"On Electric Touch and the Molecular Changes produced in Matter by Electric Waves."

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[* In the various investigations on the properties of electric waves, one property has not yet attracted so much attention as it deserves— the action of long ether waves in modifying the molecular structure of matter. Apart from the interest attached to the relation between ether, electricity, and matter, the subject is of importance as affording not only a very important verification of the identity of visible and electric radiation, but also establishing the continuity of all radiation phenomena. These phenomena occupy the borderland between physics and chemistry, and their study may therefore be expected to throw much light on several subjects at present imperfectly understood. The study of the action of electricity and of ether waves on matter in the form of solids presents many difficulties, owing to the great complexity of atomic and molecular aggregation which characterises the solid state of matter. But the phenomena often met with in theory and practice is, unfortunately, in reference to matter in a solid state. The means of investigation are almost wanting: chemical tests give us no information, for they tell us (and that in a few cases only) of the ultimate change in the mass as a whole, and not of the protean transformations that are constantly taking place in it under the action of ever-varying changes in physical environments. In the following investigations the difficulties mentioned above were constantly present, and the attempts to meet them may therefore be of some interest.]

In my former paper† I described the contact-sensitiveness of various elementary substances to electric radiation. It was shown that though many substances exhibit a diminution of contact-resistance, there are others which show an increase of resistance—an increase which, in certain cases, lasts only during the impact of electric waves, the sensitive substance automatically recovering its original conductivity on the cessation of radiation. There are thus produced two opposite effects, either an increase or a diminution of resistance, depending on the nature of the substance.

The effect of increase of contact-resistance is not an exceptional or isolated phenomenon, but is as normal and definite under varied con-

* Matter in brackets [ ] added March, 1900.

† "On a Self-recovering Coherer, and the Study of the Cohering Action of Different Metals," 'Roy. Soc. Proc.,' vol. 65.

ditions as the diminution of resistance noticed in the case of iron filings. These two specifically different effects have to be recognised, and it would be advisable, to avoid misunderstanding, to use a simple term to indicate both these effects, and distinguish them from one another, by calling the one positive and the other negative. The term "coherence" applied to the normal *diminution* of resistance exhibited by certain metals by the action of electric waves cannot be applied in all cases, as there is, as has been said before, another class of substances which exhibits under *normal* conditions an *increase* of resistance. The term "decoherence" has been used to indicate the effect of mechanical tapping on fatigued substances of the former class; this produces an increase of resistance, and at the same time restores the sensitiveness. The action of tapping on fatigued specimens of the latter class is, however, a diminution of resistance.

I have shown in a former paper that the seat of sensitiveness is confined mainly to the surface layer of the sensitive substance, and that the nature of the substratum has little or no effect on the sensitiveness. Thus, a substance which exhibits a strong diminution of resistance, if coated with an extremely thin layer of a substance of the other class which shows an increase of resistance, will now exhibit an increase of resistance. It is seen that the action is one of the bounding layer or skin of the sensitive substance. There is a Sanskrit word, *twach*, which means the skin; and as the phenomenon dealt with in the present paper is one of sensitiveness of *twach*, I shall use the expression "electric touch" in the restricted sense of contact sensitiveness to electric stimulus, the touch being regarded as *positive* when electric oscillation produces an increase of conductivity or diminution of resistance, and *negative* when the contrary effect is produced. Substances which exhibit a decrease of resistance will be called positive, and those which show an increase will be regarded as negative. The above terms are to be regarded as convenient substitutes for long descriptive phrases.

The phenomenon of contact-sensitiveness seems at first to be extremely anomalous, and there appears to be little relation between substances which exhibit similar electric sensitiveness. Taking iron as an example of a very sensitive substance, it is seen to be easily oxidised, and from this it may be inferred that a slight oxidation on the surface is favourable for sensitiveness. This view obtains some support from the consideration that the so-called noble metals are not as sensitive as iron. But the metals nickel and cobalt, which are bright and not easily oxidised, are also very sensitive. The very sensitive metals iron, nickel, and cobalt are all magnetic, and it might be thought that magnetic property is favourable for electric sensitiveness, but a dial magnetic substance like bismuth is also found to exhibit a fairly strong sensitiveness. Again, from the strong diminution of resistance exhibited by magnesium, it may be inferred that the sensitiveness depends

on the electro-positive character of the metal; but potassium, one of the most electro-positive metals, exhibits an unusual increase of resistance, a property which it will be shown in a future paper it shares with some of the most electro-negative elements.

There is one property, however, which at first would seem to be in some way related to the sensitiveness of metals—the volatility of metals under the cathodic stimulus, investigated by Sir William Crookes,* who gives the following list of metals, arranged according to their volatility :—

Palladium	108	Copper	40
Gold	100	Cadmium	31·99
Silver..................	80·68	Nickel	10·99
Lead	75·04	Indium	10·49
Tin......................	56·96	Iron	5·5
Brass	51·58	Magnesium	very slight
Platinum	44	Aluminium	very slight

In this list the substances which are most volatile, *e.g.*, Pd, Au, Ag, are not very sensitive, whereas Fe, Al, Mg, which are least volatile, are strongly sensitive. But the above series does not exactly coincide with the series of electric sensitiveness. Again, the volatility of platinum is retarded in hydrogen gas, but an experiment carried out to determine the sensitiveness of platinum in hydrogen failed to show any great increase in the sensitiveness.

None of the above suppositions give any satisfactory explanation of the numerous anomalies in the contact-sensitiveness of metals. It then appeared that the observed effect is not due to a single cause but to many causes. An observer studying the dilatation of a gas under reduced pressure, and ignorant of the effect of temperature, will doubtless encounter many anomalies. In the phenomena of contact-sensitiveness the variables are, however, far more numerous, and the different possible combinations are practically unlimited. It therefore became necessary, by a long and tedious process of successive elimination, to find out the causes which are instrumental in producing the observed effect; the results obtained throw some light on this intricate subject. The following are some of the principal directions in which a systematic inquiry was carried out :—

A. On the difference between mass action and molecular or atomic action, with reference to the phenomenon of contact-sensitiveness.

