It follows, therefore, that as the potential of the currents generated by moderately large induction coils is always very considerable, they are capable of producing a current of considerably more strength in a given time, or in other words, one which will reach the extremity of the line with sufficient strength to operate an electro-magnet in a shorter time than a galvanic current. On the other hand, as these currents are of very short duration, it is necessary that in operating subterranean or submarine lines they should have a comparatively high potential, in order that they may reach the distant extremity of the line with sufficient strength to move the instruments. The liability, however, of these intense currents to injure the insulating coating of subterranean and submarine lines is so great as to render their employment for this purpose unadvisable.

CHAPTER XXVIII.

THE EARTH A RESERVOIR OF ELECTRICITY.

When Steinheil made the discovery, in 1838, that the earth might be made use of to complete the circuit of a telegraph line, he, in common with other physicists, was at once led to the conclusion that the earth actually conveyed the electric current from one earth plate to the other in the same manner as a metallic conductor, and that the resistance of the great mass of the earth was almost infinitely small in comparison to that of a metallic wire of equal length.

The experiments of Matteucci seemed to confirm this theory. He caused four wells to be dug in a straight line, at distances of 80, 30 and 50 yards from each other, and immersed in the two extreme wells two metallic plates connected with the poles of a battery of ten Bunsen's elements, while the terminals of a galvanometer were connected in the same manner with the two intermediate wells. When the circuit was closed, the needle of the galvanometer was deflected 35 to 40 degrees, from which he concluded that the current actually passed through the earth from one plate to the other. It is, however, quite possible that when the plates are at a distance of only 160 yards from each other, that the current really does pass through the earth, for it is usually easy to demonstrate the passage of a tolerably powerful current through a section of earth or of water 20 to 30 feet in length, placed in a wooden trough. But when the earth plates are several miles apart other conditions affect the result, to which these remarks do not apply.

Baumgartner entertains the same opinion as Steinheil and Matteucci, which is based upon his observation that the resistance increases with the section of earth which is interposed between the plates. If these observations applied directly to the matter under consideration they would settle it at once, but this is not exactly the case. What Baumgartner really did was to compare the resistances of three lines when the circuit was metallic throughout, and when one part of it was metallic and the rest earth. Taking the wire as a unit he found the following proportions:

Route.	*Distance.*	*Proportion.*
Vienna-Ganserndorf, - - -	19.44 miles	3.14
Vienna-Gloggnitz, - - - -	52.36 "	6.98
Vienna-Gratz, - - - - -	134.06 "	4.70

Comparing these proportions, we at once discover that they

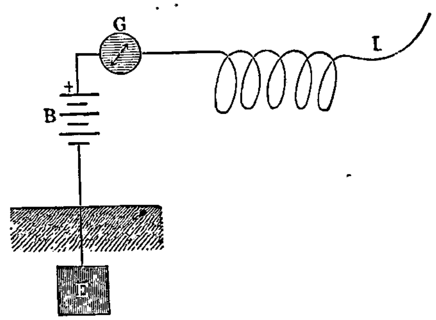

Fig. 213.

do not support the theory that the resistance of the earth increases in proportion to the distance between the plates. Baumgartner, however, concludes that this discrepancy is caused by the varying conductivity of the matter in the earth. In regard to his conclusions, Poggendorff very justly observes that the question of polarization has not been taken into account.

If we are to consider the earth as a reservoir of the electricity generated by a battery, the first thing is to prove that the battery will produce a current in the metallic part of the line without it being necessary for the earth to present a conducting medium. This proof may be readily furnished in the following way:

When one pole of a battery B (fig. 213) is in connection with the earth E, the other pole being connected to a long line L,

and a galvanometer G is inserted between this pole and the line, the electricity produced in the battery rushes into the line, and the galvanometer indicates a current which lasts until the electricity reaches the distant end. The longer the line is, the longer will be the duration of the current, and as Dub justly remarks, assuming that the velocity of electricity is 60,000 miles per second, on a wire four million miles long we would have a current for more than an hour after making the connection, without having joined the poles at all. In this case the current flows into the earth in the same way that a constant supply of water

