II. *Fourth Letter on Voltaic Combinations, with reference to the Mutual Relations of the Generating and Conducting Surfaces. Addressed to* MICHAEL FARADAY, *Esq. D.C.L. F.R.S., Fullerian Prof. Chem. Royal Institution, &c. &c. &c. By* J. FREDERIC DANIELL, *F.R.S., Prof. Chem. in King's College, London.*

Received January 18,—Read January 25, 1838.

MY DEAR FARADAY,

IN my second* letter to you upon Voltaic Combinations, I suggested that, in a theoretical point of view, the most simple and perfect combination would probably consist of a solid sphere (or rather active point) of a generating metal, surrounded by a hollow sphere of an inactive conducting metal, with an intervening liquid electrolyte; the circuit being completed by a conducting wire properly disposed for connecting the two metals. Further reflection led me to believe that a series of experiments commencing as nearly as possible with these most simple conditions of the problem, might throw some light upon the relative dimensions, positions and actions of the generating and conducting plates of voltaic combinations in general; which appeared to me not to have received all the elucidation of which they might be susceptible. The subject, it is true, has not escaped the attention of experimenters; but most of the results with which I am acquainted are so involved in the errors arising from the variable condition of the source of the current itself, which I have already pointed out, as to leave it in a very unsatisfactory state. I moreover proposed to myself, in the investigation which I consequently undertook, to trace the self-distribution of the force from its origin, by the indications of reduced copper, in the manner described in my first letter†. I have thus been led to some results which I trust you will consider of sufficient importance to justify my troubling you with another communication upon the subject.

My first apparatus, which it is necessary to describe, consists of two hollow hemispheres of brass, fitting together water-tight by means of exterior flanges half an inch wide, and a collar of leather, and thus forming a sphere, the interior diameter of which is $9\frac{1}{4}$ inches; consequently exposing a surface of about 268·8 square inches. The lower hemisphere is fitted into a frame carrying buttons, by which the upper can be securely wedged down upon it; and underneath there is a small cock, by which any liquid in the interior may be drawn off. The upper part of the upper hemisphere terminates in a tube of about one inch in length, forming an opening through which a membranous bag may be introduced, and from which it may be suspended. The

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* Philosophical Transactions, 1836, p. 128.

† Ibid. p. 113.

electrolyte which I employed in all the following experiments was the same as that which I employ in the constant battery, viz. eight parts of water, by measure, to one part of oil of vitriol in contact with the generating surface, and the same diluted acid, further saturated with sulphate of copper, in contact with the conducting surface.

The measures of the force to which I had recourse were, in the first instance, a coarse galvanometer consisting of a single needle seven inches in length, with a coil of twenty turns of wire $\frac{1}{20}$th of an inch in diameter. The large scale of the experiments precluded me from employing delicate instruments with astatic needles. Being dissatisfied with this measure, I afterwards employed a BRÉGUET's thermometer fitted up according to the plan of Professor DE LA RIVE[*], which measures the force of a current which passes through it by the differences of its heating power upon the compound spiral of platinum and silver of which it consists, the degrees into which it is divided being directly proportional to such differences. I had every reason to be satisfied with this instrument; and have no doubt of its accuracy, in the case, at least, of currents of such low tension as those for which alone I have hitherto employed it.

In my first experiment the sphere was charged with the solution of copper, and the membrane with the plain acid; a small sphere of amalgamated zinc, one inch diameter (and exposing a surface therefore of 3·14 square inches), was suspended by means of a well-varnished copper wire in the centre of the latter: the other extremity of the wire was connected with one of the cups of the galvanometer, and the circuit was completed by a wire leading from the other cup to a small mercury cup upon the upper brass hemisphere, placed at a distance of two inches from the tube. The deviation of the needle was 60°; and it remained steady for a long period, during which the experiment was repeated and varied. When, instead of the galvanometer, the circuit was closed with a piece of platinum wire one inch in length and $\frac{1}{150}$ inch diameter, it continued red hot for a period of five hours. The circuit remained closed for seventeen hours, and the apparatus was then opened and examined. The zinc ball had dropped off the wire, and was reduced to about one half of its original size. The upper hemisphere was found coated with reduced copper, beautifully marked half-way up from the equator with concentric circles of alternate dark and light stripes of pink and red; these were followed by a broad even band of pink, which reached to a circle within 1½ inch of the aperture, which was composed of the unchanged surface of the brass, and which evidently had not been in contact with the liquid. The lower hemisphere, which had been insulated from the upper by the collar of leather, had no copper precipitated upon it.

The sphere was again put together, and charged as before, with a new zinc ball. The circuit was closed, as in the first experiment, with the galvanometer in contact with the upper hemisphere, and the deviation of the needle was 60°.

The connexion was then broken with the upper hemisphere, and made with the bottom of the lower hemisphere; the deviation was again 60°.

