practically identical with what is now known as Sir William Thomson's galvanometer, having been re-invented by him.

The greater part of Weber's work, however, was in close relation with the working out of the electro-magnetic measurement of electric currents, as in the case of his invention of the electro-dynamometer, now so extensively used in the numerous forms which it has assumed to meet the various requirements of the electrical engineer.

Weber's attempt to explain the phenomena of electric current induction by means of an electrostatic repulsion between moving particles carrying electric charges formed a portion of his researches on the electro-magnetic measurement of electric currents, published in 1864 and subsequent years under the title of "Elektrodynamische Maasbestimmungen," in the "Abhandlungen der Math. Phys. Classe der königlichen Sachsischen Gesellschaft der Wissenschaften." Helmholtz showed that Weber's formula led, in certain cases, to impossible results, but Prof. Lindmann, in 1888, showed that certain assumptions as to the nature of the molecules of matter led to Weber's formula, so long as the relative velocity of the particles does not exceed the velocity of light, but when this critical value is exceeded the law no longer holds, and in this form it is not open to Helmholtz's objection.

Weber's well-known theory of magnetic induction was another contribution to electrical science of which it would be difficult to exaggerate the importance, for, although in the light of our present knowledge it is in many respects inadequate, it undoubtedly formed the basis upon which a theory of magnetic induction is being gradually built up.

THE HISTORICAL DEVELOPMENT OF THE INDUCTION COIL AND TRANSFORMER.

BY DR. J. A. FLEMING, M.A.

(Continued from page 213.)

In Silliman's Journal of Science, Page made some very excellent remarks upon the action of "closed circuits" in preventing or reducing the inductive action of the primary current upon the secondary circuit. He states that if a closed circuit, such as a metallic sheath or tube, is interposed between the primary or secondary circuits, it more or less annuls the inductive action of the former on the latter. He hence notes that wrapping, what he calls a "compound magnet," *i.e.*, an induction coil with two separate circuits, in a metallic sheath, greatly reduces the inductive action of the primary on the secondary, although it does not prevent the action of the primary circuit in permanently magnetising the core. The same action he points out proves prejudicial if bobbins, made of metal, or having metal cheeks, are used upon which to wind the circuits of the coil. Hence, bobbins for induction coils should be made entirely of non-conducting material.

We also find that in 1840, J. H. Abbot, of Boston, U.S.A., constructed a large induction coil (see *Silliman's American Journal of Science*, Vol. XL., April, 1841, p. 107), which was capable of charging a Leyden jar, and which gave small secondary sparks. The break was a hand-worked break (*see* Fig. 16*a*). The secondary terminals were described as being luminous in the dark when the coil was in action. This coil was modelled on Page's.

It is evident from the foregoing that, even in the year 1838, C. G. Page had brought the induction coil to a high degree of perfection by his researches made at Salem and at Washington, and in particular had shown that the secondary circuit could exhibit effects of "tension" and produce electrostatic change in conductors having capacity connected with them when induction coils were used in which the secondary currents consisted of great lengths of fine wire. He had obtained sparks in air from the secondary terminals of coils, and shown the conditions under which these "electrostatic" effects could be exalted. We must also credit him with being an independent inventor of the self-acting hammer electro-magnetic contact breaker.

Continuing his researches, Page made many coils between 1838 and 1850, having highly insulated secondary circuits and vibrating automatic contact breakers. He found, as above observed, that he could charge Leyden jars, diverge the gold leaves of electroscopes, and produce many of the effects hitherto only obtained with electrostatic machines by means of these induction coils. With one of his coils he found he could obtain sparks half an inch long in air from the secondary terminals. He noted, also, the effect of rarefying the air round these terminals on the length of discharge. With one coil, which gave a secondary spark of $\frac{1}{18}$th of an inch in air, he obtained a

