INDUCTION COILS

IN

THEORY AND PRACTICE

By

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Price $1.00

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Author of:

- *How to Make High-Pressure Transformers*
- *How to Make Low-Pressure Transformers*
- *Examples in Battery Engineering*
- *How to Make Telephones, and Signaling Apparatus*
- *Examples in Alternating Currents*
- *Preliminary Mathematics*
- *Examples in Magnetism*
- *Generator and Motor Examples*
- *Laboratory Experiments with Direct Currents*

These books may be consulted at public libraries or purchased from reliable dealers.

1. Throughout the consideration and the discussion of the theory of induction coils it is necessary at times to employ the so-called *metric system* of units, such as the centimeter and the gram. It is therefore advisable to know about the relation of some of the metric units to the ordinary English units. The important relation is that of the centimeter and the inch, and

2.54 centimeters=1 inch.

2. From this relation, all relations of lengths, areas, and volume may be obtained. For example, the *number of centimeters in one foot* is found from 2.54×12=**30.48,** and the number of centimeters per yard is 2.54×12×3=91.44.

3. The *number of square centimeters in one square inch is* found from 2.54×2.54=**6.4516.** The value 6.45 is near enough for ordinary computations. The number of square centimeters per square foot is found from 12×12×6.4516=144×6.4516=929.0304.

4. The number of cubic centimeters per cubic inch may be found by multiplying 2.54×2.54×2.54,* giving 16.387064; 16.38 being sufficient for ordinary calculations. It is evident that any relation may be found by calculation from the fundamental relation *2.54 centimeters=1 inch.*

5. To aid in other calculations the following units in the metric system are given:

1 millimeter=$\frac{1}{10}$ of a centimeter.
1 decimeter =10 centimeters=$\frac{1}{10}$ of a meter.
1 meter =100 centimeters.
1 kilometer =1000 meters.

6. The relations between the weights in the metric system and those in the English system may be found by calculations from the fundamental relation that

453.6 grams=1 pound.

* This is the same as 2.54^3.

LESSON I.

THE INDUCTION COIL, IN THEORY AND PRACTICE.

7. The theory of the operation of the induction coil should be carefully considered by all who desire to construct their own wireless outfit, and by those who intend to become radio operators. In fact it may well be said that the induction coil or the transformer is the vital part of all wireless outfits.

8. In addition to the importance of the induction coil in radio work, it is of very great importance in many other branches of electrical engineering practice involving very high pressures.

9. The line of demarkation between induction coils and transformers is not at all a sharp one as they are at present constructed.

The theory underlying the operation of induction coils is the same as that applying to transformers. Transformers are often classified as open and closed core transformers. The open core transformer is in reality an induction coil. The real difference between a transformer and an induction coil is in operation rather than in construction. Transformers are operated by alternating currents as a rule, while induction coils are more often operated by so-called direct currents (as obtained from primary cells and storage batteries), which are, however, made *intermittent* by some circuit breaking, or interrupting device.

A transformer may be used to step down a pressure as well as to increase it.

10. The chief function of an induction coil is to step up or to increase electric pressures.

One should not at the outset entertain erroneous ideas regarding this important and interesting function of increasing pressures. It is impossible to employ this feature to produce perpetual motion, as too many eagerly imagine. The great and universal law of the conservation of energy cannot be broken in any engineering application of power or work.

11. It is impossible to *create* energy. Now it should be very carefully observed that electrical pressure is only one factor of electrical power; the other factor being electric current. Electric power is considered to be the product of electric current multiplied by electric pressure, and may be expressed in symbols by

$$W=E\times I$$

In other words, power in *watts* is equal to pressure in *volts* times current in *amperes.*

12. A certain amount of electric power is sent into a transformer or into an induction coil, and a certain *less* amount of power is obtainable therefrom. The electric power supplied may be at a definite pressure and current, while the power delivered from the device may be at a higher pressure, it therefore must be at a correspondingly *less* current.

This may be expressed in a slightly different manner as follows. Suppose the power supplied to an induction coil or a transformer, be denoted by $W_p=E_pI_p$, while the power delivered from the same coil is denoted by $W_s=E_sI_s$.

W_p denotes supplied power, in watts.
E_p denotes pressure, in volts, of the supplied power.
I_p denotes the current, in amperes, of the supplied power.
W_s denotes the delivered power, in watts.
E_s denotes the pressure, in volts, of the delivered power.
I_s denotes the current, in amperes, of the delivered power.

13. If there were no losses of any kind in the induction coil the output and the input would of course be equal to each other. Then the following expression would be true: $E_pI_p=E_sI_s$. This is a simple equation stating that the pressure applied to the so-called primary of an induction coil, multiplied by the current in the primary, is equal to the pressure produced in the so-called secondary circuit of the coil, multiplied by the current in the secondary.

It is plainly evident from simple mathematics, that if the input E_pI_p is equal to the output E_sI_s, that if E_s is greater than E_p, then I_s must be *less* than I_p.

14. A numerical example may make the matter more comprehensible. Suppose that the primary pressure is $E_p=6$ volts, and the primary current is $I_p=5$ amperes. Then $W_p=E_pI_p=6\times5=30$ watts. If there were no losses then would $W_s=E_sI_s=30$ watts. Now suppose E_s to be 60 volts, then I_s would be only $\frac{1}{2}$ ampere. $60\times\frac{1}{2}=30$. The pressure having been stepped up 10 times, the current perforce becomes *stepped down* to $\frac{1}{10}$ its original value. As a matter of fact, if the primary pressure were stepped up 10 times, the secondary current would be considerably less than $\frac{1}{10}$ of the primary current, because the efficiency of the induction coil can never be 100%. That is it can never deliver from its secondary anywhere near as much power as is supplied to its primary.

Suppose the efficiency of a coil is 50% for example; meaning the secondary power output is one-half the power input to the primary.

The symbolic expression of this condition is

$$\textit{power efficiency}=\frac{E_sI_s}{E_pI_p}=\tfrac{1}{2}=\mathbf{0.5\ or\ 50\%}.$$

Then the following is true:

$$E_pI_p=2\,E_sI_s.$$

If, according to this equation, the secondary pressure should be $E_s=10\,E_p$, then by substitution,

$$E_pI_p=2\times10\,E_pI_s \text{ from which}$$
$$I_p=20\,I_s \text{ or } I_s=\tfrac{1}{20}\,I_p.$$

15. The greater the power efficiency of a coil the less will be secondary current for any definite secondary pressure.

16. A general description of the ordinary induction coil may now be considered.

The primary coil or winding consists of a number of turns of comparatively large, double covered cotton insulated copper magnet wire, wound around a cylindrical bundle of straight soft iron wires which are commonly insulated from each other by varnish; or simply because they are covered with iron rust; that is iron oxide. Outside or surrounding the primary windings are wound the secondary coils or windings, consisting of a large number of turns of fine copper wire, also double cotton covered, or perhaps covered with varnish or so-called *enamel.*

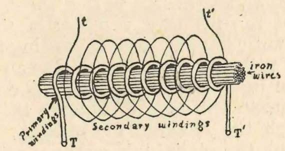


Fig. 1.

Figure 1 will serve to show the general arrangement of the primary, the secondary and the iron core.

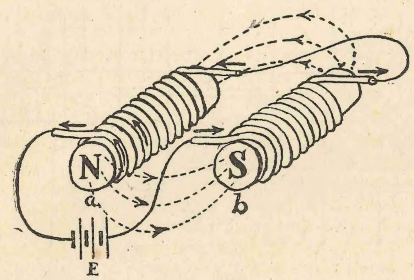


Fig. 2.

17. Whenever a current of electricity passes through a coil surrounding an iron core, magnetic lines of force are set up in the iron core, whose direction is always definitely related to the direction of the current in the wire of the coil. This is shown by figure 2. If the current is passing around the core in a direction opposite the direction of the hands of a watch, that is *counter clockwise,* then the end of the core facing the observer is a N pole, as at (a), and the magnetic lines of force will come out from this end and pass around through the air and enter the opposite or the S end of the iron core.

If the current in the winding has a clockwise direction, then the end of the iron core facing the observer will be an S end, as shown at (b). If the current is counter clockwise as one faces one end of a given coil, the current will be clockwise as one faces the opposite end.

18. It is evident that the iron core, in figure 1, may be magnetized in either one direction or the other by sending the current through the primary, first in one direction and then in the other. This would be the case were the primary connected with a source of alternating-current supply. Such, however, is not the usual form of supply to an induction coil.

19. The current supplied to the primary winding is usually a direct current and increases to a certain value, then decreases to zero, and again increases in the *same direction* as at first, and this cycle is repeated continuously;* so that the *direction* of the magnetization in the iron core does

* See figure 24.

not change, but the intensity of the magnetization, or the number of magnetic lines of force changes, and the change is usually very rapid; the more rapid the change in the magnetism, the better the results.

20. The function of the primary winding of an induction coil is to cause an increase of magnetic lines of force threading through the secondary windings. The electric pressure produced between the terminals of the secondary windings is an *induced* pressure, and like all induced pressures, its magnitude depends upon the rate of change of the magnetic lines of force that thread through the secondary windings. That is the induced pressure depends not upon the *magnitude* of the magnetic flux through the iron core, or to the total *number* of magnetic lines of force threading through the secondary turns, but depends upon the rate at which the number of magnetic lines changes per second; or in other words depends upon the change in the magnetic core flux per second.

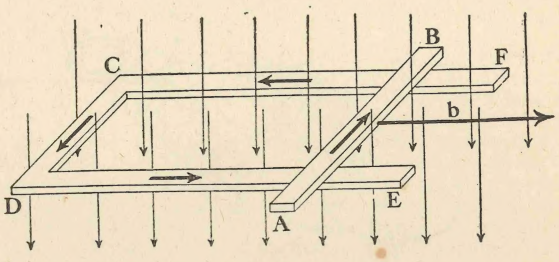


FIG. 3.

21. The more rapidly, therefore, the number of lines of core flux can be increased from zero or from any value to any greater value, or from any higher to a lower value, the greater will be the induced secondary pressure.

LESSON II.

THE RIGHT-HAND RULE.

22. In order to have a clear understanding of the phenomena attending the practical operation of an induction coil, the fundamental law of induction called the right-hand rule should be carefully studied.

Suppose in figure 3, that A B denotes a movable conductor that can be slid along the parallel arms of the U-shaped conductor F C D E, and

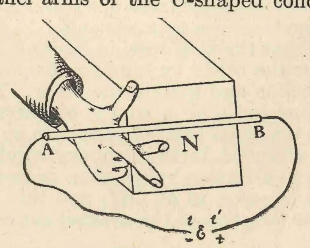


FIG. 4.

suppose the arrangement is in a magnetic field having the direction of its lines downward as indicated. If the slider A B be moved to the right, cutting across the vertical magnetic lines, then an electric pressure is induced in the moving slider having a direction as indicated; or from A to B.

23. The application of the right-hand rule is as follows: If the forefinger, the second finger and the thumb of the right hand are all held perpendicularly to each other as indicated in figure 4, with the forefinger pointing in the direction of the magnetic lines of force and the thumb pointing in the direction of the moving slider, A B, then the second finger will point in the direction of the induced pressure. The moving slider A B is alluded to as an *inductor*. It should be noted that if the circuit A B C D, figure 3, is a complete or a closed circuit that the pressure in-

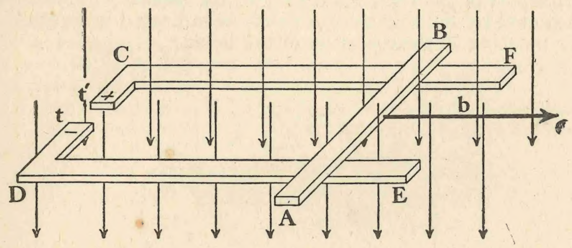


FIG. 5.

duced by the moving inductor A B will cause a current to flow around the circuit as indicated by the small arrows; that is, the induced current will be in a counter clockwise direction. It should further be observed that as the inductor A B is constantly moved to the right, the number of magnetic lines included by or passing down through the circuit A B C D is constantly *increasing*. The included area is constantly increasing, and since the field is constant in value per unit area, the total included flux must be increased.