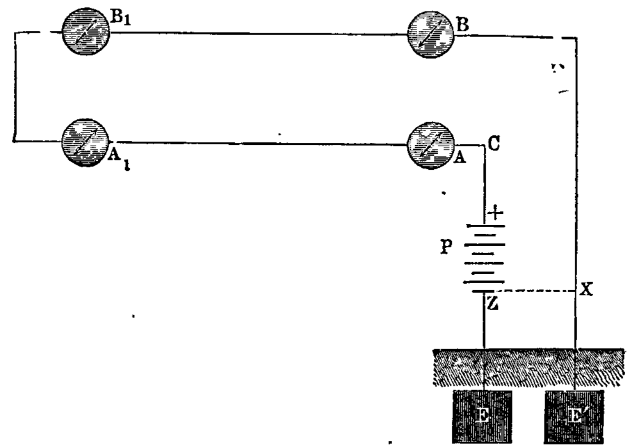

Fig. 214.

would flow into an infinitely large reservoir, without there being a possibility of any accumulation.

We see, therefore, that when we employ an infinitely large conductor, it is not necessary to make connection between the poles in order to obtain a current. As it makes no difference which of the two poles of the battery is connected to earth, it is natural to suppose that the current will pass also when both poles are to earth, without admitting the necessity of any connection between the currents through the earth.

The following experiment, the results of which strongly support the opinion that the earth acts as a reservoir instead of a conductor, was made by Wheatstone on a submarine cable of 660 miles in length. The zinc pole of the battery P (fig. 214) was connected at Z and X with the cable, and four galvanometers, A B A_1 and B_1, were included in the circuit in such a way that the two former were in the immediate vicinity of the battery, and the other two were placed almost in the centre of the line, so that the distance between A and A_1 as well as from B to B_1, was about 330 statute miles. When the circuit was closed at C, the needles of the galvanometers A and B were deflected instantly and simultaneously, while those of A_1 and B_1 followed somewhat later.

When, however, the connection Z X was interrupted (represented by dotted lines in the figure), and the pole Z, as well as the end X of the line, was connected by means of two metallic plates E and E_1 with the earth, the result was quite different. The galvanometer A was first deflected, then A_1 and B_1, and last of all B. It follows, therefore, that the earth between E and E_1 undoubtedly performs a different office from that of the wire Z X between the same parts of the circuit, and, consequently, that it does not act merely as a conductor. It may be objected that the resistance of the circuit has been increased so much, by including the earth between E and E_1, that the relative position of the galvanometer B in the circuit has been changed. This theory, however, proves to be untenable from the fact, which is proved by experiment, that the resistance of the earth is infinitely small compared to that of a long telegraph line. Nothing, therefore, remains but the conclusion that the earth does not play the part of a conductor in the latter case. On the other hand, the phenomenon is easily explained on the supposition that the earth acts as a reservoir into which the current from the battery flows. We have already seen, when one end of a long line is insulated and the other is connected to a battery whose opposite pole is to earth, that the charge proceeds gradually from the battery end towards the end that is insulated, the flow continuing until all parts of the line have received the same potential. From this it is evident that the galvanometer

A, which is nearest the battery, should be deflected first, and that the others should follow in the order of their position.

Now, in order that the current may be continuous, it is only necessary for the electricity to be carried off as fast as it is generated in the battery, and this, in fact, is exactly what is done by the earth.

Another experiment, by Caselli, is no less decisive in its bearing on the question. If the two ends of a long air line (fig. 215) are connected to the two poles of the battery P, and two very sensitive galvanometers are inserted at B and C, the needles of both, in consequence of the derivations or leakages at the various points of support, will remain slightly deflected after the

