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and in 1857 the army, breaking away from the chief's control, besieged the British residency, and took advantage of the mutiny of the Bengal sepoys to spread disorder over that part of central India. The country was pacified after some fighting. In 1899 a British resident was appointed to Indore, which had formerly been directly under the agent to the governor-general in central India. At the same time a change was made in the system of administration, which was from that date carried on by a council. In 1903 the Maharaja, Shivaji Rao Holkar, G.C.S.I., abdicated in favour of his son Tukoji Rao, a boy of twelve, and died in 1908.

The City of Indore is situated 1738 ft. above the sea, on the river Saraswati, near its junction with the Khan. Pop. (1901) 86,686. These figures do not include the tract assigned to the resident, known as "the camp" (pop. 11,118), which is under British administration. The city is one of the most important trading centres in central India.

Indore Residency, a political charge in central India, is not co-extensive with the state, though it includes all of it except some outlying tracts. Area, 8960 sq. m.; pop. (1901) 833,410. (J. S. Co.)

INDORSEMENT, or Endorsement (from Med. Lat. *indorsare,* to write upon the *dorsum,* or back), anything written or printed upon the back of a document. In its technical sense, it is the writing upon a bill of exchange, cheque or other negotiable instrument, by one who has a right to the instrument and who thereby transmits the right and incurs certain liabilities. See Bill of Exchange.

INDO-SCYTHIANS, a name commonly given to various tribes from central Asia, who invaded northern India and founded kingdoms there. They comprise the Sakas, the Yue-Chi or Kushans and the Ephthalites or Hūnas.

INDRA, in early Hindu mythology, god of the clear sky and greatest of the Vedic deities. The origin of the name is doubtful, but is by some connected with *indu,* drop. His importance is shown by the fact that about 250 hymns celebrate his greatness, nearly one-fourth of the total number in the Rig Veda. He is represented as specially lord of the elements, the thunder-god. But Indra was more than a great god in the ancient Vedic pantheon. He is the patron-deity of the invading Aryan race in India, the god of battle to whose help they look in their struggles with the dark aborigines. Indra is the child of Dyaus, the Heaven. In Indian art he is represented as a man with four arms and hands; in two he holds a lance and in the third a thunderbolt. He is often painted with eyes all over his body and then he is called Sahasraksha, "the thousand eyed." He lost much of his supremacy when the triad Brahma, Siva and Vishnu became predominant. He gradually became identified merely with the headship of Swarga, a local vice-regent of the abode of the gods.

See A. A. Macdonell, *Vedic Mythology* (Strassburg, 1897).

INDRE, a department of central France, formed in 1790 from parts of the old provinces of Berry, Orléanais, Marche and Touraine. Pop. (1906) 290,216. Area 2666 sq. m. It is bounded N. by the department of Loir-et-Cher, E. by Cher, S. by Creuse and Haute-Vienne, S.W. by Vienne and N.W. by Indre-et-Loire. It takes its name from the river Indre, which flows through it. The surface forms a vast plateau divided into three districts, the Boischaut, Champagne and Brenne. The Boischaut is a large well-wooded plain comprising seven-tenths of the entire area and covering the south, east and centre of the department. The Champagne, a monotonous but fertile district in the north, produces abundant cereal crops, and affords excellent pasturage for large numbers of sheep, celebrated for the fineness of their wool. The Brenne, which occupies the west of the department, was formerly marshy and unhealthy, but draining and afforestation have brought about considerable improvement.

The department is divided into the arrondissements of Châteauroux, Le Blanc, La Châtre and Issoudun, with 23 cantons and 245 communes. At Neuvy-St-Sépulchre there is a circular church of the 11th century, to which a nave was added in the 12th century, and at Mézières-en-Brenne there i interesting church of the 14th century. At Levroux there fine church of the 13th century and the remains of a f fortress, and there is a magnificent château in the Renaiss style at Valençay.

INDRE-ET-LOIRE, a department of central France, consi of nearly the whole of the old province of Touraine and of s portions of Orléanais, Anjou and Poitou. Pop. (1906) 337 Area 2377 sq. m. It is bounded N. by the department Sarthe and Loir-et-Cher, E. by Loir-et-Cher and Indre, S. S.W. by Vienne and W. by Maine-et-Loire. It takes its n from the Loire and its tributary the Indre, which enter i its eastern border and unite not far from its western bo The other chief affluents of the Loire in the department the Cher, which joins it below Tours, and the Vienne, w waters the department's southern region. Indre-et-Loir generally level and comprises the following districts: Gâtine, a pebbly and sterile region to the north of the Lo largely consisting of forests and heaths with numerous sı lakes; the fertile Varenne or valley of the Loire; the Ch peigne, a chain of vine-clad slopes, separating the valleys of Cher and Indre; the Véron, a region of vines and orcha in the angle formed by the Loire and Vienne; the plat of Sainte-Maure, a hilly and unproductive district in the ce of which are found extensive deposits of shell-marl; and in south the Brenne, traversed by the Claise and the Creuse a forming part of the marshy territory which extends under same name into Indre.