24. It might now be supposed that the arm D C of the circuit is cut through as indicated at **t t′** in figure 5. If the inductor be now moved to the right an induced pressure will result, but no current can now pass in the circuit A B C D since it is an open circuit. A difference of pressure will, however, exist between the terminals **t** and **t′**, and **t′** will be the positive or + terminal, while **t** will be the negative or − terminal. If

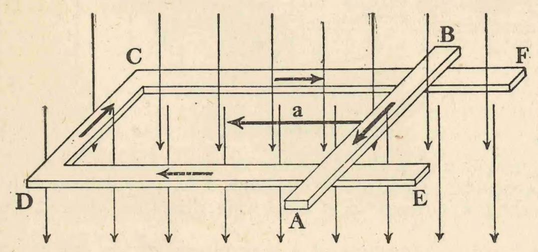


FIG. 6.

while the inductor A B is moving, the terminals **t** and **t′** be connected by a wire, then a current will pass around the circuit as indicated in figure 3. The *amount* of current will depend upon the pressure induced, and inversely upon the resistance of the complete circuit.

25. It may now be noted that should the inductor A B be moved toward the left, the direction of the induced pressure will be exactly opposite that indicated in figures 3 and 5; or the induced current will have a clockwise direction as indicated in figure 6. The number of lines of force included by the circuit A B C D is in this case constantly *decreasing*.

THE LEFT-HAND RULE.

26. The right-hand rule just explained applies to an electric *generator*. The counterpart of the right-hand rule would naturally be a left-hand rule, and is depicted by holding the *left hand*, as indicated in figure 7, with the forefinger pointing in the direction of the field.

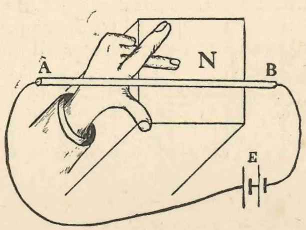


FIG. 7.

The application of the rule is as follows: If a conductor is placed in a magnetic field and a current is allowed to pass in the conductor, the conductor *tends* to move in a direction perpendicular to the lines of force; as indicated by the thumb in figure 7 and by the long arrow in figure 8.

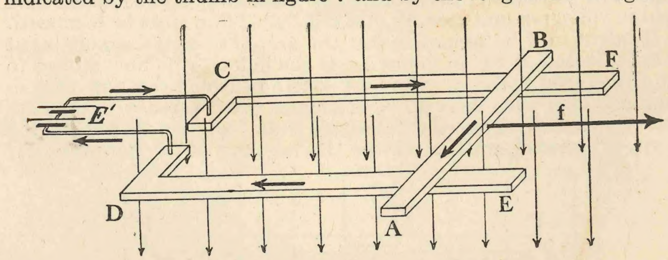


FIG. 8.

As in figures 3 and 5 the direction of the magnetic lines of force in figure 8 is downward. In figure 8, however, a battery of two cells in series is shown sending a current in a clockwise direction around the circuit A B C D.

27. The direction of motion of A B produced by the current, as shown

in figure 8, is the same as the direction of the motion given to inductor A B in figure 3, by some external mechanical force.

The direction of the current produced by the battery in figure 8 is exactly *opposite* to the direction of the induced current shown by figure 3. In figure 3, A B represents the armature of a *generator*, while in figure 8, A B represents the armature of a *motor*.

28. A very important aspect of the generator effect is that when the number of magnetic lines of force is increasing in a circuit, as shown by figure 3, the resulting induced current has a counter-clockwise direction, while if the magnetic lines are decreasing in the same circuit the induced current is clockwise; as indicated by figure 6. The *direction* of the field is not changed, however, in the two cases cited. A motion of A B to the right, in figure 3, introduces an increased number of lines of force into the circuit A B C D per second, and the more rapidly A B moves, the greater the number of lines introduced into the circuit per second.

29. A motion of A B to the left, as in figure 6, produces the same effect as *removing* lines of force from the circuit A B C D.

30. A rapid motion of A B back and forth from one side to the other, that is from left to right and from right to left, will produce an alternating current in the circuit A B C D.

31. The foregoing considerations have a very important bearing on the theory of the induction coil and the alternating-current transformer.

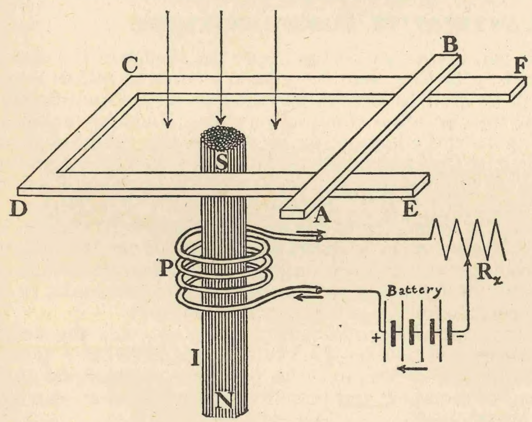


FIG. 9.

32. In order to appreciate the application of some of the preceding features, suppose an iron core as N S, in figure 9, is surrounded as shown, by a number of turns of rather large insulated magnet wire, as at P, which being connected with a battery of cells, through a variable resistance as shown at R_x, causes the magnetization of the iron core to be of south polarity at the top end and of north polarity at the lower end. The magnetic lines therefore have a direction into the top end of the core, and out of the lower end.

33. If a secondary circuit, as shown by A B C D is placed as indicated in the figure, the magnetic lines of force produced by the primary current pass downward through the secondary circuit.

34. If every portion of the secondary circuit remains fixed relative to the primary circuit, and the current in the primary is not allowed to vary, then there will be no *rate of change* in the number of magnetic lines threading downward through the secondary circuit, and therefore no induced pressure and no resulting current in the secondary circuit.

35. Suppose now the current in the primary is *increased* by *reducing* the resistance of the primary circuit; that is by moving contact at R_x, figure 9, to the *left*. The increasing primary current causes an increased number of magnetic lines in the iron core. This of course means that the rate of change of the number of lines threading downward through the secondary A B C D has been *increased* and that a current will be induced in the secondary, in a *counter-clockwise* direction according to figure 3.

36. It should be observed that the direction of the induced secondary pressure and current is opposite to that of the primary current.

37. If the primary current be now *decreased* by moving the contact on R_x to the right, to *increase* the resistance R_x, then the magnetic flux is *decreased* in both primary and secondary, and the direction of the current induced in the secondary will be clockwise, as in figure 6.

It is evident, therefore, that an increase, and a decrease of the primary current of an induction coil, will produce an alternating current in the secondary.

LESSON III.

SOME QUANTITATIVE CONSIDERATIONS.

38. The considerations pertaining to the theory of the operation of an induction coil up to this point have been *qualitative* rather than quantitative. It will be well to now mention some of the quantitative features pertaining to the operation of induction coils. The most valuable information applying to the construction of coils is the result of measurements from experiments that have been performed by careful experimenters; that is the quantitative gives information as to how much a coil will do when in actual operation; either as to its pressure output or its current output, or perhaps as to the frequency of the secondary pressure and current.

The qualitative considerations should enable one to understand how to make a coil operate, while knowledge of the quantitative should enable one to properly design a coil to meet specific requirements, or to adjust a coil already constructed to give a maximum output.

39. In considering the quantitative relations, only the simpler mathematical processes will be adopted. One should have some working knowledge of equations, however, in order to better comprehend the necessary transpositions of members and terms. A definition of an equation may be helpful in this connection.

40. An equation is an expression of equality between two quantities.

An example will be given very soon, in connection with the development of the quantitative theory.

41. The right-hand rule applying to a moving inductor is purely *qualitative*. The counterpart of this rule, expressing the quantitative, should tell how much electrical pressure, or electromotive force (usually written *e. m. f.* and expressed by $\mathcal{E}$), is produced by a given motion of the inductor. The amount of electric pressure induced in a conducting wire having a length of l centimeters when moved at a speed of v centimeters per second through a magnetic field having $\mathcal{H}$ lines of force per square centimeter may be expressed by the *equation*:

$$\mathcal{E} = \frac{l \times H \times v}{10^8} \text{ (in volts).}$$

EXAMPLE 1: What pressure, in volts, will be produced between the ends of a wire 30.48 centimeters long, if moved at a velocity of 2682.24 centimeters per second, through a magnetic field having a strength of 275 lines per square centimeter?

Data.

Making the proper numerical substitutions in the above stated equation, gives

l = 30.48 cms.
$\mathcal{H}$ = 275 lines.
v = 2682.24 cms. per second.

$$\mathcal{E} = \frac{30.48 \times 275 \times 2682.24}{10^8}$$

$$= \frac{22488556.16}{100{,}000{,}000} = \mathbf{0.224\ volt.} \quad \text{Answer.}$$

42. The reason 10^8 (which is 100,000,000 or one hundred million) is used, is because of the choice of electrical units. The fundamental unit of induced pressure has by agreement been made the pressure induced between the ends of a conductor one centimeter long, when the conductor is moved at a velocity of one centimeter per second, through a uniform magnetic field having a strength of one line of force per square centimeter. This fundamental unit pressure is called the *abvolt*. It requires 100,000,000

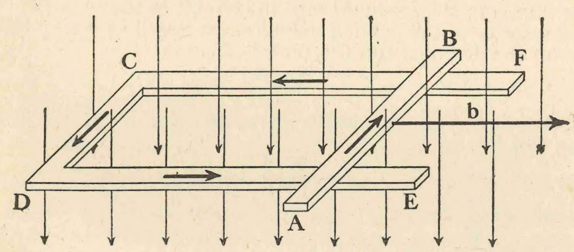


FIG. 10.

abvolts to equal the practical unit of pressure, called a *volt*. The abvolt is a very small unit; too small for practical applications.

43. A careful consideration of the example cited will show that the moving conductor or *inductor* is just one foot in length. One inch being equal to 2.54 centimeters, and 12 inches being 12×2.54 = 30.48 centimeters.

44. The velocity of 2682.24 centimeters per second corresponds to a velocity of 88 feet per second; or one mile per minute.

There being 5280 feet in a mile, a velocity of one mile per minute will equal $\frac{5280}{60}$ or 88 feet per *second*, and 88×30.48 = 2682.24 centimeters per second.

45. The result of 0.224 volt can perhaps be better understood by consulting figure 10.

Suppose the length of A B between the arms F C and E D, is one foot; or 30.48 centimeters, that there are 275 magnetic lines of force passing downward through each square centimeter of the area included by F C D E, and that the slider A B is moved to the right at the rate of 88 feet or 2682.24 centimeters per second. Then the induced pressure between the ends A and B will be 0.224 volt. If the *active* length of the inductor A B is one foot or 30.48 centimeters, the distance between the parallel arms F C and E D is also 30.48 centimeters. At a velocity of 2682.24 centimeters per second, the actual *area* swept over by the moving inductor during one second must be 30.48×2682.24 or 81754.6752 *square centimeters,* and there must be a uniform magnetic field over this complete area.

It may be said then that during each second that the inductor moves, 81754.6752 times 275 or 22488556.16 magnetic lines of force are introduced into the area included by the closed circuit A B C D.

During two seconds of motion of the inductor, 2×22488556.16 or 44977112.32 lines will be introduced into the circuit.

46. If the total number of lines *that are introduced into the circuit* be denoted by Φ (the Greek letter phi) and the total time, *in seconds,* that the inductor moves be denoted by t, then the induced pressure may be denoted by:

$$e=\frac{\Phi}{t}\text{ abvolts.}$$

or

$$\mathcal{E}=\frac{\Phi}{10^8 t}\text{ volts.}$$

47. This is a more convenient equation for use in coil computations than is the preceding equation. It should be noted that l times the distance moved through by the inductor in the time t, multiplied by $\mathcal{H}$ will give the total flux Φ introduced into the circuit in the time t.