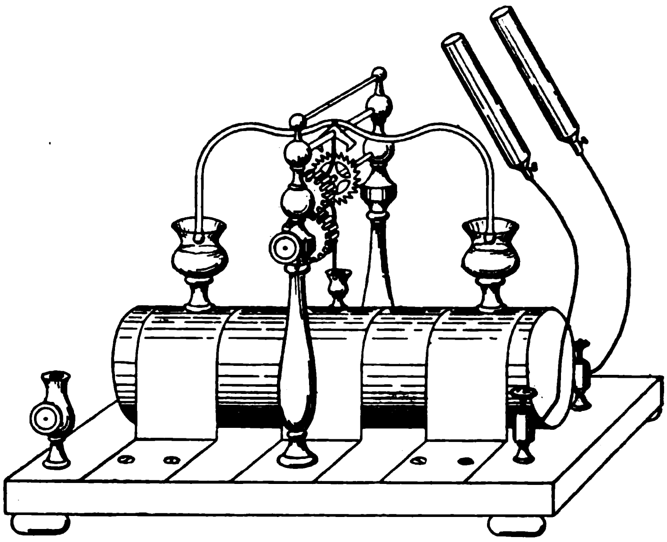

FIG. 16A.—Abbot's Induction Coil (1840).

discharge of about $4\frac{1}{2}$ inches in rarefied air, when the primary circuit was actuated by one single Grove's cell. In 1850 Page constructed a very large coil, of which the primary circuit was a wire or ribbon of copper, one quarter of an inch in diameter. This coil, when worked by 100 Grove's cells, gave sparks from the secondary circuit 8 inches in length.

One striking peculiarity about this large primary coil attracted Dr. Page's notice. When a solid iron core was put into this great helix the primary current took a very sensible fraction of a second to rise to its full value; from $\frac{1}{18}$th to two

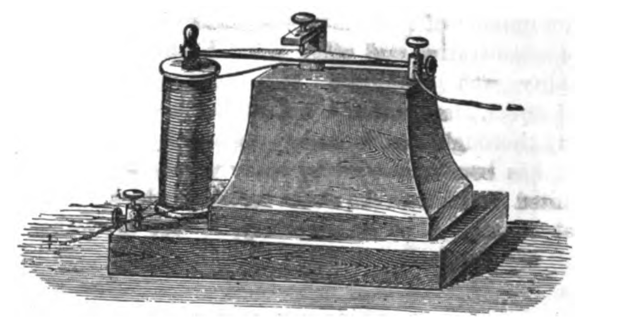

FIG. 17.—Wagner's Automatic Contact Breaker.

seconds, according to the position of the iron core. Page also noted a phenomenon, afterwards recorded by Rhyke in 1855, viz., that when the primary circuit was broken just between the poles of a powerful magnet the break-spark was extinguished with a loud explosion, like that of a pistol when fired.*

§ 10. **Wagner and Neef's Automatic Contact Breaker.**— Continental writers generally attribute the invention of the automatic vibrating electro-magnetic contact breaker to J. P.

* The greater part of Dr. C. G. Page's valuable work is recorded in his own Papers, published in *Silliman's American Journal of Science* between 1834 and 1850. He published in 1867 a *brochure* entitled the *History of Induction*, which is alluded to by Du Moncel in his work (Vol. II.) *Exposé des Applications de l'Electricité*, but this pamphlet of Page's is not to be found either in the British Museum Library or in the English Patent Office Library.

Wagner* and to Neef.† These inventors improved upon Page's mercurial break by constructing the vibrating armature with platinum contacts in the form in which it is now used in every trembling electric bell. The apparatus is too well known to need description. A form of Wagner's hammer, as it is generally called, is shown in Fig. 17, intended as an interrupter to the primary circuit of a coil. Du Moncel, however, states that MacGauley, of Dublin, independently invented the form of hammer contact as now used. From this date onwards it has generally been the custom to interrupt the primary circuit of an induction coil, if small, in the manner introduced by Page in 1838, viz., employing the intermittent magnetism

