# XXIII. ELECTROPHORIC APPARATUS, AND ILLUSTRATIONS OF VOLTAIC THEORY.

## ON A SELF-ACTING APPARATUS FOR MULTIPLYING AND MAINTAINING ELECTRIC CHARGES, WITH APPLICATIONS TO ILLUSTRATE THE VOLTAIC THEORY.

401. In explaining the water-dropping collector for atmospheric electricity, in a lecture in the Royal Institution in 1860 (§ 285, above), I pointed out how, by disinsulating the water-jar and collecting the drops in an insulated vessel, a self-acting electric condenser is obtained. If, owing to electrified bodies in the neighbourhood, the potential in the air round the place where the stream breaks into drops is positive, the drops fall away negatively electrified; or *vice versa*, if the potential is negative, the drops fall away positively electrified. The stream of water descending does not in any way detract from the charges of the electrified bodies to which its electric action is due, provided always these bodies are kept properly insulated; but by the dynamical energy of fluid-motion, and work performed by gravity upon the descending drops, electricity may be unceasingly produced on the same principle as by the electrophorus. But, as in the electrophorus there was no provision except good insulation for maintaining the charge of the electrified body or bodies from which the induction originates, this want is supplied by the following reciprocal arrangement, in which the body charged by the drops of water is made the inductor for another stream, the drops from which in their turn keep up the charge of the inductor of the first.

402. To stems connected with the inside coatings of two Leyden phials are connected metal pieces, which, to avoid circumlocution, I shall call inductors and receivers. Each stem bears an inductor and a receiver, the inductor of the first jar being

vertically over the receiver of the second jar, and *vice versa.*
Each inductor consists of a vertical metal cylinder (fig. 1) open
at each end. Each receiver consists of a vertical metal cylinder

open at each end, but partially stopped in its middle
by a small funnel (fig. 1), with its narrow mouth
pointing downwards, and situated a little above the
middle of the cylinder. Two fine vertical streams
of uninsulated water are arranged to break into
drops, one as near as may be to the centre of each
inductor. The drops fall along the remainder of the
axis of the inductor, and thence downwards, along the
upper part of the axis of the receiver of the other jar,
until they meet the funnel. The water re-forms into
drops at the fine mouth of the funnel, which fall along
the lower part of the axis of the receiver and are
carried off by a proper drain below the apparatus.
Suppose now a small positive charge of electricity be
given to the first jar. Its inductor electrifies nega-
tively each drop of water breaking away in its centre
from the continuous uninsulated water above; all

*a* Water Jet.
*b* Inductor.
*c* Receiver.
these drops give up their electricity to the second jar,
when they meet the funnel in its receiver. The drops
falling away from the lower fine mouth of the funnel carry away
excessively little electricity, however highly the jar may be
charged; because the place where they break away is, as it were,
in the interior of a conductor, and therefore has nearly zero elec-
trification. The negative electrification thus produced in the
second jar acts, through its inductor, on the receiver of the first
jar, to augment the positive electrification of the first jar, and
causes the negative electrification of the second jar to go on
more rapidly, and so on. The dynamical value of the electrifi-
cations thus produced is drawn from the energy of the descend-
ing water, and is very approximately equal to the integral work
done by gravity against electric force on the drops, in their path
from the point where they break away from the uninsulated
water above, to contact with the funnel of the receiver below.
In the first part of this course each drop will be assisted down-
wards by electric repulsion from the inductively electrified
water and tube above it; but below a certain point of its course

the resultant electric force upon it will be upwards, and, according to the ordinary way of viewing the composition of electric forces, may be regarded as being at first chiefly upward repulsion of the receiver diminished by downward repulsion from the water and tube, and latterly the sum of upward repulsion of the receiver and upward attraction of the inductor. The potential method gives the integral amount, being the excess of work done *against* electric force, above work performed *by* electric force on each drop in its whole path. It is of course equal to $m$ V, if $m$ denote the quantity of electricity carried by each drop, as it breaks from the continuous water above, and V the potential of the inner coating of the jar bearing the receiver, the potential of the uninsulated water being taken as zero. The practical limit to the charges acquired is when one of them is so strong as to cause sparks to pass across some of the separating air-spaces, or to throw the drops of water out of their proper course and cause them to fall outside the receiver through which they ought to pass. It is curious, after com-