Indre-et-Loire is divided into the arrondissements of To Loches and Chinon, with 24 cantons and 282 communes.] chief town is Tours, which is the seat of an archbishopric; a Chinon, Loches, Amboise, Chenonceaux, Langeais and Az le-Rideau are also important places with châteaus. T Renaissance château of Ussé, and those of Luynes (15th a 16th centuries) and Pressigny-le-Grand (17th century) are a of note. Montbazon possesses the imposing ruins of a squ donjon of the 11th and 12th centuries. Preuilly has the m beautiful Romanesque church in Touraine. The Sainte Chape (16th century) at Champigny is a survival of a château of t dukes of Bourbon-Montpensier. The church of Montrés (1532) with its mausoleum of the family of Montrésor; that St Denis-Hors (12th and 16th century) close to Amboise, wi the curious mausoleum of Philibert Babou, minister of finan under Francis I. and Henry II.; and that of Ste Catherine Fierbois, of the 15th century, are of architectural interes The town of Richelieu, founded in 1631 by the famous minist of Louis XIII., preserves the enceinte and many of the buildin of the 17th century. Megalithic monuments are numero in the department.

INDRI, a Malagasy word believed to mean "there it goes, but now accepted as the designation of the largest of the existin Malagasy (and indeed of all) lemurs. Belonging to the famil *Lemuridae* (see Primates) it typifies the subfamily *Indrisina* which includes the avahi and the sifakas (*q.v.*). From both th latter it is distinguished by its rudimentary tail, measuring onl a couple of inches in length, whence its name of *Indris brevi caudatus.* Measuring about 24 in. in length, exclusive of th tail, the indri varies considerably in colour, but is usually black with a variable number of whitish patches, chiefly about th loins and on the fore-limbs. The forests of a comparativel small tract on the east coast of Madagascar form its home Shoots, flowers and berries form the food of the indri, whic was first discovered by the French traveller and naturalis Pierre Sonnerat in 1780. (R. L.*)

INDUCTION (from Lat. *inducere,* to lead into; cf. Gr. ἐπαγωγή), in logic, the term applied to the process of discovering principles by the observation and combination of particular instances. Aristotle, who did so much to establish the laws of deductive reasoning, neglected induction, which he identified with a complete enumeration of facts; and the schoolmen were wholly concerned with syllogistic logic. A new era opens with Bacon, whose writings all preach the principle of investigating the laws of nature with the purpose of improving the conditions of human life. Unluckily his mind was still enslaved by the formulae of the quasi-mechanical scholastic logic. He supposed that natural laws would disclose themselves by the accumulation and due arrangement of instances without any need for original speculation on the part of the investigator. In his *Novum Organum* there are directions for drawing up the various kinds of lists of instances. For two hundred years after Bacon's death little was done towards the theory of induction; the reason being, probably, that the practical scientists knew no logic, while the university logicians, with their conservative devotion to the syllogism, knew no science. Whewell's *Philosophy of the Inductive Sciences* (1840), the work of a thoroughly equipped scientist, if not of a great philosopher, shows due appreciation of the cardinal point neglected by Bacon, the function of theorizing in inductive research. He saw that science advances only in so far as the mind of the inquirer is able to suggest organizing ideas whereby our observations and experiments are colligated into intelligible system. In this respect J. S. Mill is inferior to Whewell: throughout his *System of Logic* (1843) he ignores the constitutive work of the mind, and regards knowledge as the merely passive reception of sensuous impressions. His work was intended mainly to reduce the procedure of induction to a regular demonstrative system like that of the syllogism; and it was for this purpose that he formulated his famous Four Methods of Experimental Inquiry. His work has contributed greatly to the systematic treatment of induction. But it must be remarked that his Four Methods are not methods of formal proof, as their author supposed, but methods whereby hypotheses are suggested or tested. The actual proof of an hypothesis is never formal, but always lies in the tests of experiment or observation to which it is subjected.