The velocity of the moving inductor, expressed by v may be expressed in terms of the distance and the time as follows:

$$v=\frac{d}{t}.$$

Substituting this equivalent expression for v in the fundamental equation will give:

$$\mathcal{E}=\frac{l\,\mathcal{H}\,d}{10^8 t}\text{ volts.}$$

But since $l\,\mathcal{H}\,d=\Phi$

Then $\mathcal{E}=\frac{\Phi}{10^8\,t}$ volts, as before.

48. Φ denotes the number of lines that are *introduced* into the circuit, and t denotes the time in seconds or fraction thereof, *during which* the introduction of lines takes place.

49. An example will be given to show how the last equation may be employed in calculating an induced pressure.

EXAMPLE 2: If 67465668.8 magnetic lines of force are introduced into a circuit in 30 seconds what pressure, in volts, will be induced in the circuit?

Data.

Φ=67465668.8.

t=30 seconds.

$$\mathcal{E}=\frac{\Phi}{t\times10^8}=\frac{67465668.8}{30\times100{,}000{,}000}$$

=**0.224 volt.** Answer.

50. Another example involving a shorter time may be instructive.

EXAMPLE 3: If ten million magnetic lines of force are introduced into a circuit in $\frac{1}{100}$ of a second find the pressure, in volts, induced in the circuit.

Data.

Φ=10,000,000 lines.

$t=\frac{1}{100}$ of a second.

$$\mathcal{E}=\frac{10{,}000{,}000}{\frac{1}{100}\times10{,}000{,}000}=\frac{10{,}000{,}000}{\frac{10{,}000{,}000}{100}}=\frac{100\times10{,}000{,}000}{10{,}000{,}000}$$

=**100 volts.** Answer.

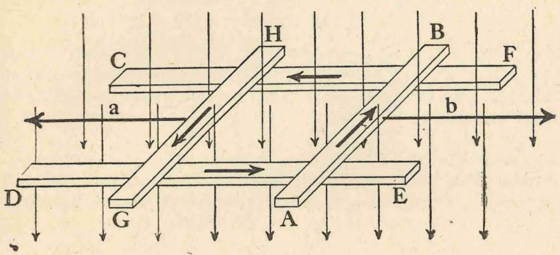


FIG. 11.

51. It is evident from these calculations that a strong magnetic field must be cut across or through, by a somewhat long wire, when moved at a considerable velocity, in order to produce a pressure of say 5000 volts.

52. From a careful study of the last equation for induced pressure, $\mathcal{E}=\frac{\Phi}{t}$, it may be seen that the *smaller* the value of t for any given value of Φ, the *greater* will be the induced pressure. If, in example 3, the ten million lines could have been introduced into the circuit in $\frac{1}{1000}$ of a second instead of in only $\frac{1}{100}$ of a second, then the resulting induced pressure would have been ten times as great, or 1000 volts. The quicker the change in the magnetic flux threading a circuit the greater will be the induced pressure. *It is therefore advisable to resort to methods that shall effect very rapid changes.*

53. Figure 11 illustrates a method for increasing the induced pressure twofold, by arranging an inductor G H so it may be moved to the *left* at the same speed and at the same time that A B is moved to the *right.* Applying the right-hand rule will show that the two induced pressures act together to send a counter clockwise current around the circuit. Magnetic lines of force are thus introduced into the circuit just twice as rapidly as when only one inductor is moved, and without increasing the velocity of each individual inductor.

54. As has been mentioned, the same numerical value of induced pressure may be effected by *removing* the same amount of magnetic flux from a circuit in the same time, as by introducing the flux, and as a matter of fact the removal of flux from a circuit may be effected in very much less time than the introduction of the same flux can be effected. This fact has a very important bearing on the operation of induction coils.

LESSON IV.

MAGNETIC CIRCUITS.

55. As the action of the induction coil depends upon the production and the dying away of magnetic lines of force that pass through certain definite directions in so-called *magnetic circuits,* it will be well to briefly consider some characteristics of magnetic circuits.

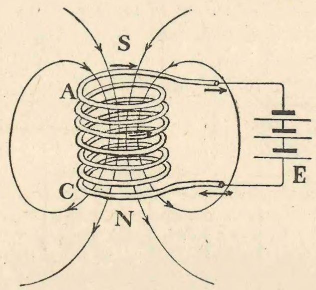


FIG. 12.

SOLENOIDS.

56. If a direct current from a battery as E in figure 12, is allowed to circulate around a conductor coiled in the form of a helix as indicated by A C, a magnetic field is set up having the direction of lines as indicated by the curved lines in the figure. The magnetic lines are set up throughout the space within the coil, and in the space surrounding the outside of the coil. Such a coil as indicated in the figure is called a *solenoid.*

57. When an iron core is inserted within the coil the arrangement is then called an electromagnet.

58. A solenoid having a current circulating in it has all the magnetic characteristics of a permanent magnet. Its ends exhibit polarity; a N pole being at one end and a S pole at the opposite end. Each magnetic line of force is complete in itself; that is if it starts inside the solenoid it may be traced around the outside of the solenoid and back into the inside. Each line in other words forms a complete circuit with regard to its self. So far as the magnetic field itself is concerned, the magnetic circuit is in this case an *air* magnetic circuit. That is the lines of force are set up in air.

59. If an iron core is inserted within the solenoid, the magnetic circuit will consist partly of air and partly of iron, and is called an *open* magnetic circuit. This is to distinguish it from a closed magnetic circuit shown by C M in figure 13. In this figure C M denotes a number of flat iron rings or washers arranged one above another to form a laminated core for the magnetizing coil A B through which a current may be sent from the

battery E. In such a magnetic circuit the magnetic lines are set up very easily; that is it requires much less magnetizing force or ampere-turns to set up a given number of lines of force than if the magnetic circuit were wholly of air. Another characteristic of such a closed magnetic circuit is

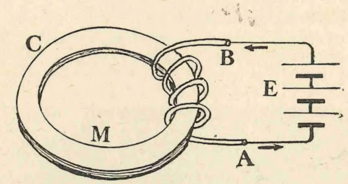


FIG. 13

that there are very few leakage lines of force; that is all of the lines set up by the ampere-turns, circle about within the iron core itself, and very few are manifest in the surrounding air. This fact renders this form of core the very best for transformers, employing alternating currents for their operation.

60. However, this form is very undesirable for induction coils because of the fact that magnetic lines once set up in it do not readily die away after the current ceases to flow in the magnetizing coil. Magnetic lines of

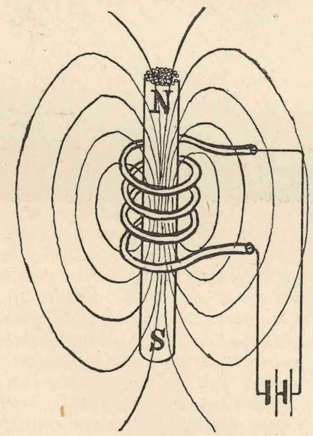


FIG. 14.

force doubtless die away in air quicker than in any other medium, but they die away very much quicker in an open magnetic circuit consisting of both iron and air than in any form of closed magnetic circuit. It seems therefore that the straight iron core forms a happy medium between a high magnetic flux density and a rapid rate of change in the flux density.

CONSIDERATION OF THE PRIMARY.

61. As has been mentioned the function of the primary winding is to conduct the primary current around an iron core in order to produce a magnetic flux or lines of force.

62. It is essential to know about the *shape* of the magnetic field, or about the directions of the lines of force constituting the field, since this matter has a marked effect upon the action of the secondary.

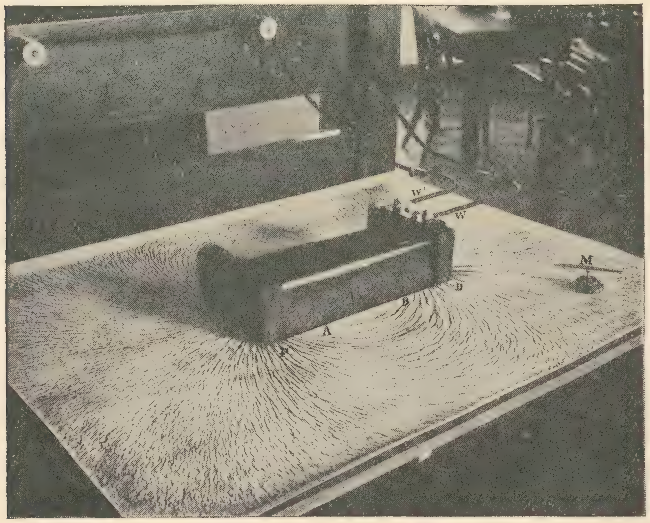


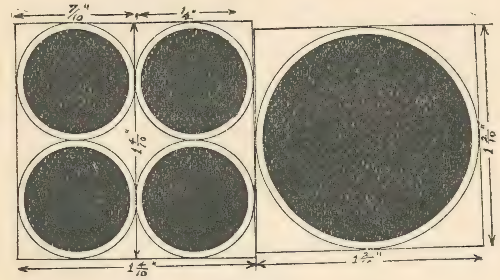
FIG. 15.

The shape of the magnetic field produced by a primary is shown by figure 14, which is somewhat conventional. Figure 15 is a half tone reproduction of a photograph of an actual field produced by the coil shown. The magnetic lines are depicted by iron filings sprinkled on a cardboard sheet. The magnetic needle shown at M indicates the direction of the field at the place it is situated; its N end pointing toward the S end of the field of the coil. It is instructive to note that in both figures 12 and 14, *all* of the magnetic lines pass through the very center of the coils; that is through the center of the iron core, and at no other point is this true. For example, not all the lines passing through the center of the iron core N S in figure 14, pass out through the N end, or enter the S end. The iron core, however, serves to cause more lines to pass through the coils than would be the case if the core were omitted. In other words soft iron is a much better conductor for magnetic lines of force than is air, or any other of the metals.

63. The number of magnetic lines passing through the iron core depends upon the strength of the current in the primary windings and also

upon the number of times the current passes around or encircles the iron core. The practical unit of electric current is the so-called *ampere,* and the magnetizing power of the primary depends on how many times a certain number of amperes encircle the core. The magnetizing power of the primary coil depends upon the number of *ampere-turns*; that is upon the number of turns in the windings of the coil and the number of amperes of current passing through the windings.

64. The magnetizing force of a given coil may be 1000 ampere-turns. The coil may have 100 turns in its windings and 10 amperes may be passing through it. $10 \times 100 = 1000$. Another coil may consist of only 10 turns, but 100 amperes may be passing through it; in this case $100 \times 10 = 1000$; or the magnetizing effect of this coil may be exactly the same as that of the other. Still another coil may have 1000 turns and only one ampere. In this also $1 \times 1000 = 1000$ ampere-turns.



a FIG. 16. b

65. Coils consisting of a large number of turns and carrying a small current are wound with smaller wire than coils having the same magnetizing force but wound with few turns and carrying a large current. The winding space required might be somewhat greater for the smaller wire because the insulation will require relatively greater space. This may be shown by figure 16, in which **a** represents the cross sections of four round wires covered with an insulation of $\frac{1}{10}$ inch. A square that will just include these four insulated wires placed side by side will be $1\frac{4}{10}$ inches on each side. At **b** is shown the cross-section of a single wire 1 inch in diameter, which has exactly the same area as the combined areas of the four small circles shown at **a**. The thickness of insulation on the large wire being the same as on the small wire, $\frac{1}{10}$ inch, the square that will just include the larger insulated wire will be only $1\frac{2}{10}$ inch on each side as shown. It is evident from a careful study of figure 16, that as the cross-section of the wires become smaller and smaller, but having the same thickness of insulation, that the insulation becomes of greater and greater significance. If the wire is extremely small, the insulation may occupy a greater space than the wire itself. This consideration relates as well to the secondary windings as to the primary. The thickness of insulation is necessary because of the electrical pressure that exists between contiguous turns or layers of winding, either primary or secondary. A table showing the relation of the diameter of bare and covered wires is given on the next page.

DATA APPLYING TO COPPER MAGNET WIRE.

