places come into conductive connexion with the earth itself. It then forms a part of the earth's conductive surface, and takes up its electricity*. The latter process most readily occurs at the declivity of steep mountains against which the layers of cloud rest. Hence mountains frequently occasion tempests. In the generation of the clouds that carry the electricity of storms electricity does

* During a voyage on the Mediterranean in the winter of 1865, in the vicinity of the Spanish coast, between Cartagena and Almeria I had an opportunity of observing the course of the phenomenon of a waterspout, which appears to me to tell decidedly in favour of this conception.

Between the ship and the coast in the vicinity of Almeria, with a vigorously agitated so-called dead sea, without any considerable motion of the air, a dense but apparently not high bank of black clouds was seen, under which the sea seemed to be in the wildest commotion. It appeared there like a roundish white spot, the diameter of which the seamen estimated at from two to three [German] nautical miles, foaming up to a great height, while the sea around it showed only smooth waves without any breakers. In spite of the considerable distance of the ship from the place of violent agitation, amounting to several leagues, it could be distinctly seen through the telescope that the angry surges rose several metres above the sharply defined surface of the relatively calm mirror of the sea. The cloud descended at one place in the shape of a funnel, forming a streak of cloud curved like an elephant's trunk, reaching down nearly to the foaming surface of the sea, and apparently joining below. Perfect contact with the foaming surface could not be perceived; and, what was surprising, no greater foaming took place under the trunk-shaped cloud than in other places. The trunk itself slowly rotated, if I remember rightly, in the direction of the hands of a watch, over the white spot; and its place of junction with the cloud took part in the motion, though not to an equal extent. Unfortunately, night coming on and the increasing distance, after about half an hour's observation, during which the trunk had made a turn and a half, keeping its point constantly at about one third of the radius of the white spot from its margin, deprived us of the further contemplation of this interesting phenomenon, which had been followed with the closest attention by myself, my brother William and his wife, and the naval officers belonging to the company of the French cable-ship, on board of which we were. No whirling motion was perceptible. Almost a dead calm prevailed. It can only have been a purely electrical phenomenon, which must have consisted in an electric current from the earth to the cloud. If we assume that this current had at one place become so strong that, by electric conveyance of the liquid, a conductive water communication between the sea and the cloud was formed, the rotation of the trunk under the influence of the earth's magnetism is also explained. During the night a storm raged on the Spanish coast, which probably originated in the waterspout observed by us. The latter, however, appeared later to have directed its course from the Spanish to the African coast; for towards the end of the night our ship near the latter coast encountered so fearful a storm of only a few minutes' duration that it was in the greatest peril, and the seamen were firmly of opinion that the waterspout had passed over the ship.

not appear to play any essential part. The cause of the formation of clouds is, as a rule, to be sought in the ascending and descending motion of the air, to which not only this and the rain falling from the clouds, but also the letting loose of storms is almost exclusively to be ascribed. The views on this subject which still prevail to a great extent in meteorology need, in my opinion, correction in some points. Were the equilibrium of the aerial ocean not constantly disturbed by unequal heating and cooling of the air by radiation, the temperature and density of the air could not but be in so-called indifferent equilibrium up to the greatest altitude, and in such wise that the loss of temperature with increasing height would be everywhere equivalent to the work of expansion of the gas. The higher temperature of the air of the lower latitudes would be equalized by slowly coursing whirlwinds with a horizontal axis of rotation, as is shown on a large scale by the trade winds, and finally the entire sea of air would possess equal temperature at equal heights. This indifferent or adiabatic equilibrium is now continually disturbed by extra heating of the earth's surface and of the lower strata of the air by solar radiation, by absorption of the same on passing through the atmosphere, and by the extra cooling of the higher strata by radiation outwards. Through this the lower strata become lighter and the upper heavier than the adiabatic equilibrium requires; and this disturbance must be compensated by ascending and descending currents in the atmosphere. As the ascending air, which has become warmer on the ground, in correspondence with the adiabatic curve of temperature preserves this excess of heat on ascending, but the upward impulse increases with the increasing height of the ascending current because the succeeding layers of air at the ground have always the same excess of temperature, the upcurrent must continue, in the places where it has once been produced by favourable local conditions, until the difference of temperatures is equalized. The work done by the upcurrent of the relatively lighter air and the descent in other places of the relatively heavier air cooled by radiation must be converted into *vis viva*, as it puts the air into quicker motion. This is effected essentially by the volume of the ascending air being increased by the diminution of pressure. Since, the diameter of the terrestrial globe being great, the air-space becomes only imperceptibly larger with the height, the velocity of the ascending air must even from this cause increase nearly proportionally to the decrease of pressure. In the highest regions of the air to which each upcurrent formed will reach, the velocity of the air must therefore be very considerable; and there with the