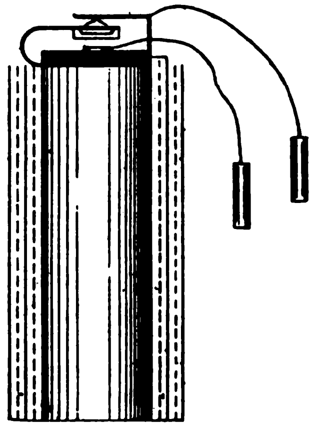

FIG. 18.—Wright's Coil and Contact Breaker.

of the soft iron core of the coil to work the vibrating hammer of the break, using, however, the platinum contacts of MacGauley or Wagner instead of Page's mercurial cup. On the other hand, when the coil is large, the break is usually made as a separate piece of apparatus with independent magnet, and in that case it is often found best to revert to the mercury cup break of Page, and cover, as he did, the surface of the mercury with oil or alcohol to prevent oxidation, as was done subsequently by Ruhmkorff and others. As is usually the case, useful improvements are invented several times over by inventors who are not familiar with what has already been

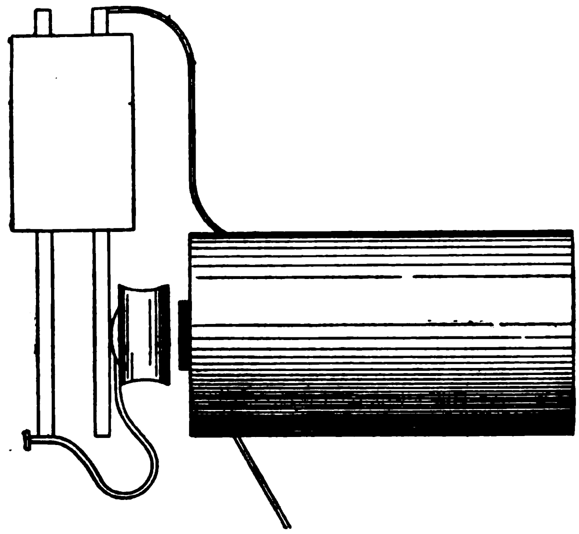

FIG. 19.—Wright's Contact Breaker.

done. We find in Sturgeon's *Annals of Electricity*, Vol. V., p. 30, a description of a coil by Thomas Wright, of Knutsford, dated 1840, in which he gives a sketch of a neat form of vibrating contact breaker (*see* Figs. 18 and 19), which is practically the same as that used on all small coils at present. Wright followed Neef and Wagner in suggesting that the contact points should be tipped with platinum. He succeeded in making some "electrotomes," as they were called, in which the spring vibrated so fast as to give out a musical note. Wright also gives details of many coils made by him about this time to determine the best dimensions of the core and of the circuits. It will be seen that by the year 1840 the induction coil had been practically completed in all essential parts, with the exception of the condenser. The separate primary and secondary circuits of thick and thin wire, the divided iron core and the vibrating contact breaker had been arrrived at and perfected; chiefly by the investigations of Callan, C. G. Page, Sturgeon, Backhoffner, Wagner, and Neef.

§ 11. **The Researches of Masson and Breguet.**—Between 1838 and 1842 the French physicists, MM. Masson and Breguet, prosecuted researches of a valuable character on the induction of electric currents. In the *Annales de Chimie et de Physique* (3rd Series, Vol. IV., 1842, page 129) will be found a long memoir, summing up the results of their work, which was communicated to the Academy of Sciences on August 23rd, 1841.

This Paper contains an account of very careful experiments on the production of electrostatic effects by secondary induced currents. In their investigations, Masson and Breguet employed a toothed wheel interrupter, or rheotrope, consisting of a brass toothed wheel having the teeth interspaces filled up with wood or ivory; one or more such wheels could be revolved on the same axis, and, by means of springs pressing against the periphery of the wheels, the primary current could be broken, and the secondary circuit closed at instants corresponding to the closing or opening of the primary circuit.