A	B	C	D	E	F	G	H	I	J
No. B. & S. Ga'ge	Diameter of Bare Wire in Inches	Diameter in Mils	Area in Circular Mils	Area in Square Inches	Diameter of D. C. C. Wire over all in in.	Weight per 1000 feet of D. C. C. Wire	Feet per Pound of D. C. C. Wire	Ohms per Foot at 68 degrees F.	Ohms per Foot at 122 degrees F.
6	.1620	162	26,244	.020612	.176	80.1	12.4	.0003944	.0004406
8	.1285	128.5	16,512	.012969	.142	50.4	19.6	.0006271	.0007007
9	.1144	114.4	13,087	.010279	.125	40.4	24.7	.0007908	.0008835
10	.1019	101.9	10,384	.0081553	.113	31.9	31.1	.0009972	.001114
12	.0808	80.8	6,528	.0051276	.092	20.1	49.2	.001586	.001771
14	.06408	64.08	4,106	.0032271	.075	12.7	77.5	.002521	.002817
16	.05082	50.82	2,583	.0020268	.060	7.99	122	.004009	.004964
18	.0403	40.3	1,624	.0012756	.050	5.05	192	.006374	.007122
20	.03196	31.96	1,022	.00080425	.041	3.22	300	.01014	.01132
22	.02535	25.35	642.4	.00050273	.0343	2.03	473	.01612	.01801
24	.02010	20.1	404.0	.00031731	.0291	1.30	729	.02563	.02863
26	.01594	15.94	254.1	.00019856	.0249	.822	1,114	.04075	.04552
28	.01264	12.64	159.8	.00012469	.0216	.526	1,700	.06479	.07239
30	.01003	10.03	100.5	.000078540	.0190	.337	2,611	.1030	.1151
32	.00795	7.95	63.2	.000049639	.0169	.222	3,788	.1618	.1830
34	.0063	6.3	39.69	.000031173	.0153	.148	5,376	.2605	.2910
36	.0050	5.0	25.00	.000019635	.0135	.101	7,937	.4142	.4627
38	.00396	3.96	15.72	.000012316	.0119	.066	11,310	.6585	.7357
40	.00314	3.14	9.88	.0000077437	.0111	.048	15,037	1.047	1.296

66. Another important consideration in the winding of the primary is illustrated by figure 17. This shows an iron core N S wound with insulated wire nearly over its entire length. When the windings cover the entire core, more of the magnetic lines are forced to traverse the complete length of the core before starting to bend around through the air from one end of the core to the other. This is shown comparatively in figures 12 and 17. It should not be imagined that *all* of the magnetic lines can be forced through the ends of the core; a few will leak out between the various turns of wire with any form of winding.

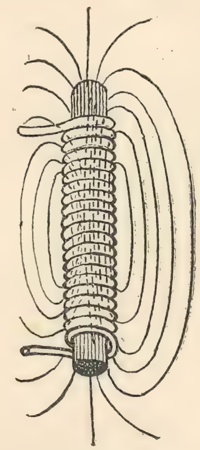


Fig. 17.

LESSON V.

CONSIDERATIONS OF THE SECONDARY.

67. Suppose a secondary, in the shape of an open ring A B C, figure 18, is placed near the N end of the iron core. Not so many lines will pass through it as when it is located at the center as indicated by A′ B′ C′. If the ring at A B C should be made larger it will of course surround or include through it more lines of force. The same would not be true regarding the ring at A′ B′ C′.

68. The induced secondary pressure between the terminals A and B will depend upon the *rate of change* in the magnetic flux threading through it, and the *direction* of the induced pressure will depend upon whether the lines of force are introduced into or removed from the ring. If the flux through the ring is increasing then the terminal B is + and A is −; while with decreasing flux A is + and B is −.

69. By having two turns of secondary as indicated in figure 19, the induced secondary pressure between A and B would be twice as great as with a single turn. It is apparent from this consideration that the greater the number of secondary turns the greater will be the *terminal* pressure of the secondary with any definite rate of change of magnetic flux.

70. The important conditions to be met, in order to obtain a considerable secondary pressure, are to so arrange the secondary windings as to include through them the greatest number of magnetic lines possible;

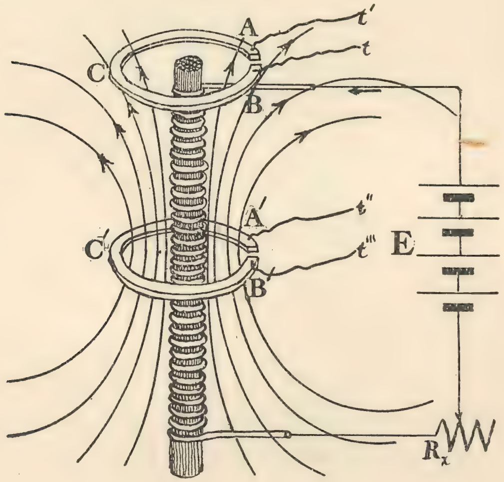


FIG. 18.

to have the change in the number of the included lines take place as rapidly as possible, and to have a great many turns in the secondary windings.

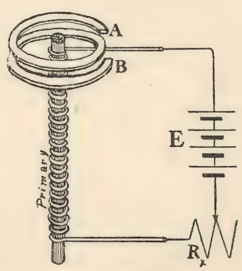


FIG. 19.

Another way of considering the matter is that the *per turn* pressure of primary and secondary are the same.

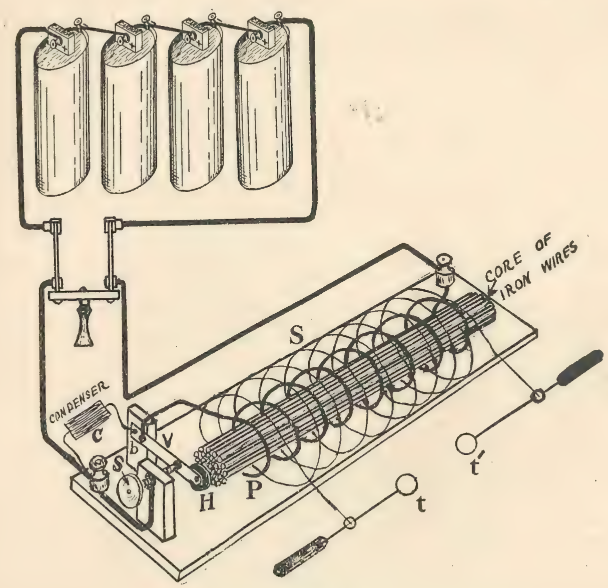


FIG. 20.

COILS OPERATED BY MECHANICAL INTERRUPTERS.

71. A diagram representing the arrangement of a coil operated by means of a spring make and break, is shown in figure 20. Here the iron core, made up of iron wires, is shown wound about by the primary turns of coarse wire, outside of which is wound a large number of turns of fine wire. The operating battery, consisting of four cells, is at E; a steel spring V, rigidly fastened at **b,** having a small piece of soft iron riveted to its free end at H, is allowed to rest against the end of an adjustable screw shown at S. The action of the system is as follows: when the spring V is in contact with the screw S, a current from the battery passes through the primary windings setting up a magnetic field in the iron core; that is makes a magnet of the core. When the core becomes magnetized the soft iron end of spring V is attracted towards the end of the core. When this occurs the contact is broken between the spring and the screw, which of course opens the battery circuit, and thus stops the flow of the current in the primary. At the cessation of the primary current the iron core loses a large proportion of its magnetism and the attraction between the soft iron end of the spring and the core becomes so reduced that the tension of the spring causes it to resume its original position, in contact with the adjusting screw. When contact is made the cycle is repeated. The cycles of operation are repeated quite rapidly in ordinary practice, depending largely upon the nature and size of the spring. The more rapidly the spring can be made to vibrate the greater will be the rate of change of the core flux and therefore the greater the induced secondary pressure, within certain limits that will be discussed more fully later on. The period of vibration of the spring can be varied considerably by adjusting the screws S.

72. If the resistance of the primary circuit, including the internal resistance of the battery is low, a considerable current will flow in the primary circuit due to the pressure of the battery, and a considerable spark or series of sparks will occur at the break between the spring and the contact screw S. By connecting a condenser as shown at C, in parallel with the spark gap, the volume of the sparks and therefore their heating effect is very greatly reduced. Without the condenser in circuit, the heat of the sparks may be sufficient to fuse the contacts together. The contact points are usually made of platinum, and sometimes of an alloy of platinum and iridium, which will resist the melting or fusing action even at high temperatures.

73. The question of condensers is taken up more at length later on so it may suffice to state at this time that the connection of a properly designed condenser across the spark gap will practically double the output of a coil, and in addition will greatly affect the nature of the output, making the secondary discharge essentially undirectional.

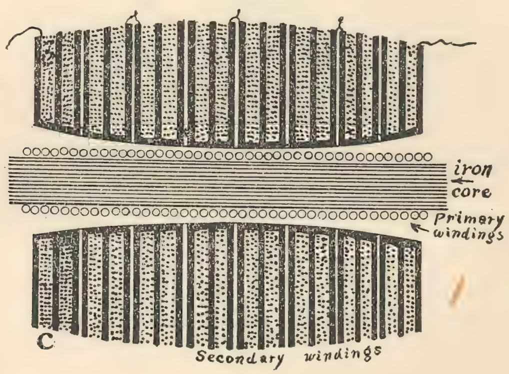


FIG. 21.

LESSON VI.

A FEW CONSTRUCTIONAL FEATURES.

74. In addition to the features already considered there are others of considerable importance if efficiency of operation is to be considered. One of course is to have the size of the secondary wire proper for the secondary current. Another is to have the secondary coils of varying diameter in order that each may include the same amount of magnetic flux as explained in connection with figure 18. Figure 21 shows a cross-section through an induction coil showing the different coil diameters.

In any coil there is always a certain difference in pressure between each of the adjacent turns in a given layer, so that the pressure is considerable between a given turn and say the hundredth turn from it. That means that the pressure is considerable between the turns of one layer and the adjacent turns of the next layer.

75. It is therefore not advisable to wind the secondary in *layers*, since with this form of winding nearly the whole secondary pressure would exist between the end turns of the layers. To avoid the possibility of breaking down the insulation of the end turns, the secondary is wound in sections as shown in figure 21. This method of winding is very desirable in that it makes repairs very much easier, as the defective coil section may be removed and another easily slipped on over the primary to replace it in a short time. One section may be removed and the remaining ones employed to give a proportionately less secondary pressure.

76. One very important feature in the construction of induction coils cannot be too greatly emphasized, and that is the insulation *between* the primary and the secondary windings.

77. The secondary should be well insulated from the primary by a comparatively thick tube of insulating material which should extend well beyond the end sections of the secondary. The amateur does not at times bear in mind that the full secondary pressure exists between the inner portion of the secondary as well as between the outer portion.

78. If the space between the primary coil and the secondary winding is small and there is not sufficient insulating material therein, the secondary may discharge from both ends of the secondary onto the ends of the primary and thus complete a discharge path of very low resistence through the primary winding. When this phenomenon occurs the coil is said to have broken down. While for economy of secondary wire and increased inductive effects it is necessary to have as small space as possible between primary and secondary, to avoid breakdown, considerable clearance and the best kind of insulation is imperative. Of course the better the grade of separating insulation employed, the nearer the two coils may approach each other.

79. Linseed oil that has been thoroughly boiled in order to drive out all moisture may be used as an insulating medium for coils. This implies a tight box, having all joints carefully glued. A faucet may be inserted close to the bottom of the box by means of which the oil may be withdrawn, if the coil is a large one.

80. So-called transformer oil may also be employed as a liquid insulator. The advantages of a liquid insulator is that of mending itself should a breakdown occur, and the readiness with which it conducts the heat away from the copper windings and the core.

LESSON VII.

MATHEMATICAL THEORY OF OPERATION OF INDUCTION COILS.

81. The following discussion, while involving some considerable mathematical theory, really forms the basis for the operation of induction coils under any system employing a direct-current source of supply, and the *results* of the mathematical process may be usefully applied by anyone either in the design or in the operation of all classes of coils, even though the various mathematical processes may not be fully comprehended because of necessary brevity in the matter of deriving equations. The derivation of the fundamental equations is better reserved for special study, while familiarity with the practical application of these fundamental equations is acquired.