same velocity the surrounding calm air must be pushed aside in order to make room for that which has arrived. This displacement will take place chiefly in the direction to where a descending current has been formed to replace the overheated air flowing at the surface of the earth to the place of the up-current. This downflowing air now becomes denser again correspondingly to its altitude, it is true ; *but at the same time it retains the velocity it acquired in the upper regions*. It is evident that the final result may be a very great velocity of air at the earth's surface, if the disturbance of the adiabatic equilibrium was qualitatively and quantitatively considerable. These local storms, the direction of which is modified according to Dove's law of rotation by the rotation of the earth, must become peculiarly violent if the upcurrent itself is confined within narrow limits, since then the compensating process, *i. e.* the conversion of the energy accumulated in the disturbance of equilibrium into air-velocity, is confined to a proportionately small quantity of air. Yet powerful storms, passing over whole continents, may also be produced by ascending currents of air of wide local extent. That the descending current produces an increase of pressure upon the ground, and the ascending current a decrease, follows from the laws of mechanical motion. The mere motion of the air, however, must of itself always occasion a fall of the barometer, since the moved air carries away with it the still air at the contact boundary and consequently produces a rarefaction. The final result of the compensation of the disturbance will therefore be to put greater and greater masses of air into whirling motion, and last of all to bring the *vis viva* back, by friction, into the form of heat.

It follows from these considerations that the aqueous vapour in the air does not play the great part in the movement of the air that is usually attributed to it, since the phenomena of the motion and pressure of the air can be accounted for without the water contained in the air. The origin of storms, *i. e.* in this case the place of the acceleration of the masses of air, must only be sought, not at the surface of the earth, but essentially in the highest regions of the air. If the atmosphere consisted of aqueous vapour only, the phenomena would be altogether similar. Aqueous vapour is as subject to the law of adiabatic expansion as air ; only its density and temperature decrease with increasing height much less than those of the permanent gases of the atmosphere. According to Ritter a vapour atmosphere would be about thirteen times as high as an atmosphere of air. It is true that, according to Clausius and Sir William Thomson, with the adiabatic expansion of vapour a

continual condensation takes place; but, at the heights in which according to experience the formation of clouds occurs, it must still be too inconsiderable to bring about the observed precipitation. The reason of the condensation that takes place in ascending air-currents lies essentially in this—that the aqueous vapour is intimately mixed with the air, and that in the ascending current it does not take the adiabatic temperature belonging to itself, but that of the greatly preponderating mass of air with which it is mixed. Now, as the air is cooled much more quickly with increasing height than the vapour, the latter is cooled below the adiabatic temperature belonging to it; and this diminution of temperature gives rise to its condensation if the point of saturation of the vapour is overpassed.

This conception is apparently contradicted by the circumstance that aeronauts have repeatedly proved that strata of warmer air frequently overlies colder ones, while the law of adiabatic expansion requires a continuous decrease of pressure and temperature. But this is easily explained by the dissimilar constitution of the earth's surface, owing to which the ascending current frequently, and in many places, has a much higher temperature and contains a far greater quantity of aqueous vapour than in others. If the amount of water held by such a hot ascending mass of air is so great that part of it is separated during the ascent and falls as rain, the air met with in the upper strata of the atmosphere is still further heated by taking up the latent heat of the aqueous vapour; and thereby its volume and upward impulse are augmented; and the final result must be a stratum of relatively warm and comparatively waterless air, which is then pushed by its expansion over colder air, but which, from containing more aqueous vapour, is lighter*. These departures from the rule that the temperature and density of the atmosphere decrease as the height increases, while the contained water must increase, are easily accounted for. The latter must be the rule for the higher latitudes at least, since the masses of warm air containing relatively much water continually ascending in the calms, on their way to higher latitudes, after loss of their greater heat by radiation, it is true for the most part sink to earth again as descending currents; but they must also in part reach the high latitudes as an upper equatorial current.

* Krönig has already proved that the aqueous vapour mixed with an ascending current produces by its condensation no diminution, but an augmentation of volume, as the latent heat of the vapour enlarges the volume of the air by a much greater amount than the volume of the condensed vapour before its condensation (*Fortschr. d. Phys.* xx. p. 626).

In this greater humidity of the higher strata of the atmosphere is to be sought the reason why even with descending currents of air falls of rain may occur. If the temperature of a very moist upper current be cooled by radiation below the point of saturation of the vapour, cirrus clouds will be formed, probably consisting of ice crystals*. The latent heat of the vapour and water thereby set free will again heat these strata of the air and protract the process of formation of heavier snow-clouds; but if by continued loss of heat by radiation the process be completed, the weight of the ice, no longer filling any considerable space, must disturb the adiabatic equilibrium, and a sinking of the mass of cloud commence. The condensation and heating then taking place melt the snow again; and the requisite latent heat is withdrawn from the air. The adiabatic equilibrium is hence still further disturbed; and the final result will be a cold descending current with rain. The density of these slowly descending rain-clouds, however, will not be great enough to make the cloud electrically conductive; consequently there will be no formation of electricity by distribution. The course of things, however, will be different when by local overheating of the air in the vicinity of the ground a local upcurrent with rainfall is produced. The upcurrent may then acquire a velocity greater than that of the falling drops formed in the resisting air; hence these will be whirled with the current into the upper regions, the temperature of which lies far below the freezing-point, and frozen to hailstones. By the rapid increase of volume, and the corresponding lateral expansion of the accelerated current, the next higher strata of air, which are relatively moist and cold, are set whirling with a horizontal axis of rotation; and these whirlwinds combine with that which is ascending and rotating about a vertical axis. The violent whirling motion into which