B. On the change of sign of response in a receiver due to a variation of the radiation intensity.

* Crookes, 'Roy. Soc. Proc.,' vol. 50.

C. On the physico-chemical changes produced in a sensitive substance by the action of electric radiation, and on the radiation-product.

D. The phenomena of electric reversal and of radio-molecular oscillation.

E. On "fatigue" and the action of mechanical tapping and other disturbances by which the sensitiveness of a fatigued receiver may be restored.

F. On the nature of the passage of electricity through imperfect contacts, and the influence of various physical agents on the current.

G. On the systematic study of the contact-sensitiveness exhibited by metals, non-metals, and metalloids.

H. On the contact-sensitiveness exhibited by alloys and compounds.

I intend to treat the above subjects in some detail, and in the present paper will especially deal with the first five lines of investigation. These, it is hoped, will afford an explanation of some of the most perplexing anomalies. All the subjects mentioned above are more or less interdependent, but their treatment in one paper would make the subject very complicated. It would be easier to take a more generalised and complete view of the subject as a whole, after each of the above-mentioned inquiries has been separately considered. With reference to the flow of electricity through imperfect contacts, I need only mention here that the phenomenon seldom obeys Ohm's law. In many instances the phenomenon appears more allied to the discharge of electricity through a gaseous medium.

Mass Action and Molecular Action.

Of the attempts made to explain the action of contact-sensitiveness, Professor Lodge's theory of coherence has been the most suggestive. The coalescence of water and mercury drops in Lord Rayleigh's experiments, and Professor Lodge's observation of the welding of two metallic spheres by powerful oscillatory discharge in the neighbourhood, apparently lend much support to the theory of electric welding, which explains in a simple manner the diminution of contact-resistance of various metallic filings when subjected to strong electric variation.

On this theory it follows that *all* imperfect contacts should exhibit a diminution of resistance when subjected to electric radiation. In carrying out a systematic investigation of the contact-sensitiveness of metals, I, however, found that there are substances, of which potassium may be taken as a type, which exhibit an increase of resistance. Potassium is not a solitary instance; I have found a large number of elements exhibiting this action; the number of compounds which exhibits a similar action is also considerable. Other experiments will

be presently described which would show that the theory of coherence is inadequate. From the above it would appear that the subject is far more complex than was at first supposed. For various reasons it would be best to distinguish between the two different actions, which may conveniently be described as mass action and molecular action.

Mass Action.—By this is meant the general action, say, between two masses when placed in a very strong electric field. Under the given circumstance, sparking may take place between the bodies, and the two may thus be welded together. From what has been said it will be seen that such action is *non-discriminative*—that is to say, the action will be the same whatever the chemical or physical nature of the substance may be. The best way of showing this action is with drops of liquid, with surface contamination, for any incipient welding will be at once exhibited by the complete coalescence of the drops. The non-discriminative nature of the action is shown in a striking manner in the following experiment. I may mention here that fragments of solid potassium, and in a lesser degree sodium, exhibit an increase of contact-resistance under the action of electric waves. I made a liquid alloy of potassium and sodium, and drops of this alloy were allowed to float on the stratum separating dense Rangoon oil from lighter kerosine, the alloy being of an intermediate density. The drops coalesced when placed in an intense alternating electric field. The next experiment was made with potassium heated under melted (hard) paraffin. By stirring the molten K with a glass rod, the metal was broken up into numerous spherical drops. These also coalesced under similar electric influence. It is, however, to be borne in mind (1) that in the above experiment the substance is in the form of a liquid, and that in this particular condition certain important molecular changes, to be presently described, cannot very well take place; (2) that the conditions of the experiment are abnormal.

Experiments will be presently described which will show that the observed variation of conductivity produced by radiation is not due to coherence, but to certain molecular changes of an allotropic nature.

Molecular Action.—By this I mean the allotropic modification produced in a substance by the action of electric waves, the allotropic change being due to a difference in the atomic or molecular aggregation. It will be shown that such molecular change does take place by the action of electric waves, and that all the observed effects of variation of resistance of the sensitive substance may be explained on the theory of allotropic transformation due to the above cause. The effect due to molecular changes in a substance is also expected to be modified by the chemical nature of the substance; thus the molecular action due to radiation, giving rise ultimately to the variation of conductivity of the sensitive substance, will be *discriminative*, in contradistinction to the non-discriminative mass action.

Is the effect of radiation due to non-discriminative coherer action or to the discriminative molecular action? That the effect is discriminative, and therefore molecular, appears to be decisively proved by the experiments described below. If further proofs are necessary, they are afforded by the characteristic curves of variation of current with the E.M.F. given by the three types of substances, positive, negative, and neutral; by the continuity of radiation effect on matter; and, lastly, by certain remarkable results I obtained, which show that the effect of ether waves on elementary substances depends on the chemical nature of the substance; in other words, the effect is found to be a periodic function of the atomic weight of the substance. A detailed account of the above will be given in a future paper.

On the Change of Sign of Response in the Receiver, due to a Variation of Intensity of Radiation.

After finding the increase of resistance exhibited by certain substances, I wished to see whether these showed any further difference as compared to substances which exhibit a diminution of resistance. In my determination of the "Index of Refraction of Sulphur for the Electric Ray,"* I used the method of total reflection. I often noticed that just before total reflection, when the intensity of the transmitted beam became comparatively feeble, the receiver indicated an increase instead of the usual diminution of resistance. Professor Lodge mentions in one of his papers that an iron filing coherer exhibits an increase of resistance when acted on by feeble radiation. Thus, if positive substances like iron give a negative reaction, with the diminution of radiation intensity, negative substances may be expected to give a positive reaction with feeble radiation. Very sensitive substances are, however, not so well adapted for an exhibition of this reversed action, possibly because the range of sensibility is comparatively great. But it is not difficult to demonstrate this property in the case of moderately sensitive substances.

The following experiment with a moderately negative substance (arsenic) and a moderately positive substance (osmium) will bring out this interesting peculiarity in a clear manner. The intensity of incident radiation may be varied in two ways—(1) by removing the radiator further and further from the receiver, or (2) by using polarised radiation, whose intensity may be varied by the rotation of an analyser. In the experiment to be described, the first method was adopted.