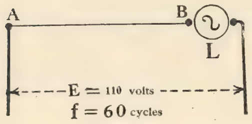


FIG. 22.

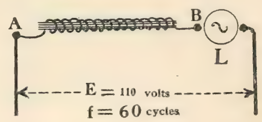


FIG. 23.

82. To illustrate a very important phenomenon resulting from coiling a length of insulated wire around an iron core, a very simple experiment might be performed by anyone. Suppose a straight piece of No. 18 insulated copper wire A B about five feet long is connected with an ordinary 110-volt 25-watt incandescent lamp L, as indicated in figure 22, and the arrangement connected with a 110-volt alternating-current circuit with a frequency of 60 cycles per second; that is with an ordinary house circuit. The lamp lights up and the filament gives off the customary amount of light, when the connection is made. Now suppose the five-foot length of insulated copper magnet wire is wound closely around a soft iron rod about a half inch in diameter, and then connected with the same lamp on the same circuit as when the wire was straight, as shown by figure 23.

The lamp will now burn dimly, showing a considerable decrease in current through it. The length and the cross-section of the wire A B has not been changed, and therefore its resistance to the flow of current has not been altered. If the ohmic resistance of the circuit has not been changed, then the pressure must have been modified in some way. As a matter of fact a counter electromotive force has been introduced into the circuit by the action of the coiled wire over the iron core, due to the changing flux produced by rapidly changing alternating current. With a direct current there would be no diminution in the current if the wire were coiled.

As is well known, if the arrangement be connected across a direct-current source, the current will follow Ohm's law; expressed by $I=\frac{E}{R}$; where I denotes the current in the circuit in amperes, E the applied pressure, in volts, and R the combined resistance of the lamp and wire of the coil.

83. To still further illustrate the matter, data will be submitted from an actual experiment. A coil $8\frac{1}{2}$ inches long and having a 2-inch diameter central hole, made of about 1500 turns of No. 16 Brown and Sharp gauge, double cotton covered, copper magnetic wire and having a resistance of 3.4 ohms, had a direct-current pressure of 80 volts applied to its terminals with a resulting direct current of 23.5 amperes.

84. When an alternating pressure of 80 volts at 63 cycles per second was applied to the terminals of the same coil a current of only 0.38 amperes resulted. The resistance R of the coil did not change. The currents in the two cases may be expressed as follows:

$$I_{D.C.}=\frac{E_{D.C.}}{R}\quad\text{(direct-current).}$$

$$I_{A.C.}=\frac{E_{A.C.}-\mathcal{E}}{R}\quad\text{(alternating-current).}$$

$\mathcal{E}$ denotes the counter electromotive force produced by the alternating magnetic flux produced by the alternating current. It may be noted particularly that there was no iron core in the coil during this experiment. Also with a direct-current supply the current will be exactly the same whether the wire is straight or coiled, if the applied direct-current pressure is the same.

85. It is interesting to calculate the numerical value of the counter electromotive $\mathcal{E}$ that existed in the coil during the experiment outlined. The alternating-current equation may be solved for $\mathcal{E}$ as follows:

$$R\,I_{A.C.}=E_{A.C.}-\mathcal{E}\ \text{ from which }\ \mathcal{E}=E_{A.C.}-R\,I_{A.C.}.$$

86. The numerical value of the counter electromotive force in the coil during the experiment outlined was

$$\mathcal{E}=80-3.4\times(0.38)^2=80-1.29=78.99\ \text{volts.}$$

87. This counter electromotive force is called the counter electromotive force of self-induction, and its magnitude always depends upon the rate of change of the magnetic field that passes through the primary coil.

88. As the rate of change in the magnetic field depends upon the rate of change in the current that produces it, and as the induced pressure depends upon the rate of change in the magnetic field, the induced pressure really may be considered to depend upon the rate of change in the current. Since the unit of pressure is not the same as the unit of current, it is obvious that it would be inconsistent to say the induced pressure is *equal* to the rate of change in the current; but the statement that the induced pressure is *proportional* to the rate of change in the current is correct. One might say that the induced pressure in volts is a certain number of times the rate of change in current, in amperes per second. In symbols the relation may be expressed as follows: $\mathcal{E}=L\frac{I}{t}$; that is, the induced counter pressure $\mathcal{E}$ of the primary (in volts), is equal to a constant L times the change in the primary current, in amperes per second. The constant quantity, or the so-called *coefficient* L is called the coefficient of self-induction, and the unit of inductance is called the "*henry*." The unit of inductance one henry means that when a coil or a circuit has an inductance of one henry, if the current in that coil or circuit changes in value at the rate of one ampere per second then the induced pressure will be one volt. If the inductance of a coil happened to be $\frac{1}{2}$ a henry, and the current change were one ampere per second, the induced pressure would be $\frac{1}{2}$ volt.

89. Under ordinary conditions the current can be made to change much more rapidly than one ampere per second. The rate of change may be as great as 100,000 amperes per second. The current is constantly changing in value in the coil when an alternating pressure is applied to the coil terminals. With a steady direct pressure applied, the current and resulting magnetic field are constant; therefore there can be no rate of change in current and field, and no *induced* pressure. An example may serve to show the application of the pressure equation and also the bearing of the coefficient of self-induction.

EXAMPLE 4: Suppose the current changes at the rate of 1000 amperes per second in a coil having a coefficient of self-induction of 2 henrys, find the induced pressure of self-induction.

Data.

$L = 2$ henrys.

$\frac{I}{t} = 1000$ amperes per second.

$$\mathcal{E} = L\frac{I}{t}$$
$$= 2 \times 1000$$
$$= \mathbf{2000\ volts.}\ \text{Answer.}$$

It is a very simple matter to determine the value of the coefficient of inductance L of any coil by experiment.

Another example will serve to emphasize the question of the "rate of change."

EXAMPLE 5: If the current changes from 10 amperes to 0 in the $\frac{1}{1000}$ part of a second, in a coil having a coefficient of inductance of $\frac{1}{10}$ of a henry, find the induced counter electromotive force of self-induction.

Data.

$L = \frac{1}{10}$ henry.

$t = \frac{1}{1000}$ second.

$I = 10$ amperes.

$$\mathcal{E} = L\frac{I}{t}$$
$$= \frac{1}{10} \times \frac{10}{\frac{1}{1000}}$$
$$= \frac{1}{10} \times 10000.$$
$$= \mathbf{1000\ volts.}\ \text{Answer.}$$

PROBLEM 5: *If the current changes from* 0 *to* 0.99 *ampere in* $\frac{1}{10}$ *of a second in a circuit having a coefficient of inductance* $L = 0.2$ *henry, find the induced counter e. m. f. of self-induction.*

Answer. **1.98 volts.**

Problem 5a: If the current changes from 0 to 0.44 amperes in $\frac{1}{10}$ of a second in a circuit having a coefficient of inductance $L = 1.7$ henry, find the induced counter *e. m. f.* of self-induction.

LESSON VIII.

90. The induced electromotive force due to self-inductance, in the primary coil of an induction coil, being directly opposed to the pressure that is applied to the primary is often called the *counter* electromotive force of self-induction, and always has the same direction as that of the secondary induced pressure. Another way of considering the matter would be to think of the counter electromotive force of inductance *per turn* of the primary coil. Dividing the value of the primary counter electromotive force by the number of primary turns, will give the induced pressure *per turn*. Each single turn of the secondary windings, encircling the primary as it does will be influenced by the same flux change as does each turn of the primary.

91. Therefore the pressure *induced* per turn of the secondary must be equal to the *per turn* induced pressure of the primary. Under this relationship, if there happened to be twice as many secondary turns as primary turns, the induced secondary *terminal* pressure would be twice as great as the counter induced electromotive force in the primary.

92. A coil having 1000 times as many secondary turns as primary turns, and a primary counter electromotive force of self-induction of 1000 volts would produce a secondary *terminal* pressure of $1000 \times 1000 = 1{,}000{,}000$ volts.

93. As the induced pressures in both the primary and the secondary of induction coils depend upon the increase or the decrease of the primary current it is essential to have some means of computing the rate of increase or of decrease in the current, which may be applicable to any coil when the resistance R of the coil in ohms, and its coefficient of self-inductance L in henrys, are known.

94. When a direct-current pressure is applied to a coil, the current in the coil does not at once arrive at a value determined by Ohm's law; that is by $I = \frac{E}{R}$ where E denotes the applied pressure in volts, R the resistance of the coil in ohms, and I the current in amperes; but only gradually approaches this value. This slowing up of the increase in the current is due to the counter electromotive force of self-inductance of the coil. The pressure that is applied to the primary terminals has to overcome the resistance of the primary wire and also is opposed by the counter electromotive force of self-induction. This may be indicated by

$$E = R\,I + L\frac{I}{t}.$$

The ohmic drop R I of the primary is usually very small since the resistance of the primary is *very* small. The resistance may be as small as $\frac{1}{100}$ ohm. With this value even with a primary current of 25 amperes the ohmic pressure drop will be only $\frac{1}{100} \times 25 = 0.25$ volt.

95. If the applied pressure happened to be 110 volts then $L\frac{I}{t} = 110 - 0.25 = 109.75$ volts. If the numerical value of L, the coefficeint of inductance of the primary, is known, then the rate of change of the current, $\frac{I}{t}$, may be found. For example, if $L = 0.2$ henry in the case mentioned, then $\frac{I}{t} = \frac{109.75}{.2} = \frac{1097.5}{2} = 548.75.$

96. Since the current cannot instantly assume the value indicated by Ohm's law when a direct-current pressure is applied, the current must increase according to some definite law. The law of increase may be expressed by the equation:

$$I = \frac{E}{R} - \frac{E}{R} \times \frac{1}{\epsilon^{\left(\frac{Rt}{L}\right)}}$$

which at first glance may appear to be somewhat complicated. However, after a little examination of the various terms and factors of the equation it becomes quite simple in both mathematical theory and practical application.

The first term of the equation, constituting the left-hand member I stands for the current in amperes in the primary circuit, at any time in seconds or fraction of a second, denoted by t, after the battery pressure (or any direct-current pressure) denoted by E has been applied to the primary coil terminals.

97. The resistance of the primary coil is denoted by R, and the inductance of this coil, in henrys, by L. The symbol ϵ which is the Greek letter *epsilon*, denotes the numerical value of a series of numbers as follows:

$$\epsilon=1+\frac{1}{1}+\frac{1}{2}+\frac{1}{2\times3}+\frac{1}{2\times3\times4}+\frac{1}{2\times3\times4\times5}, \text{ etc.}$$

$$=1+1+\frac{1}{2}+\frac{1}{6}+\frac{1}{24}+\frac{1}{120}, \text{ etc.}$$

$$=2+0.5+0.1666\tfrac{2}{3}+.04166\tfrac{2}{3}+0.00833\tfrac{1}{3}.$$

If the fractional terms are carried out sufficiently, the numerical value of ϵ becomes

$$\epsilon=2.71828.$$

98. Consulting the equation again it is evident that the second term of the equation, $\frac{E}{R}$ is the Ohm's-law value of the current in the primary, and that from this indicated value a number denoted by the third or last term is subtracted. The last term can never be *greater* than $\frac{E}{R}$ and it may be zero. If the value of the last term becomes zero, then Ohm's law is applicable, and the current really reaches its final value. It is interesting to note the mathematical condition that causes the last term to become zero in value.