By the help of this apparatus they could separate out the two induced currents, and by means of a condenser and electroscope they examined the electrostatic potential at various points on the secondary circuit. Not being aware of the previous researches of Page, these investigators were apparently under the impression that they were the first to show that a condenser could be charged from the ends of the secondary circuit. Transforming, as they called it, induced currents into static electricity, they produced luminous discharges in vacuo by means of induced currents, and showed that these discharges had all the characters of discharges produced by electrical machines or Leyden jars. These results surprised European physicists, who, as Du Moncel observes, were apparently not aware that similar experiments had already been conducted in America. Amongst the chief results of this investigation was the experimental confirmation of the fact that the two secondary induced currents, the one produced by the commencement of the primary current, and the other produced by its cessation, consisted of equal quantities of electricity set flowing in opposite directions. Also the other important fact that the maximum value of the electromotive force of the secondary current at break of the primary is much greater than the maximum value of the secondary current at the starting of the primary, was stated by them. Hence it became clear that the direct or break-induced secondary current could traverse air spaces or overcome resistance which was impossible in the case of the inverse or make-induced current. The researches of Masson and Breguet established on a quantitative basis more firmly than before the facts of the induction of electric currents, but they did not achieve more than had previously been done in exalting the spark-producing power of secondary coils.

§ 12. **Henley's Coil.**—In the years between 1842 and 1851 very little progress appears to have been made in improving induction coils. Some modifications of arrangement either of the coil or the contact breaker were introduced. To this period, probably, belong two such varieties which are mentioned and described by Noad (*Manual of Electricity*, Vol. II.). One of these is represented in Fig. 20. The primary coil consisted of about 35ft. of insulated copper wire (No. 21), and the secondary of 1,400ft. of silk-covered copper wire (No. 20). The battery contact is renewed and broken by the rotation of the soft iron bar, which, mounted between two brass supports, is situated immediately over the axis of the coil, in which is placed a bundle of iron wires. The current from the battery passes through the support and the axis carrying the iron bar;

* See *Pogg. Annalen*, Vol. XLVI., p. 107, 1839; † and *Pogg. Annalen*, Vol. XLVI., p. 104, 1839; and compare *Wiedemann's Galvanismus*, §§ 696 and 737.

and the contact is interrupted by the small steel point, dipping as the bar revolves into and out of the mercury contained in the brass cup mounted on the brass pillar, through which the circuit is complete. This apparatus formed a self-acting shocking coil, but could produce no sparks from the secondary. Noad describes also an interesting form of coil which bears some relation to Page's electro-magnetic multiplier, and which, Noad says, was given to him by Mr. W. T. Henley. It is represented in Fig 21. A series of U-shaped bars of soft iron bolted

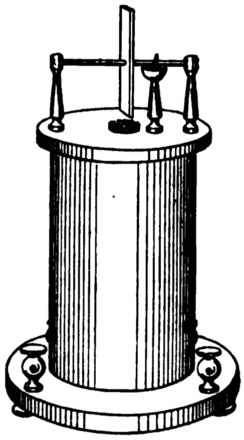

FIG. 20.

down to a base board was wound with four coils of No. 14 covered copper wire, to within an inch of either extremity. Over this was wound 1,000 yards of No. 34 silk-covered wire in one continuous length. A revolving iron armature rotates on a vertical spindle, so that in passing over the magnetic poles it nearly completes the magnetic circuit. The contact breaker consists of a bent lever, one end of which dips in a mercury cup and is so pivoted that the motion of the other end against the undulating surface of a cam-wheel attached to the spindle serves to dip the first-named end in and

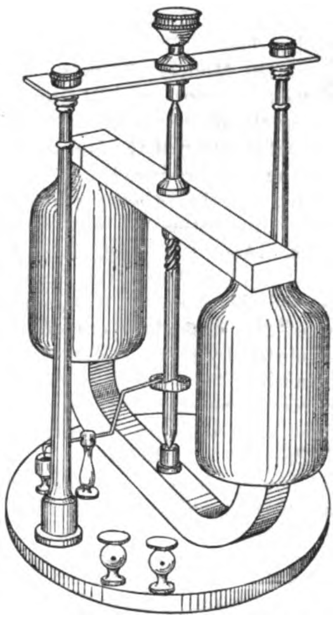

FIG. 21.—Henley's Induction Coil.