Experiments with Arsenic Receiver.—A receiver was made of freshly-powdered arsenic. The radiator used emitted radiation of strong intensity. It was at first placed close to the receiver, and there was produced a moderate increase of resistance. It was then removed

* 'Roy. Soc. Proc.,' 1895.

further and further, and the increase of resistance became less and less. When the distance was increased to 25 cm. the action was reduced to zero. When the distance was increased to 30 cm. there was a diminution of resistance, showing that 25 cm. is, in this case, the *critical* distance. The receiver continued to exhibit a diminution until the radiator was removed to a distance of 70 cm., when the radiation intensity was too feeble to affect the receiver. Now this critical distance may approximately be regarded as a measure of the sensibility of the substance. In this particular case the electric touch has a negative sign. If by any means (some of which will be described later on) the substance becomes more sensitive, *i.e.*, more negative, the critical distance will be increased. On the contrary, if the sensitiveness becomes less (the substance tending towards positive direction) the critical distance will be decreased. The application of this principle is of importance as affording a means of determining the variation of sensitiveness under different conditions.

Experiments with Osmium Receiver.—Substances which are feebly positive give a diminution of resistance when the radiator is close to the receiver, and an increase of resistance when the radiator is beyond the critical distance. Thus the critical distance for an osmium receiver (whose normal action is moderately positive) was found to be about 250 cm. The radiator at a distance of 300 cm. produced a deflection of − 3 divisions in a galvanometer placed in the receiver circuit. But at the distance of 200 cm. the deflection became + 4, and at the reduced distance of 50 cm. the deflection became + 150 divisions.

In order to avoid confusion, we may choose to call the effect due to strong intensity of radiation as the normal action. The sign of normal action might further be verified, wherever possible, by obtaining a reverse action with feeble radiation intensity.

Molecular Changes produced in Matter by the Action of Electric Waves.

A sensitive receiver made, say, of iron powder, has its conductivity suddenly increased by the action of electric radiation; but the sensitiveness of the receiver is lost after the first response, and it is necessary to tap it to restore the sensitiveness. On the theory of coherence, the loss of sensitiveness is explained by supposing that electric radiation brings the particles nearer and welds them together, and that the sensitiveness can then only be restored by the mechanical separation of the particles. This supposition, however, fails in the case of substances which exhibit an increase of resistance by the action of radiation. It may, however, be supposed that by some process, little understood, the particles are slightly separated by the action of electric waves, thus producing the observed increase of resistance. On this view, however, the restoration of sensitiveness by tapping remains unexplained.

Again, if the increase of resistance is due to a slight separation of particles, suitable small increase of pressure ought to restore the original conductivity, as also the sensitiveness. It is, however, found that a considerable pressure is required to restore the original current, as if the outer layers of the particles were rendered partially non-conducting by radiation, and had to be broken through before the original current could be re-established. It is also found that though the sensitiveness is restored by this expedient of increasing the pressure, yet the restoration is only partial, and that after a repetition of this process the receiver loses its sensitiveness almost completely.

I have attempted to find out an explanation of this obscure "fatigue" effect. This subject will best be treated in connection with the anomalous behaviour of silver, which I find is also in a manner connected with the fatigue effect. Silver, when subjected to radiation, exhibits, as indicated in my last paper, sometimes an increase, and at other times a decrease, of resistance. The difficulty in this case cannot be explained on the supposition of variations of radiation intensity, as the anomaly persists even when the intensity of radiation is maintained uniform by keeping the radiator at a fixed distance.

In order to explain these actions, I assumed the following hypotheses, which, with the necessary deductions, are given below:—

(1) That electric radiation produces molecular change or allotropic modification in a substance.

(2) That, starting from the original molecular condition A, the effect of radiation is to convert it, to a more or less extent, into the allotropic modification B (the latter condition will be designated as the "radiation product"). It follows that this change from one state to the other must be accompanied by a corresponding change in the physical properties of the substance.

(3) As one of the properties of a substance is its electric conductivity, any allotropic changes produced by radiation should be capable of being detected by a variation in the conductivity of the substance.

(4) As a molecular strain is produced during transformation from A to B, at a certain stage there may be a rebound towards the original state A. Thus, after the molecular change from A to B condition has reached a maximum value, the further action of radiation may be to reconvert, to a more or less extent, B to A, this reversal of effect being indicated (see No. 3) by a corresponding electric reversal.

(5) That the ultimate loss of sensitiveness, known as "fatigue," is due to the presence of the radiation product, or strained B variety, along with the A variety, the opposite effects produced by the two varieties neutralising each other.

The justification for the above hypotheses is to be sought for—

(1) From analogy with other known radiation phenomena.

(2) From experimental proof—

(*a*) Of the allotropic transformation being attended with changes in the conductivity of the substance.

(*b*) Of the existence (and, if possible, the production by chemical means) of an allotropic modification analogous to the radiation product or B variety, whose reaction should be opposite to that of the substance in a normal condition (A variety).

(*c*) Of the assumption that after the maximum transformation of A into B, the further action of radiation is to reconvert, to a more or less extent, the form B into A, such transformations giving rise to electric reversals.

(*d*) Of the existence of the radiation product in a fatigued specimen.

The above mentioned hypotheses will obtain still stronger support if further deductions from the above theory are borne out by confirmatory experiments.

I will now describe investigations on the lines sketched above.

Allotropic Modification produced by Visible Radiation.

As regards the action of radiation in producing allotropic modification, several such instances are known in the case of visible radiation. In the familiar example of the conversion of yellow phosphorus into the red amorphous variety, the effect is quite apparent. But this is not the case in the transformation of the soluble sulphur into an insoluble variety by the action of light; here the transformation is not apparent, and has to be indirectly inferred from the insolubility of the solarised product in carbon bisulphide. The reason why a far larger number of instances of allotropic transformation produced by light is not known is not because such effects are not more numerous, but because we are unable to detect such changes. It must be admitted that our knowledge of molecular changes, specially in a solid, and the means of their detection, is at present extremely limited.

Variation of Conductivity produced by Allotropic Changes.