The current theory of induction as set forth in the standard works is so far satisfactory that it combines the merit of Whewell's treatment with that of Mill's; and yet it is plain that there is much for the logician of the future to accomplish. The most important faculty in scientific inquiry is the faculty of suggesting new and valuable hypotheses. But no one has ever given any explanation how the hypotheses arise in the mind: we attribute it to "genius," which, of course, is no explanation at all. The logic of discovery, in the higher sense of the term, simply has no existence. Another important but neglected province of the subject is the relation of scientific induction to the inductions of everyday life. There are some who think that a study of this relation would quite transform the accepted view of induction. Consider such a piece of reasoning as may be heard any day in a court of justice, a detective who explains how in his opinion a certain burglary was effected. If all reasoning is either deductive or inductive, this must be induction. And yet it does not answer to the accepted definition of induction, "the process of discovering a general principle by observation of particular instances": what the detective does is to reconstruct a particular crime; he evolves no general principle. Such reasoning is used by every man in every hour of his life: by it we understand what people are doing around us, and what is the meaning of the sense-impressions which we receive. In the logic of the future it will probably be recognized that scientific induction is only one form of this universal constructive or reconstructive faculty. Another most important question closely akin to that just mentioned is the true relation between these reasoning processes and our general life as active intelligent beings. How is it that the detective is able to understand the burglar's plan of action?—the military commander to forecast the enemy's plan of campaign? Primarily, because he himself is capable of making such plans. Men as active creatures co-operating with their fellow-men are incessantly engaged in forming plans and in apprehending the plans of those around them. Every plan may be viewed as a form of induction: it is a scheme invented to meet a given situation, an hypothesis which is put to the test of events, and is verified or refuted by practical success or failure. Such considerations widen still farther our view of scientific induction and help us to understand its relation to ordinary human thought and activity scientific investigator in his inductive stage is endeav to make out the plan on which his material is constr The phenomena serve as indications to help him in frami hypothesis, generally a guess at first, which he proce verify by experiment and the collection of additional In the deductive stage he assumes that he has made ou plan and can apply it to the discovery of further detail. I the capacity of detecting plans in nature because he is wo form plans for practical purposes.

There are good recent accounts of induction in Welton's *M of Logic*, ii., in H. W. B. Joseph's *Introduction to Logic*, a W. R. Boyce Gibson's *Problem of Logic*; see also LOGIC. (H. S

INDUCTION COIL, an electrical instrument consistin two coils of wire wound one over the other upon a core sisting of a bundle of iron wires. One of these circuits is c the primary circuit and the other the secondary circuit an alternating or intermittent continuous current is pa through the primary circuit, it creates an alternating or ir mittent magnetization in the iron core, and this in turn cre in the secondary circuit a secondary current which is ca the induced current. For most purposes an induction coi required which is capable of giving in the secondary circ intermittent currents of very high electromotive force, and attain this result the secondary circuit must as a rule con of a very large number of turns of wire. Induction coils employed for physiological purposes and also in connexion w telephones, but their great use at the present time is in connexi with the production of high frequency electric currents, i Röntgen ray work and wireless telegraphy.

The instrument began to be devoloped soon after Farada discovery of induced currents in 1831, and the subseque researches of Joseph Henry, C. G. Page and W. Sturgeon on the induction of a current. N. J. Callan described in 1836 the construction of an electromagnet with two separate insulated wires, one thick and th other thin, wound on an iron core together. He provided th primary circuit of this instrument with an interrupter, and foun that when the primary current was rapidly intermitted, series of secondary currents was induced in the fine wire, o high electromotive force and considerable strength. Sturgeon in 1837 constructed a similar coil, and provided the primary circuit with a mercury interrupter operated by hand. Various other experimentalists took up the construction of the induction coil, and to G. H. Bachhoffner is due the suggestion of employing an iron core made of a bundle of fine iron wires. At a somewhat later date Callan constructed a very large induction coil containing a secondary circuit of very great length of wire. C. G. Page and J. H. Abbot in the United States, between 1838 and 1840, also constructed some large induction coils.[1] In all these cases the primary circuit was interrupted by a mechanically worked interrupter. On the continent of Europe the invention of the automatic primary circuit interrupter is generally attributed to C. E. Neeff and to J. P. Wagner, but it is probable that J. W. M'Gauley, of Dublin, independently invented the form of hammer break now employed. In this break the magnetization of the iron core by the primary current is made to attract an iron block fixed to the end of a spring, in such a way that two platinum points are separated and the primary circuit thus interrupted. It was not until 1853 that H. L. Fizeau added to the break the condenser which greatly improved the operation of the coil. In 1851 H. D. Rühmkorff (1803–1877), an instrument-maker in Paris, profiting by all previous experience, addressed himself to the problem of increasing the electromotive force in the secondary circuit, and induction coils with a secondary circuit of long fine wire have generally, but unnecessarily, been called Rühmkorff coils. Rühmkorff, however, greatly lengthened the secondary circuit, employing in some coils 5 or 6 m. of wire. The secondary wire was insulated with silk and shellac varnish,

Early histor.