out of the mercury. The break of the primary circuit is so adjusted as to take place just after the soft iron armature has completed the magnetic circuit. Actuated with a battery of 10 cells this coil gave sparks one-eighth of an inch long in air, and remarkable for their quantity. It is easily seen that the appliance is, at the same time, an induction coil and also an electro-magnetic motor, and that a suitable arrangement of the time of making and breaking the primary circuit will cause the soft iron armature to be kept continuously in motion. It was noted as a curious fact that when the ends of the secondary circuit were metallically joined the spark at the primary break was much reduced. This is obviously due to the fact that the closing of the secondary circuit reduces the self-induction of the primary coil. These pieces of apparatus formed no real advance on what had been done before.

(To be continued.)

ELECTRIC AND MAGNETIC THEORIES.

BY SILVANUS P. THOMPSON, F.R.S.

§ 1. As Mr. Sprague has called in question the method of my argument, which I took the pains to explain beforehand in § 2, so that no one should have any ground to accuse me for laying a pitfall, I begin my rejoinder by quoting a few lines from Mr. Sprague's reply, p. 188, § 2.

"The real point in debate is how energy is transferred by an electric *current*. I ask him, has he *any evidence* of a single case of lateral transfer during the existence of true current? It is notorious that there is no scrap of evidence."

"He has dealt (in the way of evidence) solely with the phenomena of the variable periods."

"Therefore he avoids this difficulty by a logical dodge. He says, practically, if I can show that there are *some* cases in which we must agree that energy is transferred through the medium, I am entitled to assert that it is so in all cases. Bad logic and worse science."

Now, without admitting for a moment that I resorted to any "logical dodge," or argued with bad logic and worse science, I will at once say that I entirely agree with the first four sentences that I have quoted. There is *no evidence* (and I said as much on p. 44) *during the steady flow of the current* that the energy is transferred *laterally* across the medium. Neither is there any evidence during the steady flow that the energy is transferred along the wire *longitudinally*. The simple fact is that the current in the case of unvarying flow gives *no evidence at all* of the mode of propagation of the energy, and, therefore, in the present state of science affords no basis for an argument either way, in favour of lateral propagation or in favour of longitudinal.

Under these circumstances what can we do, in default of any crucial proof, to discover how the energy is propagated? The only course is that which in every branch of every science has proved the key to discovery, namely, argue forward from the known to the unknown. Find a case in which direct evidence exists, and argue on from this to those cases in which we have not yet been able to find direct evidence. If this procedure is to be stigmatised as a "logical dodge" then I fear that most of the advances of science during the last century must be set down as the result of logical dodges also. To argue from the known to the unknown, and then to test the result by probing to the bottom the necessary consequences of the step, is the one true scientific course in such a dilemma.

What did I say at the outset, on page 44? "Since in those cases in which the hypothesis of lateral transfer cannot in the present science be directly demonstrated, there is no evidence to show that the transfer takes place in any other way, then *in the absence of such evidence* one is logically driven to the conclusion that in all cases the mode of transfer is the same as in those cases in which a direct demonstration is possible." Is not that simply a statement that I proposed to argue from the known and demonstrable to the unknown and yet undemonstrated? A "dodge" it is not; it is a legitimate proceeding, both logical and scientific.

§ 2. Mr. Sprague denies the legitimacy of arguing from the cases of variable currents to that of steady currents. He virtually says that, when looking for evidence of the invisible mechanism by which a current is sustained, we have no business to regard any evidence derived from altering the strength of the current. Why does he lay down any such short-sighted limitation? If I want to find out whether a leak of gas comes from a certain pipe, must I refuse to make such