There is one method of detecting these molecular variations to which little attention has hitherto been given, but which appears to be of great interest, and promises to yield important results in investigations of this class. It is evident that changes in molecular structure must be attended with changes of physical properties, electric conductivity being one of them. Among other instances of allotropic changes attended with changes in electric conductivity may be mentioned the wide difference of conducting power between graphite and diamond. The same great differences of conductivity is seen between the crystalline and amorphous varieties of silicon, and between the "metallic"

and white varieties of phosphorus. But it is not at all necessary to take only such extreme cases to show the influence of molecular or atomic aggregation in influencing the conductivity. This effect is brought into painful prominence by the variation produced in spite of all precautions in our standards of resistance.

Experimental Proof of Allotropic Changes being attended with Variation of Conductivity.—I shall now describe a direct experiment by which the change of conductivity produced in a substance by molecular change is exhibited. Red mercuric iodide is converted into the yellow variety by the application of heat, and the substance does not return to its original state till after a considerable lapse of time. The recovery here is very slow. A small quantity of mercuric iodide was now placed in a tube provided with sliding electrodes, and a current was made to pass through the substance by suitable compression. The conductivity of the substance is rather small, and therefore a thin stratum should be taken for experiment. The current is observed by means of a delicate galvanometer. On the application of heat to the tube (which converts the red into the yellow variety), there was at once produced, simultaneously with the molecular transformation, an increase of conductivity. This effect is not due to a rise of temperature, for the increased conductivity was still exhibited on cooling the tube. From this experiment it is seen that the molecular changes can be inferred from changes in the conductivity. In the case described above, the recovery from the B, or second stage, to the first stage, A, is slow; but there may be substances (and there are such substances) where, under the given conditions of temperature and other physical surroundings, the first stage is far more stable than the second; the substance will then pass back quickly from the B condition to the primitive state, on the cessation of the exciting cause, which gave rise to the transient B effect. The substance will in this case be "self-recovering."

[*Electrical Reversal in the Radiation Product.*

In the hypotheses given above, it was said that the reaction of the radiation product, or B variety, should be opposite to that of the substance in the normal condition, or in the A state. Thus a negative substance which by the action of radiation shows an increase of resistance during conversion from the A to the B state should exhibit a diminution of resistance when B variety is acted on by electric waves. The contrary would be the case with positive substances.

The following tabulated statement indicates the phenomena exhibited by two classes of substances :—

Sign of electric touch.	Action of radiation on the fresh or A variety of the substance.	Further action of radiation on the radiation product or B variety.
Positive, *e.g.*, iron	Diminution of resistance.	Increase of resistance.
Negative, *e.g.*, arsenic...	Increase of resistance.	Diminution of resistance.

We have thus two distinct classes of phenomena dependent on the sign of electric touch. If K_A represents the conductivity of the fresh substance, and K_B the conductivity of the radiation product, then

(1) With positive substances, as the conductivity of the radiation product is greater ($K_B > K_A$), the first action of radiation would be to produce a diminution of resistance. This diminution will continue to be exhibited till the maximum amount of B variety is produced. The further action of radiation now will be to reconvert B into A; but as $K_A < K_B$ there would now be produced a diminution of conductivity, and a galvanometer in circuit will indicate an electrical reversal. The reconverted A variety may again be transformed to a greater or less extent to B, and in this way a series of reversals may take place, due to the continued action of radiation producing oscillation in molecular or atomic groupings. I shall designate this as the phenomenon of radio-molecular oscillation.

(2) With negative substances the conductivity of the radiation product is less ($K \; < K_A$), and the first action of radiation will therefore be an increase of resistance. The phenomena exhibited by these negative substances will precisely be opposite to those shown by the positive substances.

The above is but an approximate representation of the phenomena. To be more accurate, one has to take into account the partial changes and the effect of radiation on these changed products. Thus, at first suppose the substance to be entirely made up of A variety (this would rarely be the case). The first flash of radiation converts a large portion of A into B, the substance now being a mixture of A and B. The action of the next flash would be to convert the unchanged A into B, and reconvert to a more or less extent B into A. The electric response will thus be very strong at the beginning, but will become continuously less and less. When the proportion of B has attained a maximum value, the reconversion of B into A will become relatively large, and thus give rise to reversal effect.

I spoke of the conversion "to a greater or less extent" of one variety into the other. There is also the question of the relative stability of the two varieties under the given conditions. From the above it will be seen what possibilities there are in the way of different combinations, and the varied phenomena thereby rendered possible. I will presently describe some of the typical cases.

In the above it has been assumed that the reaction of B variety is opposite to that of A. As previously mentioned, in working with a silver receiver I found it, when fresh, exhibiting at first a diminution and, subsequently, an increase of resistance. The anomalous action may be explained by supposing the normal fresh silver Ag to be positive, and the radiation product Ag′ negative. These two varieties would thus give rise to opposite reactions. To justify the assumptions made above, it became necessary to obtain by some other means a variety of silver Ag′, analogous to the hypothetical negative variety.]

Two Varieties of Silver.

After many unsuccessful attempts, I at last obtained a variety of silver which gives a moderately negative reaction (increase of resistance). Silver chloride was first precipitated by the addition of dilute hydrochloric acid to silver nitrate solution. The precipitate was then reduced to metallic silver by zinc filings, the excess of zinc being dissolved off by the action of HCl. This form of silver gives a negative reaction. Direct precipitation of silver produced by dipping a piece of zinc in $AgNO_3$ solution gives a positive variety. The negative product Ag′ is perhaps better formed at relatively low temperatures, for the products obtained on certain warm days, the thermometer registering 27° C., were very feebly negative, and passed into the positive state after an interval of twenty-four hours. But on cold days (temperature = 22° C.) the products obtained were stable. I have specimens which have kept the negative property unimpaired for nearly three months. The negative property is not due to any accidental impurity, for pure silver obtained by Stas' method also gave the negative reaction. The negative reaction may, however, be supposed to be due to a thin film of chloride formed during reduction. I washed the Ag′ with NH_3, then with water, and, after drying, the result was still a negative reaction. I then carried out a parallel set of experiments with ordinary silver filings. Two separate quantities were taken; one was shaken with only HCl, the other was mixed with zinc filings, and the excess of zinc was dissolved off with HCl; the two specimens were then washed and dried. Both gave the positive reaction of ordinary silver. The above experiments are interesting for the production, by chemical means, of an allotropic variety analogous to the transitory radiation product.