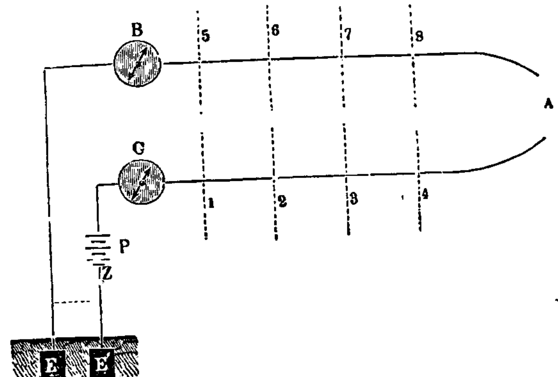

Fig. 215.

circuit has been broken at A. But if, instead of completing the circuit by a metallic conductor, as shown by the dotted lines, we connect the end x of the line to earth by the plate E and the battery pole Z to earth by the plate E_1, the result is quite different. Although nothing has been changed, except the substitution of the earth between E and E_1 for the wire Zx, it is evident that the earth does not act the part of a conductor in this case. The result, however, is easily explained if we consider the earth as a reservoir. In the first instance, when the wire Zx is in circuit, the + electricity flows through C and the derivations 1, 2, 3, 4 to earth, where it disappears; the galvanometer C is, therefore, deflected by a positive current; at the same time the — electricity flows through ZxB, and the derivations 5, 6, 7, 8 to earth; the galvanometer B should, therefore, show an opposite deflection, and this it does, as experience shows. If, now, we replace the wire Zx by the earth between E and E_1, the positive electricity flows as before through C and the derivations 1, 2, 3 and 4 to earth, causing a deflection at C; but the — electricity, on the contrary flows directly to the earth, and is absorbed; consequently, no electricity appears in the wire xBA, and the instrument B remains undisturbed. This experiment

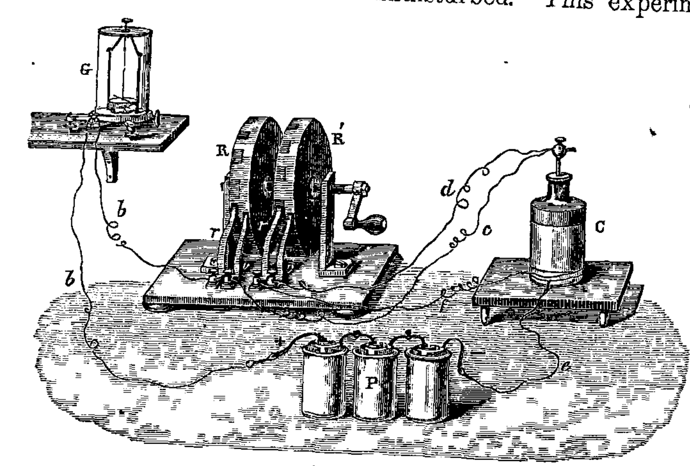

Fig. 216.

appears to show beyond a doubt that the earth acts merely as a reservoir, and, consequently, that no actual current passes from one earth plate to the other.

We are also indebted to Guillemin for a very ingenious experiment, which is a most convincing demonstration of the preceding principle. Let P (fig. 216) represent a battery and C a condenser, both of which are well insulated. Between the two is placed an interrupter with two wheels, R, R′, fixed upon the same axis. The metallic strips fixed on the circumference have an equal number of teeth, which are equally spaced and so arranged that the intervals of interruption alternate between one

wheel and the other. The interior coating of the condenser C communicates with the springs v v' by the wires c d; the exterior coating with the spring r' by the wire f. The latter is also permanently connected with the negative pole of the battery by the wire e; finally, the positive pole of the battery communicates with the spring r by the wire b b, in the circuit of which a galvanometer, G, is placed. When the interrupter is in motion, the interior coating of the condenser communicates with the positive pole of the battery every time that the spring r passes over a metallic tooth; but r' is then on an insulated space, and the two armatures are insulated from each other. On the contrary, when r is on an insulated space, r' is on a metallic tooth; the interior coating is then insulated from the positive pole of the battery, but communicates freely with the exterior armature through the wheel R′. The result is, therefore, that during the rotation of the interrupter, the condenser C is alternately charged when r is on a metallic tooth, and discharged when r' is in the same position. Now, although the battery under these circumstances can never be actually closed, since the insulating substance of the condenser always intervenes between the ends of the polar wires, nevertheless, when a rapid rotary motion is imparted to the interrupter, the needle of the galvanometer G is deflected, and indicates the passage of a positive current from the battery to the interior coating of the condenser.