[1] For a full history of the early development of the induction coil see J. A. Fleming, *The Alternate Current Transformer*, vol. ii. chap. i.

and each layer of wire was separated from the next by means of varnished silk or shellac paper; the secondary circuit was also carefully insulated from the primary circuit by a glass tube. Rühmkorff, by providing with his coil an automatic break of the hammer type, and equipping it with a condenser as suggested by Fizeau, arrived at the modern form of induction coil. J. N. Hearder in England and E. S. Ritchie in the United States began the construction of large coils, the last named constructing a specially large one to the order of J. P. Gassiot in 1858. In the following decade A. Apps devoted great attention to the production of large induction coils, constructing some of the most powerful coils in existence, and introduced the important improvement of making the secondary circuit of numerous flat coils of wire insulated by varnished or paraffined paper. In 1869 he built for the old Polytechnic Institution in London a coil having a secondary circuit 150 m. in length. The diameter of the wire was 0·014 in., and the secondary bobbin when complete had an external diameter of 2 ft. and a length of 4 ft. 10 ins. The primary bobbin weighed 145 lb, and consisted of 6000 turns of copper wire 3770 yds. in length, the wire being ·095 of an inch in diameter. Excited by the current from 40 large Bunsen cells, this coil could give secondary sparks 30 in. in length. Subsequently, in 1876, Apps constructed a still larger coil for William Spottiswoode, which is now in the possession of the Royal Institution. The secondary circuit consisted of 280 m. of copper wire about 0·01 of an inch in diameter, forming a cylinder 37 in. long and 20 in. in external diameter; it was wound in flat disks in a large number of separate sections, the total number of turns being 341,850. Various primary circuits were employed with this coil, which when at its best could give a spark of 42 in. in length.

Construction.

A general description of the mode of constructing a modern induction coil, such as is used for wireless telegraphy or Röntgen ray apparatus, is as follows: The iron core consists of a bundle of soft iron wires inserted in the interior of an ebonite tube. On the outside of this tube is wound the primary circuit, which generally consists of several distinct wires capable of being joined either in series or parallel as required. Over the primary circuit is placed another thick ebonite tube, the thickness of the walls of which is proportional to the spark-producing power of the secondary circuit. The primary coil must be wholly enclosed in ebonite, and the tube containing it is generally longer than the secondary bobbin. The second circuit consists of a number of flat coils wound up between paraffined or shellaced paper, much as a sailor coils a rope. It is essential that no joints in this wire shall occur in inaccessible places in the interior. A machine has been devised by Leslie Miller for winding secondary circuits in flat sections without any joints in the wire at all (British Patent, No. 5811, 1903). A coil intended to give a 10 or 12 in. spark is generally wound in this fashion in several hundred sections, the object of this mode of division being to prevent any two parts of the secondary circuit which are at great differences of potential from being near to one another, unless effectively insulated by a sufficient thickness of shellaced or paraffined paper. A 10-in. coil, a size very commonly used for Röntgen ray work or wireless telegraphy, has an iron core made of a bundle of soft iron wires No. 22 S.W.G., 2 in. in diameter and 18 in. in length. The primary coil wound over this core consists of No. 14 S.W.G. copper wire, insulated with white silk laid on in three layers and having a resistance of about half an ohm. The insulating ebonite tube for such a coil should not be less than ¼ in. in thickness, and should have two ebonite cheeks on it placed 14 in. apart. This tube is supported on two hollow pedestals down which the ends of the primary wire are brought. The secondary coil consists of No. 36 or No. 32 silk-covered copper wire, and each of the sections is prepared by winding, in a suitable winding machine, a flat coiled wire in such a way that the two ends of the coil are on the outside. The coil should not be wound in less than a hundred sections, and a larger number would be still better. The adjacent ends of consecutive sections are soldered together and insulated, and the whole secondary coil should be immersed in paraffin wax. The completed coil (fig. 1) is covered with a sheet of ebonite and mounted on a base board which, in some cases, contains the primary condenser within it and carries on its upper surface a hammer break. For many purposes, however, it is better to separate the condenser and the break from the coil. Assuming that a hammer break is employed, it is generally of the Apps form. The interruption of the primary circuit is made between two contact studs which ought to be of massive platinum, and across the break points is joined the primary condenser. This consists of a number of sheets of paraffined paper interposed between sheets of tin foil, alternate sheets of the tin foil being joined together (see LEYDEN JAR). This condenser serves to quench the break spark. If the primary