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[*] Mémoires de la Soc. de Phys. de Génève, 1836, p. 140.

When connexion was made at the same time with both hemispheres, the deviation was the same. If, while in this state, either wire were lifted singly from its connexion, the needle remained perfectly steady.

When the wire from the zinc ball was lifted from the cup, there was a spark upon breaking the circuit; and there was also a spark when the wires from the two hemispheres were disconnected from the circuit together, but not when lifted singly.

Upon leading the conducting wire of the lower hemisphere into direct communication with that of the zinc ball, while the wire of the upper hemisphere was connected as before with the galvanometer, or *vice versá*, the needle only receded to 40°. From this it appeared that, although the whole amount of force originating at the zinc was capable of passing off by means of either hemisphere singly, when both passages were open it distributed itself between the two, notwithstanding the additional resistance in one by the interposition of the galvanometer.

Extra contacts made with different parts of the two hemispheres made no difference in any of the preceding experiments.

The apparatus was now left for eighteen hours with both hemispheres in connexion with one extremity of the galvanometer, and the zinc ball with the other. Upon examination the needle was found still deflected 25°; and upon agitation of the zinc ball it rose to 55°, but almost immediately declined to 25°. The acid had become nearly saturated with oxide of zinc. The sphere was opened, and both hemispheres exhibited a perfectly even coating of beautiful pink copper, through which the rings of the upper hemisphere were however still discernible.

It will perhaps be advantageous, before I proceed further, to collect into one point of view the principal conclusions which, I conceive, may be drawn from the preceding experiments with the spherical combination.

1st. The force emanating from the active zinc centre diffused itself over every part of the upper hemisphere, from which there was a good conducting passage for its circulation, to an amount which is measured by 60° of the galvanometer; and which was capable of maintaining an inch of platinum wire $\frac{1}{150}$ inch diameter at red heat.

2nd. The same amount of force was maintained by either hemisphere indifferently; but when both conducting hemispheres were in metallic communication there was no increase of force. The transfer of half the power from one hemisphere to the other occupied no appreciable interval of time.

3rd. Although the force was not increased it spread itself equally over the whole sphere, as manifested by the diffusion of the precipitated copper.

4th. When one hemisphere was connected with the zinc centre by a short wire capable of affording circulation to the whole force, and the other hemisphere was connected by a long wire through the galvanometer with the same centre, the diffusion of the force over the whole sphere was maintained, although the half of it was obliged to overcome the much greater resistance of the longer circuit.

5th. There was no greater accumulation of precipitated copper about the points with which the conducting wires were brought into contact, and towards which the force diffused over the sphere must have converged, than at any other point; proving that the force must have diverged from the centre equally through the electrolyte, and could only have drawn towards the conducting wires in the conducting sphere itself.

I now destroyed the insulation of the two hemispheres by fixing to the lower one a thin ring of brass, which came in contact with the upper when wedged down in its position by the means already described. The sphere, thus in good metallic communication in every part, was charged as before; the precipitated copper having been previously cleaned off by a little nitric acid and rotten-stone. The deviation of the galvanometer was 55°, and it was perfectly steady, whatever number of connexions were made with the sphere, or at whatever point the circuit was completed. It made no difference in the amount of the force which circulated, whether the contact with the brass was made as near as possible to the zinc conducting wire, or at the point the farthest removed from it.

I next proceeded to ascertain what would be the effect of increasing the surface of the generating metal. For this purpose two amalgamated zinc balls of the same diameter as before were placed in contact upon a varnished wire, and substituted for the single ball in the centre of the sphere: the deviation of the galvanometer only increased 5°, rising from 55° to 60°. Upon replacing the single ball it fell again to 55°, and so alternately rose and fell to the same amount upon frequent repetitions of the change. An amalgamated zinc rod six inches in length, and $\frac{1}{2}$ inch in diameter, was then substituted for the balls, but the deviation did not rise higher than 60°. Thus the generating surface was increased from about three square inches to six and 9·4 with very little increased effect.

These experiments were all made with the generating metal placed as nearly as possible in the centre of the conducting sphere: this position was now changed, and sometimes the zinc ball was placed at the bottom of the membrane almost in contact with the sphere; sometimes it was drawn up nearly to the top; again it was placed in the centre; but none of these changes produced any appreciable alteration in the deviation of the needle, the galvanometer constantly indicating 55°.

From this I was led to consider (although I am quite aware that the measures may not have been sufficiently accurate to determine the point with precision,) whether the force emanating from the zinc ball might not diffuse itself over the surrounding conducting sphere in obedience to the well-known law of radiant forces of the inverse square of the distance; since, although the cases may be dissimilar, according to this law an attractive point placed within a hollow sphere of attractive matter remains in equilibrio, whatever its position may be. Or the analogy, perhaps, is stronger of light diffusing itself from a luminous point within the sphere in the same relative positions as those of the generating ball.