There are other differences of electric behaviour between Ag and Ag′; for instance, when made into a voltaic cell, the two varieties give a P.D. of about 0·12 volt. There are other interesting peculiarities about this cell, the consideration of which is postponed to a future occasion.

Electric Reversal.

It now remains to be proved that the "radiation product" exhibits a change of sign of electric touch. The sensitiveness of certain substances belonging to each of these two classes is very great. On the other hand, in the transition from one class to the other, substances are met with the sensitiveness of which is rather feeble. The experimental verification of the hypotheses mentioned above seemed at first very difficult, as the reversed action was likely to be masked by the stronger normal action of the still unconverted portion of the substance. It however occurred to me that if slightly sensitive substances were taken, then the direct and reversed actions were likely to be obtained with less difficulty. For this reason I took for my first experiments arsenic, which is moderately negative. It is however possible, though the adjustments are difficult, to exhibit the reversed actions even with strongly sensitive substances, and as a type of such actions that of iron will be taken as an example.

Observations with Arsenic Receiver.—Experiment I.—A receiver was made with freshly powdered arsenic; the critical distance was found to be 25 cm.; that is to say, when the radiator was moved from 1 to 25 cm. there was always produced an increase of resistance, while beyond this distance there was a diminution of resistance; the critical distance, 25 cm., may therefore be taken as an approximate measure of the negative character of the specimen. As has been said before, if through any cause the substance becomes more negative, the critical distance will be increased; but if the substance tends towards the positive direction by becoming less negative, then the critical distance will be decreased. The receiver was now continuously subjected to radiation for ten minutes. After this it was found that the receiver gave a diminution or positive reaction, even when the radiator was brought close to the receiver. The action of radiation has thus reversed the sign of electric touch.

Experiment II.—Any arbitrary length of exposure labours under the defect that what is observed is the final effect, the intermediate effects not being taken into account. In order to observe the intermediate effects, a very laborious series of observations is necessary. The experiment was therefore modified in the following manner:—A fresh receiver was subjected to radiation, and observations at intervals of fifteen seconds were taken to test the nature of reaction of the sensitive substance. The first action of radiation on the fresh specimen was a great increase of resistance—so very great that the current was reduced to zero; it was no longer possible to make any further observation without re-establishing the current. This was done by a very gradual increase of pressure, effected by means of a fine micrometer screw which moved the compressing electrode in a perfectly parallel manner. There

should be no jarring motion, as mechanical disturbance was found to break up the complex atomic aggregation in the radiation product. During eight minutes of exposure the receiver continued to exhibit an increase of resistance, after which the substance became positive, being converted to the B state; this positive state lasted for a minute under exposure to radiation, then there was a reversal to the original negative state—as if the structure so laboriously built up suddenly gave way. Subsequently there were series of reversals, the specimen becoming more and more inert, and, after an exposure of about thirty minutes, the sensitiveness was practically lost.

The curve given below represents approximately the results of the experiment. During certain periods the substance became so nearly neutral that it was difficult to interpret whether the substance was positive or negative. The lower halves of the curve represent the negative and the upper halves the positive states, and the corresponding numbers represent, in minutes, the duration of these states.

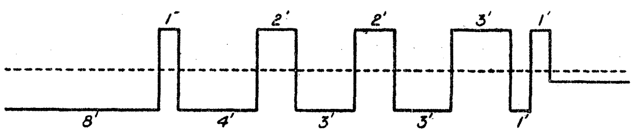

FIG. 1.—Electric Reversal Curve.

[Radio-molecular Oscillation.

It was said that, owing to molecular reversals due to radiation, there should be a corresponding series of electric reversals. In this investigation it is essential that the substance examined should be completely protected from all disturbances, such as mechanical vibration, &c., and only subjected to the action of radiation. The experimental difficulties are very great. If we take a strongly sensitive positive substance—say iron, the effect of the first flash of radiation (a diminution of resistance) is very great, and the subsequent relatively feeble reversal effects, unless carefully looked for, are liable to pass unnoticed. After the first adjustment, the receiver should on no account be touched, as mechanical jars are found to undo the effect of radiation. Though by special care the mechanical jars could be reduced to a minimum, yet it appeared advisable to devise appropriate means by which the necessity of touching the receiver for subsequent adjustments is altogether avoided. The method adopted to this end varies with individual cases. In the case of arsenic, for example, the action of radiation is often to produce a very great increase of resistance, and thus convert the substance into a non-conductor. The pressure has therefore to be so adjusted at the beginning, that the substance can never become altogether non-conducting; the

receiver is thus absolutely free from all effects, except those which are to be observed—viz., the effects due to continuous action of radiation. The time of exposure is accurately measured by counting the individual flashes of radiation, due to interruption of the primary current in the Ruhmkorff coil by a tapping key. The conductivity of the substance at a given moment is inferred from the deflection of the galvanometer in circuit with the receiver. When feeble radiation is used, it takes an inconveniently long time to obtain reversals; there is, besides, a tendency of self-recovery in the receiver. In order to expedite the reversals, the incident electric radiation is made very strong.

Before entering into the detail of the results obtained, I will say a few words about the principal types likely to be met with. We may have the following:—

I. Substances in which the B state is unstable under the given conditions; the B state will therefore only persist during the action of radiation, the substance relapsing into the original condition on the cessation of radiation. Two cases are possible (i) when the substance is positive, (ii) when the substance is negative.

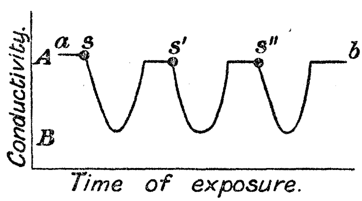

Fig. 2.—Curve for Potassium.