FIG. 2.
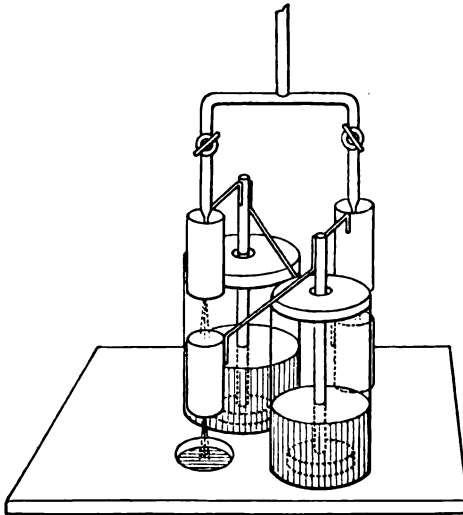


mencing with no electricity except a feeble charge in one of the jars, only discoverable by a delicate electrometer, to see in

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the course of a few minutes a somewhat rapid succession of sparks pass in some part of the apparatus, or to see the drops of water scattered about over the lips of one or both the receivers.

403. The Leyden jars represented in the sketch (fig. 2) are open-mouthed jars of ordinary flint glass, which, when very dry, I generally find to insulate electricity with wonderful perfection. The inside coatings consist of strong liquid sulphuric acid, and heavy lead tripods with vertical stems projecting upwards above the level of the acid, which, by arms projecting horizontally above the lip of the jar, bear the inductors and receivers, as shown in fig. 2.   Lids of gutta percha or sheet metal close the mouth of each jar, except a small air-space of from $\frac{1}{8}$ to $\frac{1}{4}$ of an inch round the projecting stems.   If a tube (fig. 3) be added

FIG. 3.
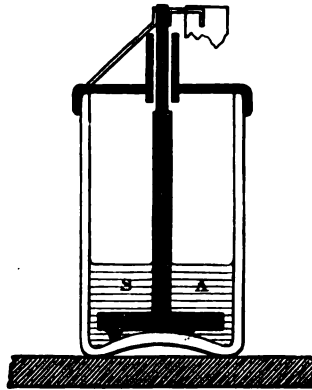


SA Sulphuric Acid.

to the lid to prevent currents of air from circulating into the interior of the jar, the insulation may be so good that the loss may be no more than one per cent. of the whole charge in three or four days.   Two such jars may be kept permanently charged from year to year by very slow water-dropping arrangements, a drop from each nozzle once every two or three minutes being quite sufficient.

404. The mathematical theory of the action, appended below*, is particularly simple, but nevertheless curiously interesting.

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* Let $c$, $c'$ be the capacities of the two jars, $l$, $l'$ their rates of loss per unit

405. The reciprocal electrostatic arrangement now described presents an interesting analogy to the self-sustaining electro-magnetic system recently brought before the Royal Society by Mr. C. W. Siemens and Professor Wheatstone, and mathemati-cally investigated by Professor Clerk Maxwell. Indeed it was from the fundamental principle of this electromagnetic system that the reciprocal part of the electrostatic arrangement occurred to me recently. The particular form of self-acting electrophorus condenser now described, I first constructed many years ago. I may take this opportunity of describing an application of it to illustrate a very important fundamental part of electric theory. I hope soon to communicate to the Royal Society a description of some other experiments which I made seven years ago on the same subject, and which I hope now to be able to prosecute further.

406. Using only a single inductor and a single receiver, as shown in fig. 1, let the inductor be put in metallic communication with a metal vessel or cistern whence the water flows; and let the receiver be put in communication with a delicate electro-scope or electrometer. If the lining of the cistern and the inner metallic surface of the inductor be different metals, an electric effect is generally found to accumulate in the receiver and electrometer. Thus, for instance, if the inner surface of the

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potential of charge, per unit of time, and D, D′ the values of the water-droppers influenced by them. Let $+v$ and $-v'$ be their potentials at time $t$; $v$ and $v'$ being of one sign in the ordinary use of the apparatus described in the text. The action is expressed by the following equations:—

$$c\frac{dv}{dt} = D'v' - lv; \qquad c'\frac{dv'}{dt} = Dv - l'v'.$$

If $c$, D, $l$, $c'$, D′, $l'$ were all constant, the solution of these equations would be, for the case of commencing with the first jar charged to potential 1, and the second zero,

$$v = \frac{(c'\rho + l')\epsilon^{\rho t} - (c'\sigma + l')\epsilon^{\sigma t}}{c'(\rho - \sigma)}, \qquad v' = D\frac{\epsilon^{\rho t} - \epsilon^{\sigma t}}{c'(\rho - \sigma)},$$

with the corresponding symmetrical expression for the case in which the second jar is charged, and the first at zero, in the beginning; the roots of the quadratic

$$(cx + l)(c'x + l') - DD' = 0$$

being denoted by $\rho$ and $\sigma$. When $ll' > DD'$, both roots are negative; and the electrification comes to zero in time, whatever may be the initial charges. But when $ll' < DD'$, one root is positive and the other negative, and ultimately the charges augment in proportion to $\epsilon^{\rho t}$ if $\rho$ be the positive root.