This conclusion, if correct, appearing to me to be of great importance, I was desirous of confirming it by repetition and variations of the experiment.

For this purpose I made use of the calorific galvanometer (as it has been named by M. De la Rive,) instead of the magnetic; and the zinc ball was a little larger than in the preceding experiments, measuring $1\frac{1}{8}$ inch in diameter, and presenting therefore a surface of 3·94 square inches. The sphere was charged as before, and when the ball was placed in the centre

The index advanced	90°
When drawn nearly to the top	90
When thrust nearly to the bottom . . .	87

The index remained perfectly steady during several repetitions of the experiments; and when the connexion with the brass sphere was changed to opposite points. There can be no doubt that these results indicate the same equality of action as before; the slight difference in the lower position being, probably, owing to accidental circumstances, such as the unequal thickness of the membrane at that point, or the speedy saturation of the acid when the solution cannot fall away from the zinc. Thus it would appear, that in none of these positions was there any virtual approximation of the generating and conducting surfaces. The diffusion of the precipitated copper was, however, very much influenced by the position of the ball; when near the top or the bottom, it was thrown down in a compact layer on a segment immediately in its vicinity, and became thinner and thinner over the more remote parts of the sphere. It was only when exactly in the centre that the diffusion was perfectly equal. To observe this effect with the greatest distinctness, the action in each case should not be allowed to continue more than ten or fifteen minutes; for the deposition becomes compact in every part in a longer time, when it is not so easy to judge of the difference of thickness.

My next step was to measure the effects of different portions of the sphere in combination with the zinc ball. I took the lower hemisphere alone of the apparatus and filled it with the solution of copper, and placing a wooden bar across it which supported the membranous bag to carry the acid, I had it in my power to immerse the ball in any required position.

I first placed the same ball as in the last experiment just below the surface exactly in the centre, and the calorific galvanometer indicated 90°: upon removing it within half an inch of the bottom it rose to 115°.

On another occasion I placed the ball in three different positions upon the surface of the liquid in the hemisphere, namely, in the centre and close to each side: in each position the instrument marked 86°. Upon lowering it as close as possible to the bottom it rose to 100°. In all these experiments the precipitated copper was diffused over the whole hemisphere.

It is worthy of remark, that the amount of force thus called into action at the surface of the liquid in the hemisphere, is nearly the same as that from the whole charged sphere, or either of its hemispheres.

These results, I conceive, are not in opposition to the law of radiant forces suggested by the experiments with the entire sphere; although I cannot vouch for the comparative measures being absolutely correct or uninfluenced, in some degree, from day to day by extraneous circumstances, and particularly by changes of temperature: nor can it, indeed, be expected that the experimental deductions from a ball of the dimensions which I employed can do more than approximate to the mathematical demonstrations of the relations of an active point within an attractive sphere.

An accidental circumstance next furnished me with an interesting variation in the combination of the whole sphere. My intention had been to fill it as before, and repeat the experiments; but I afterwards found that the liquid only reached to within 45° from the vertex. The zinc ball which I made use of was $\frac{3}{4}$ inch in diameter, and the membrane was full of the dilute acid. The experiments were made in three different positions of the ball, and with three variations of the wire connecting the circuit with the brass sphere.

The first connexion was made near the top at a point which was not within the contact of the included liquid; the results were

	Caloric Galv.
At the top	45°
Centre	55
Bottom	65

Connexion with the bottom of sphere.

Ball at the top	45°
Ball at the centre	70
Ball at the bottom	77

Connexion with the sphere both at the top and bottom.

Ball at the top	45°
Ball at the centre	73
Ball at the bottom	78

The two last series may be taken to be identical, but I am at a loss to explain the difference of the first series from these two. It is probable that the zinc ball, though wholly immersed in the acid in the membrane, was not below the surface of the exterior solution in the sphere. The results confirm in a general way the conclusions which have been previously suggested.

There was yet another combination which I thought it desirable to try; namely, with the generating ball placed within the charged sphere with its two hemispheres insulated. The zinc ball which I employed for this experiment was one inch diameter, and I tried it first with the standard acid with which all the other experiments had been made, and repeated it with the same acid diluted with an equal bulk of water, in order that I might ascertain whether the law of action were influenced at all by the amount of force put into circulation. The results were perfectly consistent with each other.

	Standard Acid.	Dilute Acid.
	°	°
The zinc ball placed near the bottom, connexion with top insulated hemisphere	52	42
Connected with bottom	59	50
The zinc ball placed near the top, connexion with bottom insulated hemisphere	51	41
Connected with top	59	50
Both hemispheres connected	59	

In these experiments, that hemisphere alone with which the connexion had been made could have influenced the results as a conducting surface.