The latter case is exemplified by potassium. In the above curve (fig. 2), A and B represent the two molecular states. The substance being negative, A is more conducting; *a* represents the conductivity of the fresh specimen; the thick dots S S′ . . . the individual flashes. It is seen that the effect of radiation is to produce a sudden diminution of conductivity, due to the transient formation of B variety with its diminished conductivity. The substance, electrically speaking, is highly elastic, and the limit of its elasticity is also very great. With the majority of substances, however, self-recovery is only possible when the narrow limit of elasticity is not exceeded.

II. In this class the radiation product is somewhat stable; the successive conversions from A to B and from B back to A are supposed to be complete. Probably there is no substance which exhibits this action in a perfect manner, but we have an approximation to this condition in the case of magnesium, which under proper adjustments shows successive complete reversals for a long time. The substance, however, after a time exhibits the effect of fatigue.

The curve given in fig. 3 clearly exhibits the reversals. This curve also explains the behaviour of magnesium noticed in my last paper, which appeared very curious at the time. "It is sometimes possible to so adjust matters that one flash of radiation produces a diminution of resistance, and the very next flash an increase of resistance. Thus a series of flashes may be made to produce alternate throws of the galvanometer needle."*

The receiver was so adjusted as to give a deflection of five divisions.

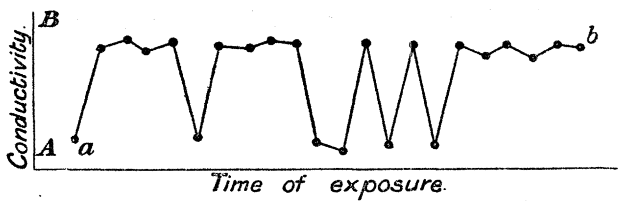

FIG. 3.—Radio-molecular Oscillation Curve for Magnesium.

The first flash of radiation produced an increased deflection of 90 divisions (magnesium having a positive electric touch); the second flash produced a further deflection of five divisions, the third flash produced a *negative* deflection of five divisions, the fourth flash produced + 5, the fifth flash gave − 90 divisions, and the sixth flash a deflection of + 90. The reversals followed each other almost regularly, till the substance became insensitive.

III. Lastly, we may have a class of substances where the conversion from one state to the other is not complete. Here, again, we get two sub-divisions, owing to the distinction between positive and negative substances.

Taking first the case of a positive substance (see fig. 4 (β)), the original conductivity of which is represented by *a*, the action of the first few flashes of radiation would be to produce a great increase of conductivity by the formation of B variety; the next flashes convert

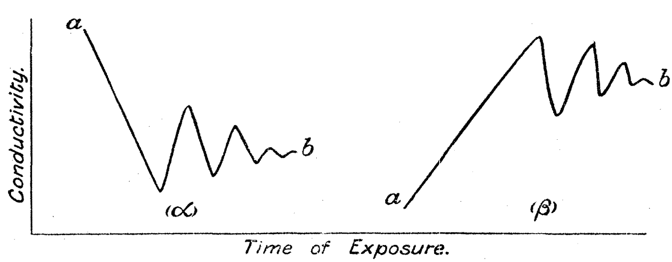

FIG. 4.—"Damped" Molecular Oscillation.

* "On a Self-recovering Coherer," &c., 'Roy. Soc. Proc.,' vol. 65, p. 169.

B back to A, but not completely, and the negative deflection will be less than the previous positive deflection. Owing to this "damping" effect, the oscillation curve will approximate to a logarithmic decrement curve. After a series of reversals the oscillation dies away, and the substance becomes almost inert. A glance at the hypothetical curve to the right shows that at the inert stage, *b*, *the substance as a whole ought to become more conducting the fresh specimen*, *a*.

The opposite should be the case with negative substances (see fig. 4 (α).

Fig. 5 exhibits the actual curve obtained with a (compound) positive substance.

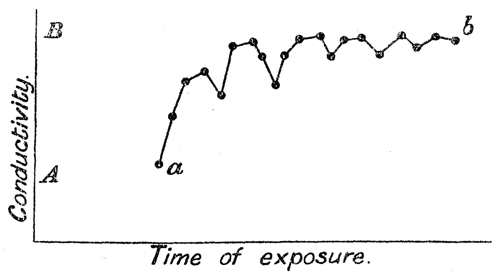

FIG. 5.—"Damped" Oscillation Curve for a Positive Substance.

It is remarkable for its regularity. The next figure (fig. 6) gives the curve for iron. The first diminution of resistance is too great to be properly represented in the diagram. Here we have the same type as in the previous case; *the inert stage, b, is also more conducting than a.*

IV. I will now consider the case of a negative substance exhibiting damping; arsenic will be taken as an example where the damping is not so great as in the case of iron.

Fig. 7 represents the actual curve obtained with arsenic (compare with the hypothetical curve for a negative substance, fig. 4 (α)).

It will be observed that *the substance in the fatigued state is, on the whole, less conducting than in the fresh condition*, as we were led to expect from the hypothetical curve. It will also be seen that the oscillations are very regular towards the end. The curves given in figs. 6 and 7 are those obtained with specimens immediately after they were set up. Had I allowed them a period of rest to allow the particles to get properly settled, I would have got curves even more regular. It is, however, evident that in substances exhibiting damping, two opposite electric conditions are induced in fatigued specimens; the positive becomes on the whole more conducting and the negative less conducting than in the fresh specimens. At the inert stage the rate of mutual conversion from one state to the other probably becomes equal, and the apparent fatigue is thus not due to the absolute want of sensi-

tiveness of the constituent varieties, but to the opposite reactions of A and B balancing each other.

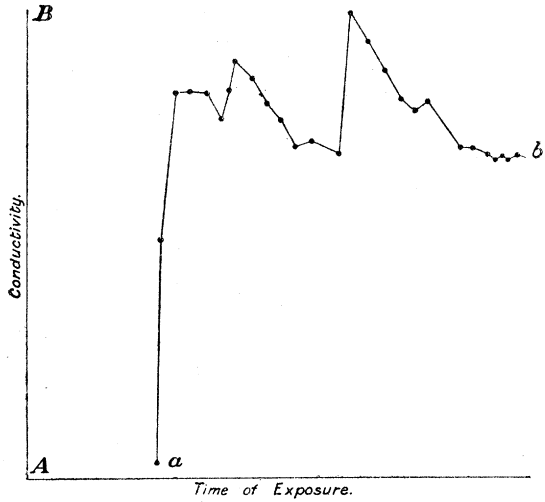

FIG. 6.—Curve for Iron.