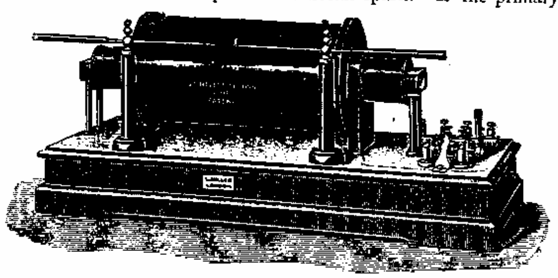

FIG. 1.

condenser is not inserted, the arc or spark which takes place at the contact points prolongs the fall of magnetism in the core, and since the secondary electromotive force is proportional to the rate at which this magnetism changes, the secondary electromotive force is greatly reduced by the presence of an arc-spark at the contact points. The primary condenser therefore serves to increase the suddenness with which the primary current is interrupted, and so greatly increases the electromotive force in the secondary circuit. Lord Rayleigh showed (*Phil. Mag.*, 1901, 581) that if the primary circuit is interrupted with sufficient suddenness, as for instance if it is severed by a bullet from a gun, then no condenser is needed. No current flows in the secondary circuit so long as a steady direct current is passing through the primary, but at the moments that the primary circuit is closed and opened two electromotive forces are set up in the secondary; these are opposite in direction, the one induced by the breaking of the primary circuit being by far the stronger. Hence the necessity for some form of circuit breaker, by the continuous action of which there results a series of discharges from one secondary terminal to the other in the form of sparks.

The hammer break is somewhat irregular in action and gives a good deal of trouble in prolonged use; hence many other forms of primary circuit interrupters have been devised.

Interrupters or Breaks.

These may be classified as (1) hand- or motor-worked dipping interrupters employing mercury or platinum contacts; (2) turbine mercury interrupters; (3) electrolytic interrupters. In the first class a steel or platinum point, operated by hand or by a motor, is periodically immersed in mercury and so serves to close the primary circuit. To prevent oxidation of the mercury by the spark and break it must be covered with oil or alcohol. In some cases the interruption is caused by the continuous rotation of a motor either working an eccentric which operates the plunger, or, as in the Mackenzie-Davidson break, rotating a slate disk having a metal stud on its surface, which is thus periodically immersed in mercury in a vessel. A better class of interrupter is the mercury turbine interrupter. In this some form of rotating turbine pump pumps mercury from a vessel and squirts it in a jet against a copper plate. Either the copper plate or the jet is made to revolve rapidly by a motor, so that the jet by turns impinges against the plate and escapes it; the mercury and plate are both covered with a deep layer of alcohol or paraffin oil, so that the jet is immersed in an insulating fluid. In a recent form the chamber in which the jet works is filled with coal gas. The current supplied to the primary circuit of the coil travels from the mercury in the vessel through the jet to the copper plate, and hence is periodically interrupted when the jet does not impinge against the plate. Mercury turbine breaks are much employed in connexion with large induction coils used for wireless telegraphy on account of their regular action and the fact that the number of interruptions per second can be controlled easily by regulating the speed of the motor which rotates the jet. But all mercury breaks employing paraffin or alcohol as an insulating medium are somewhat troublesome to use because of the necessity of periodically cleaning the mercury. Electrolytic interrupters were first brought to notice by Dr A. R. B. Wehnelt in 1898 (*Elektrotechnische Zeitschrift*, January 20th, 1899). He showed that if a large lead plate was placed in dilute sulphuric acid as a cathode, and a thick platinum wire protruding for a distance of about one millimetre beyond a glass or porcelain tube into which it tightly fitted was used as an anode, such an arrangement when inserted in the circuit of a primary coil gave rise to a rapid intermittency in the primary current. It is essential that the platinum wire should be the anode or positive pole. The frequency of the Wehnelt break can be adjusted by regulating the extent to which the platinum wire protrudes through the porcelain tube, and in modern electrolytic breaks several platinum anodes are employed. This break can be employed with any voltage between 30 and 250. The Caldwell interrupter, a modification of the Wehnelt break, consists of two electrodes immersed in dilute sulphuric acid, one of them being enclosed by a glass vessel which has a small hole in it capable of being more or less closed by a tapered glass plug. It differs from the Wehnelt break in that there is no platinum to wear away and it requires less current; hence finer regulation of the coil to the current can be obtained. It will also work with either direct or alternating currents. The hammer and mercury turbine breaks can be arranged to give interruptions from about 10 per second up to about 50 or 60. The electrolytic breaks are capable of working at a higher speed, and under some conditions will give interruptions up to a thousand per second. If the secondary terminals of the induction coils are connected to spark balls placed a short distance apart, then with an electrolytic break the discharge has a flame-like character resembling an alternating current arc. This type of break is therefore preferred for Röntgen ray work since it makes less flickering upon the screen, but its advantages in the case of wireless telegraphy are not so marked. In the Grisson interrupter the primary circuit of the induction coil is divided into two parts by a middle terminal, so that a current flowing in at this point and dividing equally between the two halves does not magnetize the iron. This terminal is connected to one pole of the battery, the other two terminals being connected alternately to the opposite pole by means of a revolving commutator which (1) passes a current through one half of the primary, thus magnetizing the core; (2) passes a current through both halves in opposite directions, thus annulling the magnetization; (3) passes a current through the second half of the primary, thus reversing the magnetization of the core; and (4) passes a current through both halves through opposite directions, thus again annulling the magnetization. As this series of operations can be performed without interrupting a large current through the inductive circuit there is not much spark at the commutator, and the speed of commutation can be regulated so as to obtain the best results due to a resonance between the primary and secondary circuits. Another device due to Grisson is the electrolytic condenser interrupter. If a plate of aluminium and one of carbon or iron is placed in an electrolyte yielding oxygen, this aluminium-carbon or aluminium-iron cell can pass current in one direction but not in the other. Much greater resistance is experienced by a current flowing from the aluminium to the iron than in the opposite direction, owing to the formation of a film of aluminic hydroxide on the aluminium. If then a cell consisting of a number of aluminium plates alternating with iron plates or carbon in alkaline solution is inserted in the primary circuit of an induction coil, the application of an electromotive force in the right direction will cause a transitory current to flow through the coil until the electrolytic condenser is charged. By the use of a proper commutator the position of the electrolytic cell in the circuit can be reversed and another transitory primary current created. This interrupted flow of electricity through the primary circuit provides the intermittent magnetization of the core necessary to produce the secondary electromotive force. This operation of commutation can be conducted without much spark at the commutator because the circuit is interrupted at the time when there is no current in it. In the case of the electrolytic condenser no supplementary paraffined paper condenser is necessary as in the case of the hammer or mercury interrupters.