A question now occurred to me of extreme interest: admitting that the force generated in the preceding combinations where it was limited in its diffusion by the concave surfaces of spherical forms, follows in its action the law of radiant forces, we know that it is not a *simple* radiant force like that of gravity, but a molecular force propagated from particle to particle, and possibly modified by other forces with which the same particles may be endowed. The law of radiation, if established, may, therefore, be the result of the concurrence of more than one force, limited by the spherical combinations with which we have been dealing. The physical law, in ordinary cases, supposes both the sphere and the point within to consist of similar attractive matter; and were the force which we are now investigating of the same nature, it would make no difference whether the sphere consisted of merely conducting metal and a small interior generating ball, or whether the sphere consisted of generating metal and the ball were an inactive conductor,—inactive I mean with regard to the electrolyte. What experimental results, therefore, would the latter combination afford?

I caused two hemispheres of zinc to be made of exactly the same form and dimensions as those of copper, and fitted together in the same way; the interior surfaces of these were thoroughly amalgamated with mercury. When wedged together by their flanges and ring of leather, metallic contact was preserved between the two by a small interior ring of amalgamated zinc. The sphere was charged with dilute acid, and the interior membranous bag with the acid solution of copper. A copper ball of one inch diameter fixed to the end of a varnished wire was then immersed in the latter, and a circuit formed by contact with different parts of the zinc sphere with the intervention of the calorific galvanometer.

The indications of the instrument were as follow:—

	°
Ball at the top	36
Ball at the centre	36
Ball at the bottom	36
Again at the top	35

The index was steady for a short time, but began slowly to decline in each instance for about 10°. Upon agitation of the ball in the solution it always rose to its previous amount.

Upon repeating the experiment and keeping the ball always agitated, the following results were obtained:—

	°
Ball at the top	40
Ball at the centre	42
Ball at the bottom	42

Another repetition gave

Ball at the top	45
Ball at the centre	46
Ball at the bottom	44

The index always fell when the ball was not agitated, and the decline may probably be ascribed to a change in the saturation of the liquid in immediate contact with the ball, which agitation prevented by keeping the solution in an uniform state.

I now separated the hemisphere and experimented with the lower one alone. The results were as follow:—

	°
Ball at the top	35
Ball at the bottom	80
Ball at the top	35
Ball half-way between	60

When the ball was placed at the centre of the surface and at the sides almost in contact with the hemisphere, the index rose to 36° in all the three positions.

Hence it appears that the same law was maintained; although the force which circulated was reduced to one half of the amount of that from the first combination.

Before I venture to offer two or three remarks upon this difference, I shall proceed to lay before you the results of some experiments upon combinations of generating and conducting surfaces of other forms, commencing with the cylindrical as approaching in simplicity to the spherical, and for the purpose of connecting my observations with that form which I have found most practically advantageous in the construction of my battery.

I took one of the cells of the small battery[*], six inches in height and eleven inches in circumference, charged in the usual way, and found that the single zinc ball of one inch diameter, produced with it a deflection of the magnetic galvanometer of 55°. Two similar balls only increased the deflection to 60°, and its own rod, six inches in length and $\frac{5}{8}$ inch diameter, did not increase the effect. These were exactly the same amounts as were produced by the same generating surfaces in the brass sphere.

An amalgamated zinc cell of exactly the same dimensions, charged with the di-

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[*] Philosophical Transactions, 1836, p. 117.

luted acid and solution of copper in the membrane, with a copper ball one inch diameter, deflected the galvanic needle 45°.

With the calorific galvanometer it moved the index to 25°.

Being desirous of ascertaining whether the same difference between the reversed combinations would exist in a series as in single circuits, I compared together three copper cylinders with three zinc rods, and three zinc cylinders with copper rods, by means of a voltameter. The former produced in $\frac{1}{4}$ hour 3·6 cubic inches of gas. The latter produced in $\frac{1}{4}$ hour 1·75 cubic inches: indicating, as before, that when the generating surface constituted the circumference of the arrangement, the force was only the half of that which was evolved when it formed the centre.

In the copper cylinder it made no difference whether the zinc ball or rod were placed in the centre, or nearly in contact with the side.

I next took an oval copper plate, the diameters of which were 13$\frac{1}{2}$ inches by 10 inches, and soldered a copper wire at one extremity of the longest diameter, in a perpendicular position, and placing it in an earthen pan, covered it with a depth of 4$\frac{1}{2}$ inches of the acid solution of copper. Over its centre I suspended, by means of a cross bar, a bag of membrane filled with the dilute acid; and nearly at the bottom of this I placed an amalgamated zinc ball, connected with a varnished copper wire. I then formed a circuit by means of the magnetic galvanometer, and the needle was deflected 55°. It remained perfectly steady for half an hour, when the plate was taken out and examined. It was found covered with fresh precipitated copper, the coat being a little thicker at the centre, and becoming thinner by almost insensible gradations towards the edge. At one point it had begun to turn round the edge and to diffuse itself on the under side.