In the last term $\frac{E}{R}$ is multiplied by the fraction $\frac{1}{\epsilon^{\left(\frac{Rt}{L}\right)}}$. If the value of t becomes zero then the value of this fraction becomes $\frac{1}{\epsilon^0}$ which is $\frac{1}{1}$ or simply 1. The value of the original equation now becomes

$$I=\frac{E}{R}-\frac{E}{R}$$

which of course is zero. This means that at the very instant, the pressure is applied to the primary, there is no current in the primary circuit. The fraction denoted by $\frac{Rt}{L}$ is the *exponent* of ϵ and the numerical value of this exponent really depends upon the value assigned to t, since the resistance R of the primary is constant, or fixed after the coil is wound, and L is considered to be constant. This last condition is not probably strictly true when the magnetic flux in the core is varying. Were there no iron in the core, L would doubtless be constant in value, regardless of the amount of magnetic flux. However, the value of L may be ascertained by experiment for a variety of primary currents and these values used in the equation. It will be assumed that L is a constant and an example will be solved to show the increase in value in the primary current, after a definite pressure has been applied to the primary terminals.

EXAMPLE 6: Compute values of the current in the primary of an induction coil, at various times, in fractions of a second, after a direct-current pressure has been applied to the primary terminals. The resistance of the primary is 10 ohms, its coefficient of inductance is 1.7 henry, and the applied pressure is 20 volts.

Data.
E = 20 volts.
R = 10 ohms.
L = 1.7 henry.
$t=\frac{1}{10}$ second.

First assume that the value of the current is desired at $\frac{1}{10}$ second after the pressure is applied to the primary.

Making the proper substitutions in the fundamental equation the following results:

$$i=\frac{20}{10}-\frac{20}{10}\times\frac{1}{2.71828^{\frac{10\times\frac{1}{10}}{1.7}}}$$

$$=\mathbf{0.888\ ampere.}$$

99. Suppose the current is desired at a time equal to $\frac{L}{R}$ after the primary pressure is applied.

Then the following results:

$$i=\frac{20}{10}-\frac{20}{10}\times\frac{1}{\epsilon}$$

$$=2-2\times\frac{1}{2.71828}=\mathbf{1.264\ amperes.}$$

100. If it is desired to find the value of the primary current at the instant the pressure is applied to the primary, make $t=0$; then

$$i=\frac{10}{10}-\frac{10}{10}\,\frac{1}{\epsilon^{\infty}}\,1-\infty=0.$$

101. The symbol ∞ denotes a number that is too large to be measured; that is it denotes a number that is too large to be expressed by any arrangement of so-called digits.

This matter will be considered more in detail under the head of "*Spark Coils*" in a subsequent lesson.

GRAPHICAL REPRESENTATION OF PRIMARY CURRENT AND SECONDARY INDUCED PRESSURE.

102. According to theory the secondary induced pressure at the "make" of the primary is less than that at "break."

Experimental determinations also prove the same relation. This is shown by figure 24 in which the relation of primary current and secondary induced pressure is shown in both magnitude and time. The primary current at no time falls below the zero value, indicated by the horizontal datum O X. The induced secondary pressure is seen to have both positive and negative values which makes it alternating in character. The primary current is seen to *decrease* very rapidly, which causes a correspondingly large value of the induced secondary pressure.

103. If the resistance between the secondary terminals should be sufficiently large, the secondary pressure denoted by the portion below the datum line O X might not be sufficient to send a secondary current through it, causing the secondary *current* to be unidirectional.

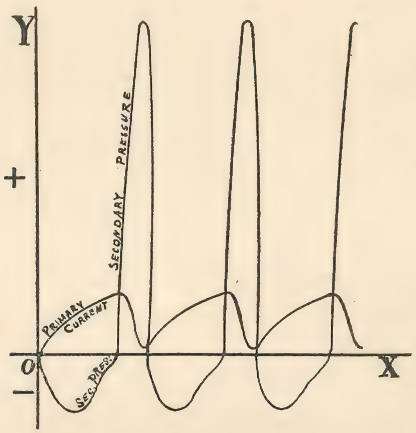


FIG. 24.

ACTION OF A CONDENSER.

104. When a condenser is connected in parallel with the spark gap of the primary the relations are no longer those depicted in figure 24. The general conditions may remain somewhat similar, but the condenser introduces a marked oscillation effect in both primary and secondary. That is instead of gradually increasing to certain values the increase is by a system of oscillations.

105. With a given condenser connected as outlined and as shown in figure 20, the secondary pressure is very greatly increased in value, and of equal importance the operation of the vibrator is rendered more dependable.

106. With any given condenser connected as indicated in figure 20, its effectiveness depends upon the frequency of the make and break of the primary circuit; that is upon the frequency of the vibrator. If the frequency is too high or too low the effect will not be so great as when a particular frequency is maintained.

This may always be ascertained by experiment; by varying the regulating thumb screw on the vibrator until a maximum result is obtained. For any given frequency of vibration f, and coefficient of inductance L_p of the primary, the capacity of the condenser to give the best results may be expressed by:

$$C = \frac{1}{4\pi^2 f^2 L}; \textit{ in farads.}$$

LESSON IX.

POWER REQUIRED TO OPERATE A COIL.

107. As has been stated, a portion only of the power in the primary of the induction coil is available in the secondary. It may be also stated that the power or energy supplied to the primary is distributed in various portions; each of which fulfill a definite service. Part of the supplied power is effective in overcoming the electrical resistance of the primary wire and supplies the heat loss in the windings; another portion is useful in building up the magnetic field in the iron core.

108. It is important to know about the relation of these two portions of supplied power with each other and with the secondary output, and some consideration will now be devoted to this phase of the subject.

109. It will be supposed that a battery of cells is connected with the primary circuit of a coil, sending an increasing current through the primary circuit as has already been explained.

Suppose the resistance of the primary to be expressed by R, and the applied pressure at the coil terminals to be denoted by E. Then during any short interval of time dt, the energy supplied to the primary may be expressed by $E\,i\,dt$. During the same interval of time the heat loss, in watts, in the primary winding due to its resistance may be expressed by $R\,i^2\,dt$ and the energy stored up by the magnetic field of the iron core during the same interval may be expressed by $L\,i\,di$. This last expression is the counter electromotive of self-induction multiplied by the current.

110. The counter electromotive force of induction is expressed by $L\frac{di}{dt}$ which multiplied by the current i and the time dt gives

$$L\frac{di}{dt}\,i\,dt = L\,i\,di.$$

The energy input and its distribution during the time dt may therefore be expressed by

$$E\,i\,dt = R\,i^2\,dt + L\,i\,di.$$

$E\,i\,dt$ expresses the energy supplied; $R\,i^2\,dt$ denotes the heat radiated from the primary, and $L\,i\,di$ denotes the energy stored up in the magnetic field.

111. It is this energy stored in the magnetic field of the iron core that is effective in producing the induced secondary pressure. This energy is stored up during a certain interval of time (dt) and may be used during a very different interval. If it is used during a shorter interval than its storage interval then the *rate* at which the energy is used will be greater than the rate at which it was stored. That is the *power* or the rate of working may be greater than the power or rate of input; but the total energy output or the *total work done* can never be greater than the total input. This is a most important consideration for two reasons: it leads to the fallacy that a rate of working being greater than a rate of input indicates more output may be realized than is really supplied; wherein lurks the alluring and ever subtle fantasmagoria of perpetual motion, and it has a most important and useful application in automobile ignition and in wireless telegraphy. The application to ignition will be considered later and its application in wireless operation may be stated to be the possibility of charging a condenser or storing up a magnetic field in a coil during a certain interval, employing rather small horse-power; say 5 or 10 horse-power and releasing the stored energy at rates of say 50 to 1000 horse-power. The *time element* of charge and discharge will always enter into the operation according to the inexorable law that the total energy output is always less than the total energy input.

112. The power or heat loss in the primary windings tends to reduce the power efficiency of the induction coil. There is a corresponding Ri^2 loss in the secondary windings when the coil is in operation. Usually the current in the secondary is very small; a small fraction of an ampere, so that the square of this current is a very small quantity. However, the resistance of the secondary wire is very large indeed so that the power loss in the secondary may be as great as that in the primary coils.

113. Whenever a current is flowing in the secondary windings, a magnetic field is set up in the iron core that is directly opposed to the magnetic field produced at the same time by the current in the primary coil. The field produced by the secondary is not so powerful as that produced by the primary; it is therefore only the difference of the two fields that in reality passes through the iron core. The less the magnetic field in the iron core the less the coefficient of inductance L_p and the less the opposition offered by the counter electromotive force in the primary. This action shows an inherent regulating effect, produced by a massless magnetic field.

114. The current in any primary having a resistance of R ohms, and an interrupter frequency denoted by f will have a current I_p very nearly expressed by the equation:

$$I_p = \frac{E_p}{\sqrt{R^2_p + (2\pi f L_p)^2}};$$

in which E_p denotes the pressure applied to the primary terminals, and L the coefficient of inductance of the primary.

115. Induction coils are not exceedingly efficient as working devices. Probably the best designed coils do not give useful outputs much greater than one-half the total input; or in other words they do not have an efficiency over 50%.

116. When a coil is once constructed, the resistance of its primary is definitely fixed in value. This depends upon the number of turns in the primary and the length of each turn. The coefficient of inductance L_p of the primary coil depends upon the square of the number of turns and upon the magnetic core flux through the primary.

When a current is flowing in the secondary windings the reaction upon the primary is such as to *reduce* the primary core flux and the coefficient of inductance L_p thus allowing more primary current to flow. This may be seen by carefully studying the effect of reducing the value of L_p in the equation just stated.

The secondary load output therefore automatically regulates the input to the primary.

LESSON X.

INTERRUPTERS.

117. As a *variable* current is necessary in the primary winding of an induction coil, in order to effect the required core flux change, the question of interrupting the primary current is a very important one indeed.

In general an interrupter should be so designed that it will close the primary circuit for a certain proper interval of time to allow the primary current to increase to a sufficient value, and to then open the circuit *very quickly*. The quicker the opening, the better will be the results; that is the greater will be the induced secondary pressure.

118. At present there are two classes or types of interrupters: mechanical and electrolytic.

There are several kinds of mechanical interrupters, such as the commutator, hammer, and mercury.

COMMUTATOR INTERRUPTER.

119. Commutator interrupters are usually operated by a motor and are employed when the primary currents are very large; that is too large to be interrupted by the other kinds of interrupters.

120. In the commutator make and break, one or more brushes are

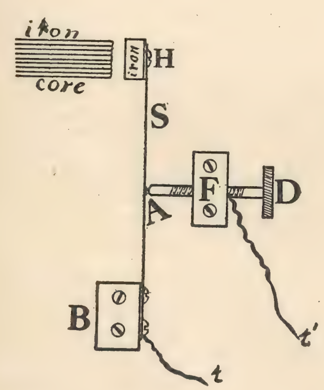


Fig. 26.

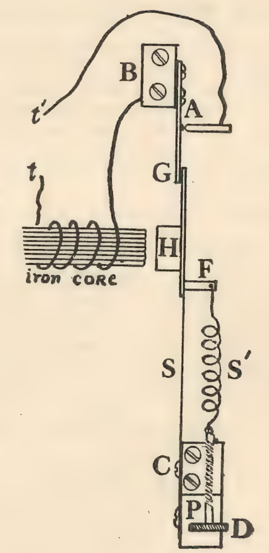


Fig. 27.

allowed to bear against a revolving disc arranged with conducting segments alternating with insulating segments.

121. The speed of the driving motor determines the rate at which the circuit is opened and closed, while the relative sizes of the conducting and insulating segments fixes the relative times of closing and opening of the circuit.

MERCURY INTERRUPTERS.

122. Mercury interrupters are employed in cases where the primary supply is at a comparatively high pressure. The arrangement is such that a fine stream of mercury is forced, by means of a small turbine pump, from a nozzle against revolving teeth or segments; or in another form such that a wire plunger is caused to dip into mercury with rapid frequency. The plunger is operated by electromagnets or by motion produced by a cam operated by a motor.

123. In the plunger type, a layer of oil is placed above the surface of the mercury, so that the spark at break is quickly extinguished when the plunger moves from the surface of the mercury; which assists in the quick opening of the circuit.

HAMMER INTERRUPTER.

124. The most common form of mechanical interrupters is the so-called hammer type. This is illustrated by figure 26. S is a spring of brass or steel rigidly fastened at one end to a base B and having a piece of soft iron H attached to its other end, which is arranged a short distance from one end of the iron core of the coil.