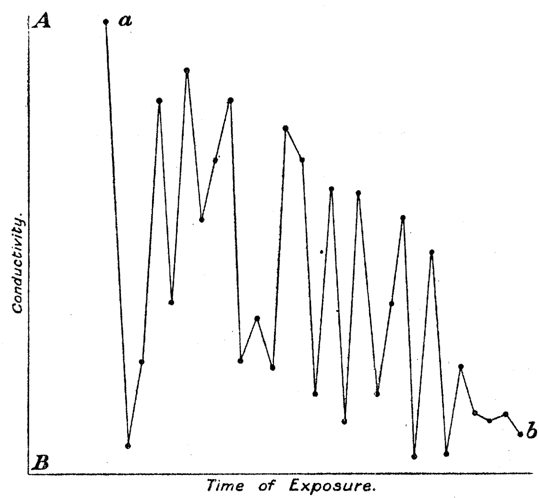

FIG. 7.—Curve for Arsenic.

We may now apply some further crucial tests to verify the suppositions made above.

Restoration of Sensitiveness to a Fatigued Substance.

It was said that the inertness of the substance, after long exposure, is due to the presence of a relatively large amount of strained B variety. It therefore follows that if by any means we can transform B into A, then after such a transformation there ought to be a restoration of the sensitiveness. It has also been stated that the B variety under ordinary circumstances is less stable than A. If now we apply a disturbing cause which is unilateral in its action—that is to say, if it converts B into A and not A into B—then such a disturbing cause will resensitise the fatigued substance.

Effect of Mechanical Disturbance.—Of the unilateral actions, mechanical vibration is one; for it is known that by the action of friction a substance may pass from one modification to another in one direction only. Thus the change of monoclinic into rhombic variety of sulphur is hastened by scratching with a glass rod, but the change does not take place in the opposite direction. We may now apply the crucial tests. Mechanical vibration will transform B into A, and with positive fatigued substances this ought to produce an *increase* of resistance (as A is less conducting than B); with negative substances the same disturbance ought to produce a *diminution* of resistance.

Effect of Heat.—There are other methods by which the B variety may be transformed into A; the more subtle molecular disturbance due to heat may be expected to be even more effective in producing the transformation. Here, too, the crucial test is that by slight heating the fatigued positive substance ought to show an increase of resistance, and the negative substance a diminution of resistance. The two following curves (figs. 8 and 9) confirm in a remarkable manner my anticipations.

Effect of Heat and Mechanical Disturbance on a Positive Fatigued Substance.—I shall at first deal with the curve for iron. At the end of No. 6 curve, the substance was left in the inert stage *b*. While in this state, the receiver was heated to a slight extent. Observe in the dotted portion of the curve the sudden fall of conductivity (increase of resistance). I should like to say here, that, though the fall has been indicated by a straight line, as representing the somewhat sudden fall of conductivity, I sometimes noticed on careful inspection a slight oscillatory movement of the galvanometer spot during this process. The significance of this I will notice on a future occasion. The ultimate effect of slight heating (excess of heat produces other complications) is the restoration of the original reduced conductivity. If the application of heat transforms B into A, we may expect the substance to regain its sensitiveness, which it lost in the fatigued stage *b*. The receiver was now exposed to radiation, and it at once responded, exhibiting almost its original sensibility. Observe how the subsequent

portion of the curve is a repetition of the curve No. 6, and how the substance arrives at the second fatigued state b'. To observe the

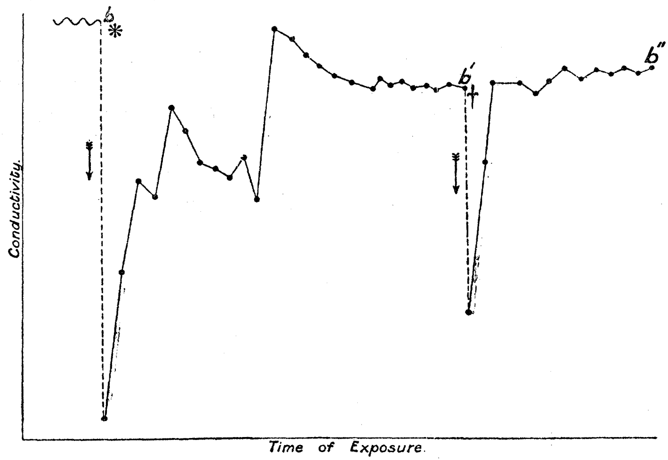

Fig. 8.—Curve showing the Effect of Heat and Mechanical Vibration on a fatigued Iron-filings Receiver.

* Application of heat. † Application of a tap.

effect of mechanical disturbance a gentle tap was given to the receiver, and at once there was produced an increase of resistance due to the transformation of B into A, the receiver regaining its sensitiveness by the transformation. The action of radiation was continued, and after a few reversals the substance once more arrived at the third fatigued state, b''. The process described above could be repeated any number of times.

Effect of Heat and Mechanical Disturbance on a Negative Fatigued Substance.

Experiments similar to the above were carried out with an arsenic receiver. From the curve given below (fig. 9) it is seen that the reaction of the negative substance is in every respect opposite to that of a positive substance. It will be noticed that the same cause—*i.e.*, heating or tapping—produces, as necessary consequences of the hypotheses previously stated, two opposite reactions in the two classes of substance. I have been able to verify this deduction by observations with nearly a dozen different substances, and have not, so far, come across any to contradict it. It thus appears that tapping restores the sensitiveness not by the separation of the electrically-welded particles (in which case tapping ought to have produced an increase of resist-

ance in *both* the classes of fatigued substance), but by removing the strain in B and thus converting it into A.