The deflection of the needle increases with the velocity of rotation; in the experiments of Guillemin it amounted to 40 degrees. In order to obtain the maximum effect, it is necessary to preserve a certain relation between the surfaces of the condenser and the power of the battery.

Whatever may be the kind of wire used for the charging circuit b, c, e, in which the galvanometer is placed, or for the discharging circuit d, f, the deflection of the needle is the same for a similar velocity of the interrupter, and the direction of the deflection may be previously known from the arrangement of the experimental apparatus.

As long as the interrupter is in motion, the charging circuit *b*, *c*, *e*, and discharging circuit *d*, *f*, are traversed by a series of instantaneous electrical impulses which act on the needle of the galvanometer, and which, when the rotation is sufficiently rapid, produce the effect of a continuous current.

The coatings of the condenser, being alternately charged and discharged with great rapidity, perform the office of insulated conductors of infinite extent, one being in connection with the positive, the other with the negative pole of the battery.

Every time that the condenser is charged, a charge of electricity passes from the positive pole of the battery to the interior coating; but with apparatus of the ordinary size a single charge is insufficient to overcome the moment of inertia of the magnetized needle, and the galvanometer does not indicate its passage. With very large condensers the electricity necessary for a charge acts in a marked manner on the needle of the galvanometer.

Let us suppose that the end of a telegraph wire is connected to the positive pole of a battery, and that the other end of the wire and negative pole of the battery communicate with metallic plates or electrodes, buried in the earth. The positive electricity transmitted by the telegraph wire, and the negative from the zinc pole of the battery, pass from the metallic plates to the adjacent layers of the earth, and are instantly diffused in every direction, without producing around them any appreciable state of potential. It cannot, therefore, be considered exact to say that the current, after having passed along the telegraph wire, is returned to the battery by the earth acting as an ordinary conductor.

This opinion could only be tenable in such a case as that where the distance between the contact points of the polar wires with the earth is very small; but when the contact points are many miles apart, the terrestrial layers actually play, in respect to the poles of the battery, the part of conductors of infinite surface, which absorb the electricity as fast as it is produced, maintaining the points of the conductors which they touch at a potential of zero, and permitting the battery to work until its materials are exhausted. The earth thus opposes to the propa-

gation of the current two kinds of resistance; one passive, the resistance to diffusion, whose value depends upon the nature of the soil and the extent of surfaces in contact; the other active, due to a polarization of the electrodes, an inevitable consequence of the decomposition of liquids with which the earth is saturated. The sum of these two resistances, or the total resistance of the earth, necessarily varies according to the inverse ratio of the extent of the metallic plates buried, and to the conductivity of the surrounding layers; but for an invariable surface of the plates and for a soil of a certain nature, it evidently preserves a constant value and is independent of the length of the telegraph line. We may also add, that when communications are well established in moist earth, or still better, in a stream of water, the diffusion takes place with extreme facility, and the resistance of the earth is always small in comparison with that of a line of any considerable length.

But, however small it may be, experience proves that, on very short lines, the resistance of the earth has an appreciable value; as its value remains constant, its influence, however, diminishes as the length of electric circuit increases, and becomes too small to be taken into account when the distance between the corresponding stations amounts to 75 miles or more.

ELECTRICAL RESISTANCE OF THE EARTH.

When the electric current flows to earth and disappears, it still meets with more or less resistance in passing from the plates to the earth; but it is obvious that this resistance is quite independent of the distance which separates the earth plates, and, under like circumstances, it would preserve an unchanged value for different distances.

As the resistance of the earth is not very great, while that of a long line is usually very considerable, we may regard the earth's resistance as infinitely small in comparison, and in this case the resistance of the entire current is only half what it would be were the circuit metallic throughout. But, if the resistance of the conductor is small, we cannot assume that of the