A set screw arrangement is shown at A, F, D. If the spring S bends to the left the contact points at A separate and thus open the primary circuit. The contact points at A are commonly tipped with platinum or iridium-platinum, to prevent the heat of the sparks fusing the tips together.

ATONIC INTERRUPTERS.

125. A special arrangement of the hammer interrupter is sometimes called "atonic." This type is shown in figure 27, which is self-explanatory. This type is susceptible to very wide variation in adjustment by means of the thumb screw D and the spring S′. This type allows a comparatively long "make" and an extremely *short* "break," since the break occurs when the hammer H has its most rapid motion.

WEHNELT INTERRUPTER.

126. There are a number of different forms of electrolytic interrupters employing different electrodes in different solutions; one of the most common being called the "*Wehnelt*"; pronounced Vainelt. This form employs a solution of sulphuric acid and water in the proportion of one part of acid to ten parts of water, into which is allowed to extend through a small hole in a porcelain tube a short piece of platinum wire about No. 10 or 12* B. and S. guage. This platinum wire forms the anode or positive terminal,† while the cathode or negative terminal consists of a plate or sheet of thin lead about 3 inches in width.

127. A cross-section of such an interrupter is shown in figure 28.

128. Such an interrupter is connected in series with the primary windings of a coil and the circuit is interrupted by the formation of bubbles of oxygen gas over the surface of the platinum electrode. The formation

* It is connected with the positive side of the direct-current supply.
† One millimeter in diameter, protruding 1 to 2 millimeters.

of such gas bubbles forms an insulating film over the surface of the platinum wire thus breaking the circuit. This action is repeated very rapidly indeed and produces very abrupt openings of the circuit.

129. An interrupter of this type when properly adjusted will produce as high as 450 to 500 interruptions per second, with a pressure of about 25 volts applied to the primary circuit.

130. Such interrupters are arranged to allow the platinum wire to protrude from the hole in the porcelain tube as desired. The further it

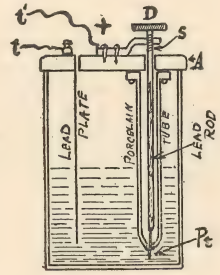


FIG. 28.

protrudes the greater will be the current in the primary circuit, and the *less* will be the frequency of interruptions.

131. It has been found that increasing the pressure applied to operate such an interrupter, the greater will be the frequency of interruptions, and as high as 1000 interruptions per second have been obtained.

132. The area of the lead plate is very great in comparison with the area of the protruding platinum wire, which wire with use wears down to a very sharp needle point, due to the action of the current. As the platinum point wears away it must be fed downward by some sort of adjusting mechanism such as a screw or lever.

133. Such an interrupter operates better with considerable inductance in series with it, and if the induction coil itself has insufficient inductance, an inductive coil is connected in series into the circuit. In addition an adjustable noninductive resistance is often connected in series to vary the applied pressure.

Hydrogen gas is formed at the cathode or lead plate, and is given off in considerable quantity if the current is considerable.

134. Should the interrupter be connected into the circuit so that the platinum is the cathode, it will be quickly melted. If thus connected by mistake a film of *hydrogen* gas rapidly forms around the platinum tip, greatly increasing the resistance at that portion of the circuit and therefore localizing the heat.

135. When in operation such an interrupter produces a loud humming noise due to the frequency, a yellowish spark is evident at the platinum electrode, and the solution grows quite hot if the interrupter is continued in use for some time. Means for cooling are resorted to, such as circulating cold water through glass or copper pipes arranged in the solution.

136. It requires a minimum of about 12 volts to properly cause such an interrupter to function; so it is not so well adapted for battery operation as it is for use with higher pressure supply mains such as 110-volt or 220-volt circuits.

137. It is interesting to note that such interrupters may be operated from 110-volt 60-cycle alternating-current mains, and when thus employed they not only interrupt the circuit at a much greater frequency than 60 cycles but they act as a one way valve for the electric current causing the secondary discharge from the secondary to be unidirectional.

138. Electrolytic interrupters require no condensers connected with them, as they themselves having capacity, act as condensers.

139. The discharge from a given coil is very different when a Wehnelt interrupter is used to operate it in place of an ordinary mechanical make and break. With the Wehnelt the secondary discharge is changed from a thin blue lightning-like spark to thick yellowish-red flaming discharge more like the ordinary flaming arc, which under careful scrutiny is seen to be made up of an immense number of individual sparks.

140. Electrolytic interrupters have not been extensively employed in wireless operation, but have found a wide field of application in connection with the "X"-rays.

For large outputs three or more of these interrupters may be connected together in parallel to operate a single coil.

Dr. Wehnelt's article in the *Elektrotechnische Zeitschrift*, January 20, 1899.

The Electrician, London, 1899, Vol. 42, pp. 721, 728, 731, 841, 842, 864 and 870.

The Electrician, London, 1899, Vol. 43, page 5.

Comptes Rendus, April 10, 1899.

The Electrical Review, 1899, Vol. 44, February 17, page 235.

ALKALINE INTERRUPTERS.

141. It may be noted that no metals can be used in electrolytic interrupters employing acid in their solution or electrolyte, that are attacked chemically by the acid. Lead and platinum are not acted upon by sulphuric acid under ordinary temperature conditions, but iron could not be employed in such a solution.

142. In order that metals cheaper than platinum may be used in an electrolytic interrupter, some other kind of a solution will need to be used.

143. Caustic soda or potash may be used to form an electrolyte and iron or steel wire may be used in place of platinum. The alkaline solution does not attack the steel, so that it is not consumed when not in operation.

144. Ordinary large size steel knitting needles may be used in place of the platinum wire, and the solution may be made of ordinary washing soda (sal-soda), making a saturated solution.

The steel needle is made the positive electrode corresponding to the platinum in the acid type. A lead plate is used as the negative electrode.

145. It is found that a certain definite length of steel needle should protrude from the porcelain tube to produce a maximum effect. Either a greater or a lesser amount is less effective.

LESSON XI.

CONDENSERS.

146. The function of the so-called condenser is of such importance in connection with the operation of the induction coil that it may well be considered as a part of the coil.

147. A condenser may be defined as two or more conductors separated by one or more insulators.

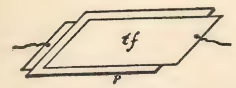


FIG. 29.

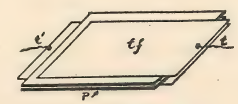


FIG. 30.

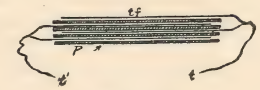


FIG. 31.

148. The conductors are usually in the form of thin sheets such as tin-foil and the insulator is usually made of paraffined paper. The paraffined paper is made two inches wider and of the same length as the tin-foil sheets.

Figure 29 shows the usual arrangement of two sheets of tin-foil separated by a sheet of paraffined paper.

149. To increase the capacity of a condenser, more sheets are employed, arranged as indicated by figure 30, and in cross-section by figure 31. The so-called electrical capacity of a condenser is commonly expressed in a unit called the *microfarad;* which is one millionth of a farad.

150. It is a fundamental experimental law that the capacity of any condenser depends upon the size or area of the sheets of tin-foil, *inversely* upon the thickness of the insulating sheets and directly upon the kind of material used as the insulator. The insulator is called the *dielectric.*

151. The paraffined paper used in making condensers may be made by heating paraffin in shallow pan somewhat larger than the sheets of paper to be used, dipping the paper in the hot melted paraffin and draining the sheet thus treated by holding it vertically over the pan. The treated sheet will gradually cool when it may be laid out flat on a board.

152. In building up a number of sheets to form a condenser, first lay down a sheet of paraffined paper and on this lay a sheet of tin-foil with one end projecting about one inch beyond one edge of the paraffined paper as indicated in figure 29. Over the tin-foil lay another sheet of paraffined paper and on this another sheet of foil extending an inch beyond the sheet of paraffined paper in the opposite direction from the first sheet. Proceed in this manner until sufficient sheets have been laid up, and then connect together all the projecting ends on one side by driving a tack or a screw down through the foil into the wood base, and the projecting edges on the opposite side in the same manner. Connecting a wire with projecting foil ends on one side will furnish one terminal of the condenser, and a wire with the opposite projecting ends will provide the other terminal.

153. Condensers for high pressure such as obtained from secondaries, must be made very different from those already described. In general the capacities of high-pressure condensers are small. They must be made of material that is not easily melted and of thicker substance than foil. Sheet copper or sheet brass is often employed as the conductors and thick glass for the dielectric.

154. Condensers for high pressure may be immersed in oil which will greatly increase their efficiency by preventing leakage losses from edges and corners.

155. Condensers may be made variable by connecting one set of plates rigidly to a rotating shaft, allowing the plates to be more or less included by the stationary plates.

156. The weak part of high-pressure condensers is the connection between the plates and the live wires. These connections should be carefully soldered if for permanent service.

157. A brief table of values of specific inductive capacities is given as follows:

Air	1	Mica	6 to 7
Castor Oil	4.7	Paraffin	2.2
Vaseline	2.17	Rosin	2.5
Flint Glass	9.9	Shellac	3.2
Crown Glass	6.96	Beeswax	4.1
Plate Glass	3.31 to 8.4	Hard Rubber	2.8

158. A general equation that is useful in designing and making condensers is given below.

$$C = .000224 \frac{An}{t} k,$$

in which C denotes the capacity in microfarads, A denotes the active area of the dielectric, in square inches, n denotes the number of sheets of dielectric, t denotes the thickness of the dielectric expressed in thousandths of an inch, and k denotes the so-called specific inductive capacity; which for paraffined paper is 2.2. The following example will perhaps show how to use the foregoing equation in making a condenser:

EXAMPLE 7: Find the number of sheets of tin-foil and paraffined paper necessary to make a condenser having a capacity of 5 microfarads, if each sheet of paraffined paper is .0025 inch thick, and is lapped by tin-foil over an area of 8 x 10 inches.

Data.

$A = 8 \times 10 = 80$ sq. inches.
$k = 2.2.$
$t = .0025 = 2.5$ mils.
$C = 5$ microfarads.

Substituting the proper numerical values in the fundamental equation:

$$C = .000224 \frac{An}{t} k$$

gives

$$5 = .000224 \frac{80 \times n}{2.5} \times 2.2$$

which solved for n will give

$$n = \frac{5 \times 2.5}{.000224 \times 80 \times 2.2} = \frac{12.5}{.039424} = 317 \text{ sheets.}$$

159. This will mean 317 sheets of paraffined paper and 318 sheets of tin-foil. The tin-foil sheets will have an area of 8 x 10 inches overlapping one another. That is the active area of the paraffined paper used as a dielectric will be 8 x 10 inches. The side margins of this paper should be at least one inch wide so that the width of the paraffined paper should be 10 inches. It should also have end margins one inch wide, so its length will be 12 inches.

PROBLEM 7: *Find the required number of sheets of paraffined paper and tin-foil to make a condenser having a capacity of 2.5 microfarads if the tin-foil sheets are to lap an area 8 x 10 inches, if the paraffined paper is $\frac{1}{400}$ of an inch thick.*

Answer. **159 sheets of paraffined paper and 160 sheets of tin-foil.**

Problem 7a: Find the number of sheets of tin-foil and paraffined paper necessary to make a condenser having a capacity of 10 microfarads, if each sheet of paraffined paper is .0025 inch thick, and is lapped by tin-foil over an area of 8 x 10 inches.

CONDENSERS FOR HIGH PRESSURES.

160. Condensers for high pressures may be made by coating ordinary pint or quart fruit jars both inside and outside to about $\frac{3}{4}$ their height, with tin-foil. A brass or copper band or wire should be clamped or wound around the outside coating for a terminal and a brass or copper wire run through a well-dried wood or hard rubber cover should make good contact with the inner coating. A brass chain is sometimes employed to make contact with the inner coating, being attached to the end of the wire terminal.

161. Such condensers are called Leyden jars.

162. A pint jar will have a capacity of about $\frac{1}{1400}$ microfarad which is equivalent to $\frac{1}{1,400,000,000}$ farad; a somewhat small capacity. Such a jar will stand 20,000 to 30,000 volts without breaking down.