The zinc ball was next placed just below the surface of the liquid in the pan, so that its least distance from the conducting plate was the same as when placed in the centre of the sphere. Upon completing the circuit the needle was deflected 45°.

The zinc ball was now drawn up in the tube so as to remain immersed in the acid, but two inches above the level of the solution; the needle was still deflected 35°. Upon again replacing it below the level it returned to 45°, and fell to the same amount upon once more drawing it up. In this case the lateral diffusion of the efficient force must have been prevented for the first two inches of its course; the mode of its after propagation was the subject of my next inquiry. While the apparatus was in this position, one zinc rod, and afterwards two, connected together, were immersed into the acid, so as to extend through the whole depth of the solution, without deflecting the needle more than 55°.

In these experiments the stem of the copper wire which was soldered to the copper plate was covered with precipitated copper as well as the plate. In subsequent experiments it was protected by varnish.

In order effectually to cut off the lateral radiation from the zinc ball, I placed it in a glass tube, six inches long; and over the lower aperture, which was 1$\frac{1}{2}$ inch diameter, I tied a piece of membrane: the tube was then filled with dilute acid and plunged into the solution of copper contained in the brass hemisphere, against the bottom of which it rested. The ball was supported within half an inch of the diaphragm. Upon closing the circuit by means of the magnetic galvanometer, the needle indicated 40°. At the expiration of five minutes the solution was drawn off and the hemisphere examined: there was found a beautiful well-defined circle of pink copper, two inches diameter, surrounded by a halo of darker colour, evidently of fresh precipitated copper of less thickness, but not extending over more than a fourth part of the surface. From this experiment it was evident that the force had diverged from the aperture of the glass tube, as from a centre, after it had entered the solution; the circle of pink copper being of a diameter half an inch greater than the aperture, and the fainter halo extending some inches around.

I now moved the tube into such a position, that, the zinc ball, remaining where it was in the tube, might be just below the level of the solution in the hemisphere; and now, notwithstanding the greater distance at which it was placed from the conducting surface, the needle rose to 45°, and the precipitated copper made its appearance over the whole hemisphere.

While the zinc ball was in its last position, the glass tube itself was pressed down till it again rested upon the bottom of the hemisphere; all lateral diffusion was thus cut off for a distance of 4½ inches, through which the force was propagated, and it could only spread after it emerged from the tube; the galvanometer indicated 30°. When the glass screen, as it may be called, was again drawn up, the needle returned to 45°.

Similar experiments were often repeated with the substitution of large flat plates for the hemisphere. When the zinc ball was thus confined in a tube with a diaphragm, and placed within an inch of the plate, the precipitation always commenced with a circle a little larger than the aperture, and gradually extended itself, so that after some hours action it formed a circle of four or five inches diameter, and sometimes turned the edge, and made its appearance on the under surface.

Being desirous of ascertaining to what amount the under surface of a plate thus immersed in the electrolyte would affect the action, I covered the upper surface of the oval copper plate with lac varnish, and replaced it in its pan; I then placed the zinc ball in the tube within half an inch of the diaphragm, and plunged it just below the surface of the solution; upon completing the circuit the needle indicated 50°. In ten minutes time I examined the plate, and found the under side covered with beautiful pink copper, with the exception of an irregular oval space, whose diameters were about 4½ inches by 4. The precipitation had evidently begun upon the edge, where it was thickest.

The plate was returned to its position, and the galvanometer again indicated 50°. When a double ball was substituted for the single it rose to 55°. It was again examined after an hour's action, and on the under side presented the appearance of a

Fig. 1.

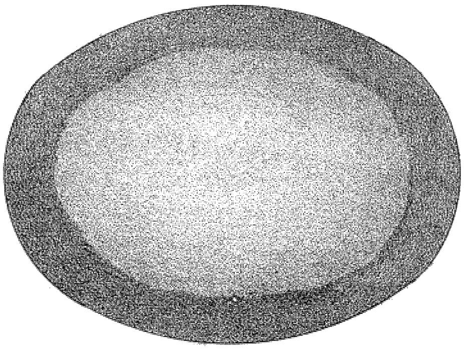


Fig. 2.

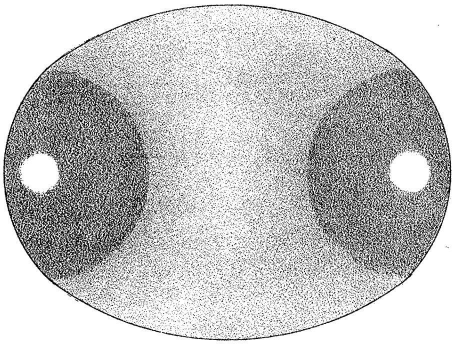


Fig. 3.