High Frequency Coils.

An induction coil for the transformation of alternating current is called a transformer (*q.v.*). One type of high frequency current transformer is called an *oscillation transformer* or sometimes a *Tesla coil*. The construction of such a coil is based on different principles from that of the coil just described. If the secondary terminals of an ordinary induction coil or transformer are connected to a pair of spark balls (fig. 2), and if these are also connected to

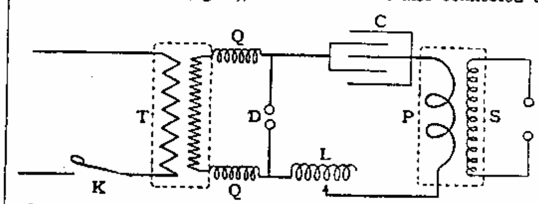

FIG. 2.—Arrangements for producing High Frequency Currents.
T, Transformer or induction coil.
Q, Q, Choking coils.
D, Spark balls.
C, Condenser.
L, Inductance.
P, Primary circuit of high frequency coil.
S, Secondary circuit.

a glass plate condenser or Leyden jar of ordinary type joined in series with a coil of wire of low resistance and few turns, then at each break of the primary circuit of the ordinary induction coil a secondary electromotive force is set up which charges the Leyden jar, and if the spark balls are set at the proper distance, this charge is succeeded by a discharge consisting of a movement of electricity backwards and forwards across the spark gap, constituting an oscillatory electric discharge (see ELECTROKINETICS). Each charge of the jar may produce from a dozen to a hundred electric oscillations which are in fact brief electric currents of gradually decreasing strength. If the circuit of few turns and low resistance through which this discharge takes place is overlaid with another circuit well insulated from it consisting of a large number of turns of finer wire, the inductive action between the two circuits creates in the secondary a smaller series of electric oscillations of higher potential. Between the terminals of this last-named coil we can then produce a series of discharges each of which consists in an extremely rapid motion of electricity to and fro, the groups of oscillations being separated by intervals of time corresponding to the frequency of the break in the primary circuit of the ordinary induction coil charging the Leyden jar or condenser. These high frequency discharges differ altogether in character from the secondary discharges of the ordinary induction coil. Theory shows that to produce the best results the primary circuit of the oscillation transformer should consist of only one thick turn of wire or, at most, but of a few turns. It is also necessary that the two circuits, primary and secondary, should be well insulated from one another, and for this purpose the oscillation transformer is immersed in a box or vessel full of highly insulating oil. For full details N. Tesla's original Papers must be consulted (see *Journ. Inst. Elect. Eng.* 21, 62).