The effect of electric radiation is thus to produce rearrangement of atoms and molecules in a substance; so does light produce new atomic and molecular aggregation in a photographic plate—a subject to be dealt with in detail in a future paper. Some of my audience at the Royal Institution (January, 1897) may remember my attempt at explaining the action of the so-called coherers (which, perhaps, may be better described as "molecular receivers") by analogy with the photographic action. I had then no proofs for the assertion. I have since been able to obtain experimental evidence that the two phenomena are

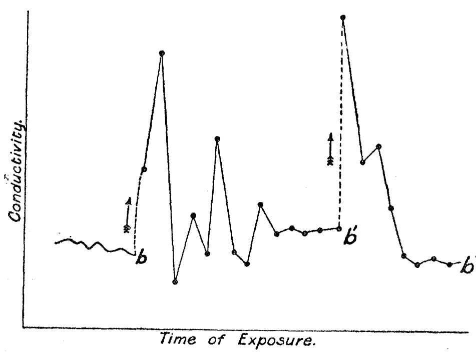

Fig. 9.—Curve showing the Effect of Heat and Mechanical Vibration on a Fatigued Arsenic Receiver.

b Effect of heat. *b'* Effect of tapping.

identical. The coherer may therefore be regarded as a linear photographic plate; since we are more likely to understand the complex photographic action from the consideration of the much simpler action of electric radiation on elementary substances, where the effects are not complicated by secondary reactions, a photographic plate may be regarded as merely an assemblage of "molecular receivers." I hope also to prove that nearly all the detectors of radiation are molecular receivers in reality. The investigation of this aspect of the subject has given me some extraordinary results; they seem to connect together many phenomena which at first sight do not seem to have anything in common. Another interesting question, the consideration of which has for the present to be postponed, is, Why is it that the sensitiveness is so marked in discontinuous metallic particles? In other words, Why is the phenomenon mainly one of skin or *touch*? Is the phenomenon wholly unknown in continuous solids?

The experiments described in the present paper show:—

(1) That ether waves produce molecular changes in matter.

(2) That the molecular or allotropic changes are attended with changes of electric conductivity, and this explains the action of the so-called coherers.

(3) That there are two classes of substances, positive and negative, which exhibit opposite variations of conductivity under the action of radiation.

(4) That the production of a particular allotropic modification depends on the intensity and duration of incident electric radiation.

(5) That the continuous action of radiation produces oscillatory changes in the molecular structure.

(6) That these periodic changes are evidenced by the corresponding electric reversals.

(7) That the "fatigue" is due to the presence of the "radiation product," or strained B variety.

(8) That by means of mechanical disturbance or heat, the strained product can be transformed into the normal form, and the sensitiveness may thereby be restored.

The method described above of detecting molecular changes is extraordinarily delicate, and is full of promise in many lines of inquiry in molecular physics. It is also seen that the phenomenon of contact sensitiveness, contrary to previous suppositions, is perfectly regular. There is no capriciousness in the response of sensitive substances to the external stimuli, which may be mechanical, thermal, or electric. The curves given above show it; but they fail to give a fair idea of the richness and variety of the molecular phenomena, seen as it were reflected in the fluttering galvanometer spot of light; of the transitory variations, of the curious molecular hesitation at critical times as to the choice of the structure to be adopted, and of the molecular inertia by which the newly-formed structure is carried beyond the position of stability, and the subsequent creeping back to the more stable position. The varieties of phenomena are unlimited, for we have in each substance to take account of the peculiarity of its chemical constitution, the nature of its response to ether waves, the lag and molecular viscosity. All these combined give to each substance its peculiar characteristic curve; it is not unlikely that these curves may give us much information as to the chemical nature and the physical condition of the different substances. I am at present trying to arrange an apparatus which will, by means of the pulsating galvanometer spot of light, automatically record the various molecular transformations caused by the action of external forces.

Before concluding, I take this opportunity of expressing my grateful acknowledgments to the Royal Society for the encouragement I

received from the Society for the last five years during which investigations on Electric Radiation have been in progress at the Presidency College. I may say that the difficulties have been very numerous and disheartening, and that without this encouragement the work which it has been my good fortune to carry out would in all probability have remained unaccomplished. The Government of Bengal has also been pleased to evince a generous interest in these investigations. My assistant, Mr. Jagadindu Ray, and my pupils, Messrs. P. K. Sen, B.A., and B. C. Sen, B.A., have rendered me active assistance.]

"Contributions to the Comparative Anatomy of the Mammalian Eye, chiefly based on Ophthalmoscopic Examination." By GEORGE LINDSAY JOHNSON, M.D., F.R.C.S. Communicated by HANS GADOW, F.R.S. Received May 7,—Read May 17, 1900.

(Abstract.)

Observations were made on the eye of the living animal, 181 different species being examined, and frequently several individuals of the same species. The species comprise representatives of all the Mammalian orders except the Cetacea and Sirenia.

The conclusions arrived at can be summed up as follows:—

The *colour of the Fundus oculi* in animals devoid of a Tapetum is mainly determined by reflection from the choroidal pigment; in those with a Tapetum cellulosum (Carnivores) by the colour of the retinal pigment; in those with a Tapetum fibrosum (Ungulates) by the structural colour of the Tapetum modified by the colour of the retinal pigment. All the animals examined may be classed under three types —red, yellow, and green.

The *vascularisation of the retina* can be summarised as follows:—

1. Indirect supply by means of osmosis from the vessels of neighbouring parts. A. Hyaloid supply. (*a*) The corpus vitreum is nourished by a processus falciformis, the hyaloid vessels lying well inside the corpus vitreum (Elasmobranchs). (*b*) The hyaloid vessels spread over the surface of the corpus vitreum, being in consequence in the immediate vicinity of the retina (*e.g.*, holosteus and many teleosteous fishes). Hereto belong also the Amphibia and most of the Reptiles devoid of a pecten. B. Choroidal supply. This is probably the chief supply of the retina in those animals which possess a well-developed pecten (most Sauropsida), but are devoid of superficial hyaloid vessels. This choroidal supply by osmosis is also with certainty demonstrated in the Mammalia for at least part of the thickness of the retina.

2. Direct supply. A. From the superficial hyaloid vessels. This is