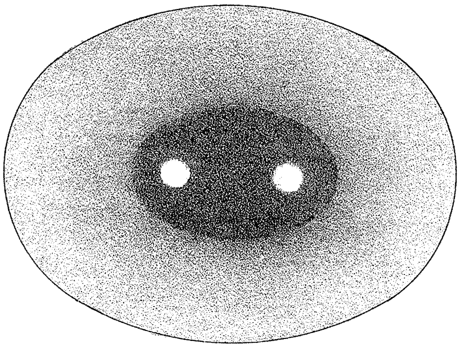


Fig. 4.

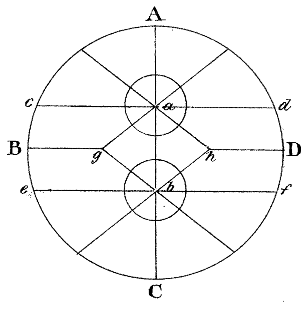
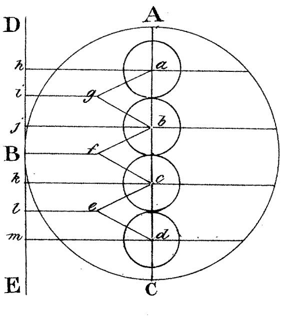


Fig. 5.



J. Basire, lith.

border of compact pink copper, varying from 1½ inch to ⅞ inch in width, but not wider at the sides than the ends; and the remainder was covered with precipitated copper of a darker red colour, into which the former graduated. On the upper varnished side there were a number of little rosettes of copper, which were loose, giving it a gritty feel, and which evidently proceeded from a number of minute points to which the varnish had not adhered. Fig. 1. (Plate II.) may convey an idea of the appearance of the precipitated copper. Both surfaces of the copper plate having been cleaned, it was replaced in the solution, and the double zinc ball in the membrane, instead of being placed over the centre, was suspended over that end of the oval which was farthest removed from the conducting wire. The galvanometer indicated 48°, and remained perfectly steady for an hour, during which the action was continued. At the expiration of this time the plate was examined, and the pink copper was found deposited only at the extremity under the ball, forming a segment of a circle, of which the ball was the centre, but still not sharply defined, but imperceptibly shading off by a darker colour to the unchanged surface at the other extremity.

Here the efficiency of the generating ball was evidently impeded by the deficiency of the conducting plate on one side. The radiation could only take place towards the other side; and although the conductor was of great extent, the increasing distance of its several points caused it to act at a disadvantage.

After these experiments the plate was cleaned and replaced in the solution; and in order to determine the action of more than one generating point, at a distance from one another upon the same conducting plate, I first placed a single zinc ball in a membrane close to the conducting wire of the plate, and found the deviation of the galvanometer 42°·5. I then broke this connexion, and placed a double ball of zinc over the farthest extremity of the oval; the galvanometer again marked 42°·5. When the circuit was completed with both together the galvanometer only rose to 45°. Upon making or breaking contact with either ball singly, while the other remained in circuit, the needle only varied 2° or 3°. When the positions of the double and single ball were changed, the difference upon breaking the contact with it was 5°. After four hours action the plate was examined, and the pink copper was found deposited in two segments of circles, of which the balls had been the respective centres; and the remainder of the plate was covered with a precipitation of a redder colour. (fig. 2.) This thinner precipitation gave no indications of an increased substance as evidence of additional action at the points where the effects spreading from the two centres must be conceived to have been superimposed.

The plate having been once more cleaned, the double ball was placed nearly over its centre, and when connected with the galvanometer in circuit it affected it 55°. The single ball placed also nearly over the centre, but about two inches removed from the position of the double ball, affected it singly 45°. When the connexion was made with both the deflection increased to 57°. After four hours action with both the balls, a beautiful well-defined oval of pink copper precipitate was found immediately under the two balls, of the diameter of 4 inches by $3\frac{1}{2}$ nearly, beyond which there was a general diffusion of darker red precipitate (fig. 3.). The surface of this oval was perfectly smooth and compact, and presented no appearance of greater thickness or inequality at the centre than at any other part. The two balls seem to have acted as one oblong piece of generating metal would have done; and, upon the hypothesis of a radiant force from each, no increase was perceived at the points upon which the double set of rays might have been supposed to impinge.