inductor be dry polished zinc, and the vessel of water above be copper, the receiver acquires a continually increasing charge of negative electricity. There is little or no effect, either positive or negative, if the inductor present a surface of polished copper to the drops where they break from the continuous water above: but if the copper surface be oxidized by the heat of a lamp, until, instead of a bright metallic surface of copper, it presents a slate-coloured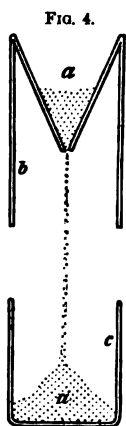 surface of oxide of copper to the drops, these become positively electrified, as is proved by a continually increasing positive charge exhibited by the electrometer. When the inner surface of the inductor is of bright metallic colour, either zinc or copper, there seems to be little difference in the effect whether it be wet with water or quite dry; also I have not found a considerable difference produced by lining the inner surface of the inductor with moist or dry paper. Copper filings falling from a copper funnel and breaking away from contact in the middle of a zinc inductor, in metallic communication with a copper funnel, as shown in fig. 4, produce a rapidly increasing negative charge in a small insulated can catching them below.

Fig. 4.



a Copper Filings.
b Inductor—Zinc.
c Receiver.

The quadrant divided-ring electrometer* indicating, by the image of a lamp on a scale, angular motions of a small concave mirror ($\frac{1}{3}$ of a grain in weight) such as I use in galvanometers, is very convenient for exhibiting these results. Its sensibility is such that it gives a deflection of 100 scale-divisions ($\frac{1}{40}$ of an inch each) on either side of zero, as the effect of a single cell of Daniell's; the focusing, by small concave mirrors supplied to me by Mr. Becker, being so good that a deflection can easily be read with accuracy to a quarter of a scale-division. By adopting Peltier's method of a small magnetic needle attached to the electric moveable body (or "needle"), and by using fixed steel magnets outside the instrument to give directing force (instead of the glass-fibre suspension of the

* See Nichol's *Encyclopædia*, 1860, article "Electricity, Atmospheric;" or *Proceedings of the Royal Institution*, May 1860, Lecture on Atmospheric Electricity [§§ 249...293, above].

divided-ring electrometers described in the articles referred to), and by giving a measurable motion by means of a micrometer screw to one of the quadrants, I have a few weeks ago succeeded in making this instrument into an independent electrometer, instead of a mere electroscope, or an electrometer in virtue of a separate gauge electrometer, as in the Kew recording atmospheric electrometer, described in the Royal Institution lecture.

407. Reverting to the arrangement described above of a copper vessel of water discharging water in drops from a nozzle through an inductor of zinc in metallic connection with the copper, let the receiver be connected with a second inductor, this inductor insulated; and let a second nozzle, from an uninsulated stream of water, discharge drops through it to a second receiver. Let this second receiver be connected with a third inductor used to electrify a third stream of water to be caught in a third receiver, and so on. We thus have an ascending scale of electrophorus action analogous to the beautiful mechanical electric multiplier of Mr. C. F. Varley, with which, by purely electrostatic induction, he obtained a rapid succession of sparks from an ordinary single voltaic element. This result is easily obtained by the self-acting arrangement now described, with the important modification in the voltaic element according to which no chemical action is called into play, and work done by gravity is substituted for work done by the combination of chemical elements.

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### ON A UNIFORM ELECTRIC CURRENT ACCUMULATOR.

408. CONCEIVE a closed circuit, $C\ T\ A\ B\ C$, according to the following description :—One portion of it, $T\ A$, tangential to a circular disc of conducting material and somewhat longer than the radius; the continuation, $A\ B$, at right angles to this in the plane of the wheel, of a length equal to the radius; and the completion of the circuit by a fork, $B\ C$, extending to an axle bearing the wheel. If all of the wheel were cut away except a portion, $C\ T$, from the axle to the point of contact at the circumference, the circuit would form a simple rectangle, $C\ T\ A\ B$, except the bifurcation of the side $B\ C$. Let a