In some cases the two circuits of the Tesla coil, the primary and secondary, are sections of one single coil. In this form the arrangement is called a *resonator* or *auto transformer*, and is much used for producing high frequency discharges for medical purposes. The construction of a resonator is as follows: A bare copper wire is wound upon an ebonite or wooden cylinder or frame, and one end of it is connected to the outside of a Leyden jar or battery of Leyden jars, the inner coating of which is connected to one spark ball of the ordinary induction coil. The other spark ball is connected to some point on the above-named copper wire not very far from the lower end. By adjusting this contact, which is movable, the electric oscillations created in the short section of the resonator coil produce by resonance oscillations in the longer free section, and a powerful high frequency electric brush or discharge is produced at the free end of the resonator spiral. An electrode or wire connected with this free end therefore furnishes a high frequency glow discharge which has been found to have valuable therapeutic powers.

Theory of Oscillation Transformers.

The general theory of an oscillation transformer containing capacity and inductance in each circuit has been given by Oberbeck, Bjerknes and Drude.[1] Suppose there are two circuits, each consisting of a coil of wire, the two being superimposed or adjacent, and let each circuit contain a condenser or Leyden jar in series with the circuit, and let one of these circuits contain a spark gap, the other being closed (fig. 3). If to the spark balls the secondary terminals of an ordinary induction coil are connected, and these spark balls are adjusted near one another, then when the ordinary coil is set in operation, sparks pass between the balls and oscillatory discharges take place in the circuit containing the spark gap. These oscillations induce other oscillations in the second circuit. The two circuits have a certain mutual inductance M, and each circuit has self inductance L_1 and L_2. If then the capacities in the two circuits are denoted by C_1 and C_2 the following simultaneous equations express the relation of the urrents, i_1 and i_2, and potentials, v_1, and v_2, in the primary and econdary circuits respectively at any instant:—

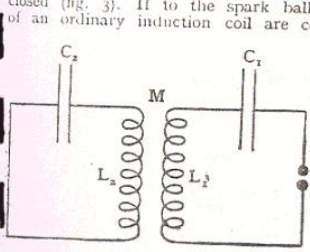

FIG. 3.

C_1, Condenser in primary circuit.
C_2, Condenser in secondary circuit.
L_1, Inductance in primary circuit.
L_2, Inductance in secondary circuit.

$$L_1\frac{di_1}{dt} + M\frac{di_2}{dt} + R_1 i_1 + v_1 = 0,$$

$$L_2\frac{di_2}{dt} + M\frac{di_1}{dt} + R_2 i_2 + v_2 = 0,$$

R_1 and R_2 being the resistances of the two circuits. If for the moment we neglect the resistances of the two circuits, and consider that the oscillations in each circuit follow a simple harmonic law =I sin *pt* we can transform the above equations into a biquadratic

$$p^4 + p^2\frac{L_1C_1 + L_2C_2}{C_1C_2(L_1L_2 - M^2)} + \frac{1}{C_1C_2(L_1L_2 - M^2)} = 0.$$

The capacity and inductance in each circuit can be so adjusted that their products are the same number, that is $C_1L_1 = C_2L_2 = CL$. The two circuits are then said to be in resonance or to be tuned together. In this particular and unique case the above biquadratic reduces to

$$p^2 = \frac{1}{CL}\cdot\frac{1 \pm k}{1 - k^2},$$

where k is written for $M\sqrt{(L_1L_2)}$ and is called the *coefficient of coupling*. In this case of resonant circuits it can also be shown that the maximum potential differences at the primary and secondary condenser terminals are determined by the rule $V_1/V_2 = 2\sqrt{C_2}/\sqrt{C_1}$. Hence the transformation ratio is not determined by the relative number of turns on the primary and secondary circuits, as in the case of an ordinary alternating current transformer (see TRANSFORMERS), but by the ratio of the capacity in the two oscillation circuits. For full proofs of the above the reader is referred to the original papers.