I was desirous to repeat once more the experiments with the opposite sides of the conducting plate, and to connect them more closely with some of the previous series, by measuring the effects upon the calorific galvanometer, and by varying the form of the plate. For this purpose I took a circular plate of copper of the same diameter as the sphere, and immersed it in the copper solution. A zinc ball of $1\frac{1}{8}$ inch diameter, placed in a membrane of acid over the centre, gave the following results:—

	First Series.	Second Series.
Ball at top . . .	79°	82°
Ball at middle . .	89	92
Ball at bottom . .	103	105

After these experiments the copper was found diffused over both sides of the plate, but did not extend to the centre of the under side.

The upper surface of the plate having been thoroughly covered with lac varnish, the experiment was repeated with the following results:—

Ball at top	69°
Ball at middle	75
Ball at bottom	70

The precipitated copper was here found deposited upon the under side in a ring about two inches in breadth from the edge, and there was very little in the centre of the plate, and none upon the upper surface.

I finally covered the under surface with varnish, leaving the upper exposed, with the following results:—

Ball at top	73°
Ball at middle	83
Ball at bottom	93

Hence it appears, that the under surface, which by itself is capable of sustaining an action from the ball in the centre of the solution nearly as great as the upper surface, when combined with the latter, adds no more than 10°, or about one-eighth to its efficiency. It appears also that, whereas with the upper surface, the action increases in some inverse ratio of the distance, of the generating from the conducting surface, with the under surface, there is a maximum point, on both sides of which it decreases.

This point is doubtless dependent upon the angle at which the force, which radiates (as it were) from the ball, meets the edge of the plate.

Wishing now to draw the preceding experiments into closer comparison with similar ones which had hitherto, generally, been made in a different form, I had a square glass cell constructed, measuring 3½ inches and four deep. This was cut in two in the middle, and the edges having been ground admitted of being clamped together, with the interposition of a piece of bladder. When thus put together it formed a cell divided into two by a diaphragm of membrane in the liquid, on either side of which different generating and conducting plates might be immersed. The forms which I selected were copper and zinc plates 3¼ inches square, and copper and zinc balls of one inch diameter: the results obtained by different combinations of these, at different distances apart, measured by the calorific galvanometer, are contained in the following Table. The electrolyte which was employed was, in one series, the standard acid on both sides of the diaphragm, and in the other the same acid in contact with the zinc, and the solution of copper with the copper. In the near distance the surfaces were about half an inch apart; in the farther three inches; and the balls were always placed opposite to the centre of the associated plate.

	Equal Plates.		Copper Plate and Zinc Ball.		Zinc Plate and Copper Ball.		Equal Balls.	
	Close.	Distant.	Close.	Distant.	Close.	Distant.	Close.	Distant.
Acid alone	15°	13°	11°	10°	6°	5°	—°	4°
Acid and Sol. Cop.	73	51	67	53	32	30	26	24

The precipitated copper in all these cases had been pretty evenly diffused over the near surface of the plates, and was to be traced to all parts of the opposite surface, but more upon the edges than towards the centres.

Upon this Table we may remark:—

1st. That the energy of the force was about sextupled by the absorption of the hydrogen upon the conducting surface, except in the case of the equal plates, when it was more than quadrupled.

2nd. That the effect of distance was much more decided in the instances where the amount of the circulating force was greater, than in the contrary cases.

3rd. That the amount of force put into circulation from a large surface of zinc towards a central ball of copper was, as in former instances of similar combinations, about one half of that from the reverse arrangement.

4th. That a ball of zinc exposing a surface of 3·14 square inches placed over the centre of a plate of copper exposing on its two sides a surface of twenty-eight square inches, sustained an action of nearly the same amount as a plate of zinc of the same dimensions as the copper, placed at the same distances.

This result, as well as the small effect produced in preceding experiments by substituting two equal balls, or a rod, for one ball of zinc, may, upon the supposition of a force of the nature of a radiant force, be probably explained by the interference of the rays at points where their directions cross each other.

Let A B C D represent the sphere and *a* and *b* two active points within; the force radiates from *a* to *c* and A and *d*, and from *b* to *e* and *f* and C without interruption. But the rays proceeding from *a* to *g* and from *b* to *g*, encounter one another, and the force would appear to be directed in the diagonal of the two, or from *g* to B, and in a direction parallel to *a c* and *b c*.

A rod may obviously be considered as a succession of such balls or radiant points, and hence the force would be propagated in a direction at right angles to its axis towards a circumscribing sphere or cylinder.

Let *a b c d* represent the radiant points, then will the rays *a g* and *b g* interfere at *g* and pass on to *i*, *b f* and *c f* to B, and *c e*, *d e* to *l*. Or the same letters may represent radiant points in a plate A C, the rays of which will thus pass in a parallel direction to the opposite points of a conducting plate D E.

Without attaching, however, any importance to the geometrical diagrams, I would merely suggest that the resultants of all the radiant points acting from *a* to *d* towards D E may be parallel, and that such an hypothesis would account for the phenomena. The demonstration of this, if possible, would go far beyond my power in mathematical science.