* It is extremely probable, however, that in the high regions of the atmosphere both water and vapour retain their state of aggregation down to far below the temperature of their points of freezing and condensation respectively. That water without the presence of solid bodies to induce crystallization, and without violent agitation, can be cooled far below -20°C . without freezing is a fact. That steam in like manner can retain the form of vapour below its point of condensation has not yet been proved experimentally. We know only the retardation of boiling, which so frequently gives rise to steam-boiler explosions. It is at all events not improbable that this retardation of boiling also stands opposed to a retardation of condensation. This can only with difficulty be ascertained by experiments, since means are wanting to cool a mass of steam out of contact with solid or liquid bodies. Without assuming this it cannot well be explained why the sky is not always entirely covered with cirrus clouds; for it would have to be assumed that water particles liquefied in the great rarefaction of the higher strata of air do not appear as clouds.

the hitherto calm overcooled aerial sea is thrown will now induce in it a sudden formation of water and ice. The whirlings with horizontal axis of rotation may at the same time acquire a great diameter and hurl up the grains of ice repeatedly into the ice-region, until they have grown too heavy and fall to the ground as hailstones or, after passing through lower warm air, as cold drops of rain. By this copious formation of rain in a short time the water particles of the path of cloud are brought so close together up to the highest air-strata, that it becomes a conductor of electricity and is consequently exposed to electrical distribution. If at any place it is in conductive connexion with the earth, the earth's electricity must flow into it; and it then receives the same electricity. If it is not so, it becomes charged in the vicinity of the earth with the contrary electricity, while the similar electricity escapes by the conductive vortex-cloud into the higher regions. Where the conduction of the cloud is imperfect, it is temporarily restored by lightning-flashes springing between the layers of cloud insulated from one another, or between cloud and earth; and finally, on the whirling storm passing away, and the cloud formed by it breaking up, the whole of the electricity will again equalize itself with the earth's electricity by flashes of lightning, or will in part pass into the air as atmospheric electricity.

Many observations of the formation of thunder-storms have been made from the summits of high mountains or from balloons; and almost all of the observers have spoken of several layers of clouds one above another, either joined together or between which flashes of lightning sprang. The most instructive description is that given by M. Wite*, who observed from a balloon the rise of a heavy thunder-storm. He saw "two layers of cloud, one about 2000 feet above the other, of which the upper one sent snow, rain, and hail to the lower. *Between the two passed noiseless undulating masses of yellowish light.* Electric discharges, with lightning and thunder, occurred always in the lower layer; yet the thunder-storm was far more violent *above both layers* than below them. The upper layer was strongly agitated by a west wind." That the observer could see only two clouds, one above the other, is explicable, since his balloon was at the altitude of the interval. It is to be presumed that several more such layers of cloud, up to the highest region of the atmosphere, were present, between which the observed precipitation and processes of electric conduction took place. By the heavy rain falling from the upper cloud layer, especially from its middle, the two were conduc-

* *Fortschr. der Physik*, 1852, p. 762.

tively connected, and thereby submitted to the process of electric distribution.

To the theory of the sun's electric potential might still be opposed the objection that the electric attraction between the sun and the planets, and the repulsion which the latter would necessarily exert upon one another and upon their satellites, would modify the basis of the astronomical calculations, since then, besides gravitation, an additional force, the electrical, would have to be taken into account.

This objection is perfectly legitimate. But as electric force, equally with gravitation, stands in the ratio of the square of the distance of the centres, the paths of the planets would remain unaltered if a part of the gravitational were replaced by an electrical attraction. Only the calculated ratio of the masses of the sun and planets to that of the earth would be changed. These alterations would be sensible, especially in the case of the small planets and the satellites, since electric force is a function of the surface. On the other hand, however, the disturbing influences exerted by the planets and their satellites upon one another's paths must be changed if gravitation be diminished by electric repulsion.

Perhaps it is reserved for astronomy to bring out from the perturbations of the paths of Mercury, the asteroids, and the satellites the demonstration of the existence or nonexistence of an electric potential of the sun.

XXVI. *On Porous Bodies in relation to Sound.* By Lord RAYLEIGH, D.C.L., F.R.S., Cavendish Professor of Physics in the University of Cambridge*.

IN Acoustics we have sometimes to consider the incidence of aerial waves upon porous bodies, in whose interstices some sort of aerial continuity is preserved. Tyndall has shown that in many cases sound penetrates such bodies, *e. g.* thick pieces of felt, more freely than would have been expected, though it is reflected from quite thin layers of continuous solid matter. On the other hand, a hay-stack seems to form a very perfect obstacle. It is probable that porous walls give a diminished reflection, so that within a building so bounded resonance is less prolonged than would otherwise be the case.

When we inquire into the matter mechanically, it is evident that sound is not destroyed by obstacles as such. In the absence of dissipative forces, what is not transmitted must be reflected. Destruction depends upon viscosity and upon

* Communicated by the Author.