Each of the two circuits constituting the oscillation transformer taken separately has a natural time period of oscillation; that is to say, if the electric charge in it is disturbed, it oscillates to and fro in a certain constant period like a pendulum and therefore with a certain frequency. If the circuits have the same frequency when separated they are said to be isochronous. If n stands for the natural frequency of each circuit, where $n = p/2\pi$ the above equations show that when the two circuits are coupled together, oscillations set up in one circuit create oscillations of two frequencies in the secondary circuit. A mechanical analogue to the above electrical effect can be obtained as follows: Let a string be strung loosely between two fixed points, and from it let two other strings of equal length hang down at a certain distance apart, each of them having a weight at the bottom and forming a simple pendulum. If one pendulum is set in oscillation it will gradually impart this motion to the second, but in so doing it will bring itself to rest; in like manner the second pendulum being set in oscillation gives back its motion to the first. The graphic representation, therefore, of the motion of each pendulum would be a line as in fig. 4. Such a curve

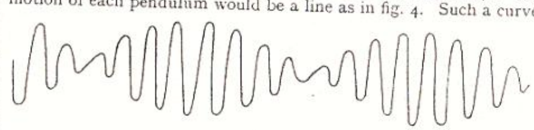

FIG. 4.

represents the effect in music known as beats, and can easily be shown to be due to the combined effect of two simple harmonic motions or simple periodic curves of different frequency superimposed. Accordingly, the effect of inductively coupling together two electrical circuits, each having capacity and inductance, is that if oscillations are started in one circuit, oscillations of two frequencies are found in the secondary circuit, the frequencies differing from one another and differing from the natural frequency of each circuit taken alone. This matter is of importance in connexion with wireless telegraphy (see TELEGRAPH), as in apparatus for conducting it, oscillation transformers as above described, having two circuits in resonance with one another, are employed.

REFERENCES.—J. A. Fleming, *The Alternate Current Transformer* (2 vols., London, 1900), containing a full history of the induction coil; *id.*, *Electric Wave Telegraphy* (London, 1906), dealing in chap. i. with the construction of the induction coil and various forms of interrupter as well as with the theory of oscillation transformers; A. T. Hare, *The Construction of Large Induction Coils* (London, 1900); J. Trowbridge, "On the Induction Coil," *Phil. Mag.* (1902), 3, p. 393; Lord Rayleigh, "On the Induction Coil," *Phil. Mag.* (1901), 2, p. 581; J. E. Ives, "Contributions to the Study of the Induction Coil," *Physical Review* (1902), vols. 14 and 15.
(J. A. F.)

INDULGENCE (Lat. *indulgentia*, *indulgere*, to grant, concede), in theology, a term defined by the official catechism of the Roman Catholic Church in England as "the remission of the temporal punishment which often remains due to sin after its guilt has been forgiven." This remission may be either total (*plenary*) or partial, according to the terms of the Indulgence. Such remission was popularly called a *pardon* in the middle ages—a term which still survives, *e.g.* in Brittany.

The theory of Indulgences is based by theologians on the following texts: 2 Samuel (Vulgate, 2 Kings) xii. 14; Matt. xvi. 19 and xviii. 17, 18; 1 Cor. v. 4, 5; 2 Cor. ii. 6-11; but the practice itself is confessedly of later growth. As Bishop Fisher says in his Confutation of Luther, "in the early church, faith in Purgatory and in Indulgences was less necessary than now. . . . But in our days a great part of the people would rather cast off Christianity than submit to the rigour of the [ancient] canons: wherefore it is a most wholesome dispensation of the Holy Ghost that, after so great a lapse of time, the belief in purgatory and the practice of Indulgences have become generally received among the orthodox" (*Confutatio*, cap. xviii.; cf. Cardinal Caietan, *Tract. XV. de indulg.* cap. i.). The nearest equivalent in the ancient Church was the local and temporary African practice of restoring lapsed Christians to communion at the intercession of confessors and prospective martyrs in prison. But such reconciliations differed from later Indulgences in at least one essential particular, since they brought no remission of ecclesiastical penance save in very exceptional cases. However, as the primitive practice of public penance for sins died out in the Church, there grew up a system of equivalent, or nominally equivalent, private penances. Just as many of the punishments enjoined by the Roman criminal code were gradually commuted by medieval legislators for pecuniary fines, so the years or months of fasting enjoined by the earlier ecclesiastical codes were commuted for proportionate fines, the recitation of a certain number of psalms, and the like. "Historically speaking, it is indisputable that the practice of Indulgences in the medieval

[1] See A. Oberbeck, *Wied. Ann.* (1895), 55, p. 623; V. F. R. Bjerknes, (1895), 55, p. 121, and (1891), 44, p. 74; and P. K. L. Drude, *Ann. Phys.* (1904), 13, p. 512.