The rays thus supposed to pass between two equal plates become parallel, and hence the decrease of the force will be directly as the distance, as Mr. SNOW HARRIS found it by direct experiment.

Now nearly the whole of the preceding experiments, except those of the zinc sphere, had been made before I had the pleasure of reading the Eleventh of your Series of Experimental Researches on Electric Induction*; and I had been led to the supposition, which I believe I mentioned to you, that the force which is developed by voltaic combinations might be subject to the law of radiant forces; but I had been utterly at a loss to understand how, upon this hypothesis, it could extend its influence to the side of a plate opposite to that to which it was directed in right lines; how, in short (to make use of a term which you have happily employed to describe, what I now believe to be, a perfectly analogous phenomenon), it could "*turn a corner*." Since the perusal of that paper, however, everything seems to me to fall in so naturally with the general views which you have therein explained, that I almost feel as if I were intruding upon ground which is properly your own in venturing to apply the laws which you have established of the "Essential and Fundamental Principle of Induction"† to the explanation of some of the foregoing results. Supposing my views to be correct, you must have been led to them in the natural course of your investigations; and nothing in my own opinion could justify my interference in a work which must have been more completely performed by you, but the circumstance that I was led to it by the obvious direction of my own previous inquiries into voltaic combinations.

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* Philosophical Transactions, 1838, p. 1.

† Ibid. p. 2.

The direction of the force through an electrolyte placed between a generating and conducting surface of two metals, may, I conceive, be expressed in the very words which you have employed to describe that of the *direct inductive force* in statical electricity.

"It may be conceived to be exerted in lines between the two limiting conducting surfaces, and is accompanied by a lateral or transverse force equivalent to a dilatation or repulsion of these representative lines; or the attractive force which exists amongst the particles of the electrolyte (dielectric) in the direction of the current (induction) is accompanied by a repulsive or diverging force in the transverse direction*."

The proof of this is exactly of the same nature as that which you have brought forward in the parallel instance of induction, namely, the turning round the corner of a plate; and I cannot but advert to the complete analogy of the case in which you brought your carrier ball near to the middle of a flat disc of metal placed upon an excited shell-lac cylinder when no charge was communicated, although one was obtained at the edge of the disc; and that of the deposition of a ring of precipitated copper round the edge of the under surface of a brass plate while the centre was free from it (fig. 1.).

This "lateral tension of the lines of force on one another" is quite consistent with their *divergence* from an active centre: may it not even be considered as the cause of their radiation? It is most particularly evidenced by the results of those experiments, in which the immediate divergence of the force from the active centre was prevented, by placing the latter in a glass tube, or by drawing it up above the general level of the surrounding electrolyte. In these instances the first impulse must have been propagated in a perpendicular direction; but the instant it was at liberty to influence the general mass, the molecules of the latter were thrown into the polarized state, and the direction of the force opened out as from a centre.

On the other hand, the same "repulsive force in a transverse direction" must be opposed to the *convergence* of the lines from an active sphere towards an interior conducting point, when the force is not stationary but current: may not this opposition account for the reduced action of a sphere of zinc upon a ball of copper? The difference of the *statical induction* and the *current induction* is, that in the former the force is not progressive, while in the latter it is in a state of perpetual flux; the state of polarity, however, and of tension, is maintained in both.

The transfer of the elements of the electrolyte in opposite directions under that peculiar molecular arrangement or polarity, "which is the first step in all electrolyzation," is quite compatible with their unequal distribution upon the limiting conducting surfaces, according to the varying relations of their dimensions and distances, as was evidenced by the unequal precipitation of the reduced copper in several of the preceding instances; but no correspondent inequality of the force can exist upon the surface of the conductors themselves, upon all parts of which it can instantaneously distribute itself with comparative facility.

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* Philosophical Transactions, 1838, p. 37.

The principal circumstance which might be supposed to limit the power of an active point within a conducting sphere in any given electrolyte, is the resistance of that electrolyte, which increases in a certain ratio to its depth or thickness; and this thickness may be considered virtually the same, wherever the included point may be placed, but to increase with the diameter of the sphere. It is also the same, and consequently the resistance is also the same, when placed anywhere within the plane which divides the sphere into two hemispheres. But in an insulated hemisphere, the approximation of the active point to the lower surface virtually decreases the thickness of the electrolyte through which its action has to be propagated, by increasing the extent of surface which cuts the divergent lines of force; and consequently the force increases. In this respect the action of a point upon a plate may be considered the same as upon an indefinitely large hemisphere, towards which as the point approaches the force increases.

It appears to me that practical consequences of some importance flow from the preceding conclusions, upon which I may be tempted to address you again at no distant period.

I remain, my dear FARADAY,
Ever faithfully yours,
J. F. DANIELL.

King's College,
January 13, 1838.