163. The amount of energy that can be stored in such a jar at a pressure of 20,000 volts may be found from the expression:

$$J = \frac{1}{2} C E^2$$

In which J stands for joules, C for the capacity in farads and E for the pressure applied to the jar, in volts.

Then:

$$J = \frac{1}{2} \times \frac{1}{1,400,000,000} \times 20,000^2$$

$$= \frac{1}{2} \times \frac{1}{1,400,000,000} \times 20,000 \times 20,000$$

$$= \frac{1}{2} \times \frac{1}{14} \times 4 = \frac{1}{7} = 0.14 \text{ joule.}$$

164. A gallon jar would have about double the capacity of the pint size.

165. Small Leyden jars may be made with ordinary test tubes allowing the tin-foil coatings to cover only about three-fourths the area of the glass.

166. The inner coatings of Leyden jars may be formed by partially filling the jars with filings or turning of any kind of metal, running a brass or copper wire down some distance into the mass to effect a good electrical contact. Jars may be partially filled with alkaline solutions for inner coatings.

SPECIFICATIONS FOR A SIX-INCH COIL.

167. The following specifications wil enable anyone to build a coil that will give a secondary spark discharge six inches in length, when the secondary terminals are connected with pointed discharge tips.

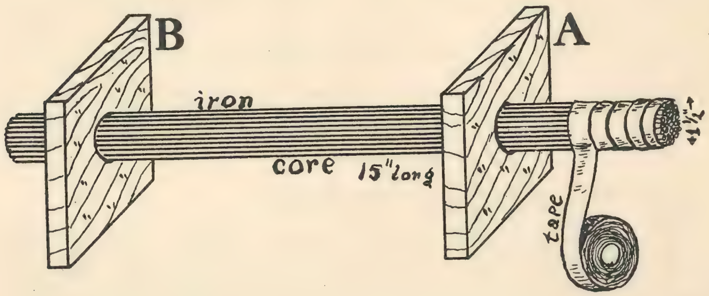


FIG. 32.

168. The core is made of a bundle of soft iron wires, of No. 16 B. & S. gauge, 15 inches long and 1½ inches in diameter. Iron wire used for cores in induction coils should be carefully varnished with shellac varnish after being cut to length. This insulates individual wires from one another when assembled and greatly reduces losses due to so-called eddy currents. Rusty iron wire is desirable since iron rust is a good insulator.

The core is built up by inserting the wires in two soft wood blocks bored out with holes 1½ inches in diameter, as indicated in figure 32. The holes should not be filled too full, but so as to allow the blocks to be moved along the core. The block A should be moved about three inches from the end of the core, and cloth braid or tape wound around the core as indicated. As the winding proceeds the block A may be moved along. The complete core should be covered with the tape, and another layer of tape wound on over the first, in the opposite direction.

169. On the taped core wind for the primary two closely wound layers of No. 10 B. & S. gauge, double covered cotton wound copper magnet wire. This will require about five pounds of wire.

170. The secondary should be wound on four spools as shown in figure 33. One section of each spool should be wound nearly full of wire, starting the inner end as at **t**, and with the outer end as at **t′**. The wire for the other section should be carefully soldered to the inner end **t**, using a small soldering iron, and the wire wound as a continuation of the winding of the first section. The outer terminal of winding in the second section should be brought out on the opposite end of the spool from **t′**. This should provide

a continuous winding in the *same* direction, from one end of the spool to the other.

171. After the four spools are wound, they should be slipped on over a tube made of cardboard to hold them in line, and the primary inserted in this tube.

172. The primary may be centered in the tube by using three rings of soft wood made of the proper size.

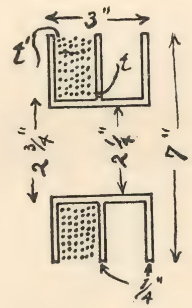


FIG. 33.

173. The secondary winding consists of about 5½ pounds of double covered cotton No. 38 Brown & Sharp gauge copper magnet wire.

174. The terminals of the secondary coils should be properly soldered together, using a small soldering iron so as not to burn the small wires.

The completed primary and secondary should be placed in a tight wooden box having inside dimensions 15½ x 6½ x 6½ inches, and a mixture of one part paraffin to twenty parts vaseline, heated to nearly boiling point and poured into the box to completely cover the windings. The box should be very carefully constructed with tightly glued joints to prevent the melted compound from leaking out.

The completed coil should stand at least 24 hours before being tested, in order that the compound may become cool.

175. If this coil is to be operated by a so-called hammer interrupter or spring make and break, the following condenser should be made of tin-foil and paraffined paper: 150 tin-foil sheets 6 x 12 inches, and 150 sheets of paraffined paper 8 x 13 inches. This condenser should be constructed according to the general directions given under condensers.

176. If this coil is operated by a mechanical make and break, a condenser should be constructed of 200 sheets of tin-foil 5 x 10 inches, separated by paraffined paper sheets 7 x 11 inches, to be connected in parallel with the primary spark gap. The condenser may be made in separate box or arranged in the base of coil. Boxes for condensers should be made of soft pine, which retains its shape better than other woods when subjected to variations in temperature and moisture.

LESSON XII.

SPECIFICATIONS FOR A THREE-INCH COIL.

177. The core consists of a round bundle of soft iron wires, No. 20 Brown & Sharp gauge, 13 inches long by $1\frac{1}{4}$ inches in diameter.

178. The core is built up and taped according to the directions given for a six-inch coil.

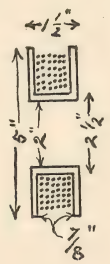


FIG. 35.

179. The primary consists of four closely wound layers of No. 12 double cotton-covered copper magnet wire. This will weigh about $4\frac{1}{2}$ pounds.

180. The secondary consists of about $4\frac{1}{2}$ pounds of No. 36 double cotton-covered copper magnet wire, wound on eight spools, each as shown in figure 35. The spools are all wound in the same direction and so assembled that two inner terminals and two outer terminals are soldered together.

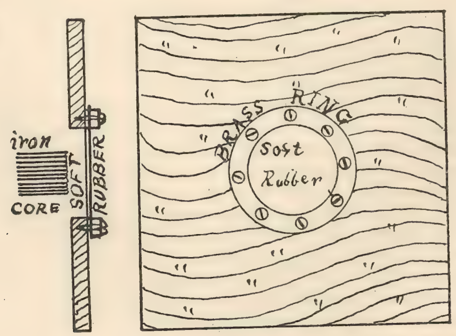


FIG. 36.

181. The secondary spools are held in place by slipping them on a cardboard tube of the proper size. The spools may be turned out of soft pine wood on a lathe.

182. The assembled coil may be inserted in a tight wooden box, $13\frac{1}{2} \times 5\frac{1}{2} \times 5\frac{1}{2}$ inches inside dimensions, and surrounded by a boiling hot compound of one part paraffin to twenty parts vaseline.

183. If a hammer interrupter is to be used on such a coil a diaphragm of rubber, such as rubber gaskets are made of, should be placed on one end of the containing box, opposite the end of the iron core as indicated in figure 36.

The rubber should be about $\frac{1}{8}$ inch in thickness. A thin brass or aluminum disc might be used in place of the rubber, but if this is done, a rubber gasket should be placed between the disc and the wooden end in order to insure a tight joint. A thin disc of wood might also be employed if desired.

CONDENSER FOR THREE-INCH COIL.

184. If the above coil is to be operated by a mechanical make and break, the following condenser should be constructed: 140 sheets of tin-foil, 6 inches by 12 inches, separated by paraffined paper sheets, 8 by 13 inches.

COIL TO GIVE ONE HALF INCH SPARK.

185. A small coil suitable for many experimental purposes, giving from $\frac{1}{2}$ to $\frac{3}{4}$ inch spark, may be made as follows: Iron core of No. 12 B. & S. gauge soft iron wires, $7\frac{1}{2}$ inches in length made up into a round bundle 1 inch in diameter. After this is carefully wound with cloth tape, wind on two closely wound layers of double cotton-covered, copper magnet wire No. 16 B. & S gauge, for the primary.

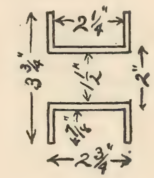


FIG. 37.

186. The secondary consists of No. 30 B. & S. gauge double cotton-covered copper magnet wire, wound smoothly and closely in layers on two spools $3\frac{3}{4}$ inches in diameter having a central hole $1\frac{1}{2}$ inch in diameter, as shown in figure 37. The walls of the spool are made $\frac{1}{4}$ inch thick which allows a winding space of $2\frac{1}{4} \times \frac{7}{8}$ inch as indicated in the figure. The secondary wire should be wound on very carefully in even layers, and each layer separated by a strip of thin paper $2\frac{1}{4}$ inches wide. It will be well not to continue the winding of each layer to the ends of the spool but to leave a space of about $\frac{1}{16}$ to $\frac{1}{8}$ inch.

187. The spools should be wound very nearly full of the wire, and of course when assembled should be carefully connected with each other electrically so that they will act together and not in opposition, and should be carefully centered relative to the primary.

188. The terminals should be carefully arranged so as not to short circuit any portion of the windings and might be inserted in small rubber tubing as an extra precaution.

189. The complete coil should be placed in a tight wooden box of the proper size and surrounded with melted vaseline or petrolatum. After this has sufficiently cooled the coil may be tested.

190. Such a coil may be operated by an ordinary spring interrupter, and a condenser made of about 100 sheets of tin-foil 5×7 inches, separated by paraffined sheets of ordinary thin typewriter paper will be proper in connection with the mechanical interrupter.

DATA FOR A TEN INCH SPARK INDUCTION COIL.

191. Primary should consist of 350 turns of No. 12 B. & S. gauge double cotton-covered copper magnet wire, wound on a core of No. 18 to 22 B. & S. gauge soft iron wires, two inches in diameter. Such a primary will have a resistance of about 0.36 ohm, and a coefficient of inductance $L_p = 0.02$ henry.

192. The secondary should consist of 18 pounds No. 34 B. & S. double cotton-covered copper magnet wire, making about 50,000 turns, having a resistance of 25,000 ohms, and a coefficient of inductance $L_s = 460$ henrys.

193. A primary current of 10 amperes will be necessary for a secondary spark 10 inches in length, and the primary pressure should be about 20 volts if the coil is operated by a hammer or mechanical make and break. The mutual inductance of such a coil may be about 2.75 henry.

INDUCTION COIL DATA.

194. Giving Spark One Meter Long.

Primary Data.

Diam. of primary wire 2.4 mm., =0.24 cm. =0.0944 inch.

Length of primary 603.5 meters, = { 60350 cms. / 1979.6 feet.

Consists of six layers.
Resistance of 2.3 ohms.
Ratio of primary turns to secondary turns = 1 to 700.

Secondary Data.

Diam. of secondary wire = 0.24 mm. = .024 cm. = .00944 inch.

Length of secondary wire = 450 kilometers { =450,000 meters / =45,000,000 cms. / =1,476,377 feet

Consists of four sections.
Total turns on secondary about 340,000.
Resistance of 110,200 ohms.

Core Data.

Core consists of a bundle of iron wires 110 cms. long and 8.9 cms. in diameter, weighing 30 kilograms or about 66 pounds. Weight of entire coil is about 700 kilograms, or about 1543 pounds.

LESSON XIII.

SPARK COILS.

195. The so-called "spark coil" is employed for furnishing the necessary sparks for lighting gas jets and in some types of gas engine ignition.

The spark coil is simply a coil of insulated wire, usually of copper, wound in a large number of layers about an iron core of soft iron wires. In reality it is the same as the primary of an induction coil with a large number of turns; provided with a large iron core but with no secondary windings.

196. The large number of turns and large core are necessary to provide a large coefficient of self-inductance L. The coil is connected in series with a battery by means of platinum tipped contacts. When the circuit is closed the current I in the coil increases according to the law expressed by the equation:

$$I = \frac{E}{R} - \frac{E}{R\epsilon^{\frac{Rt}{L}}};$$

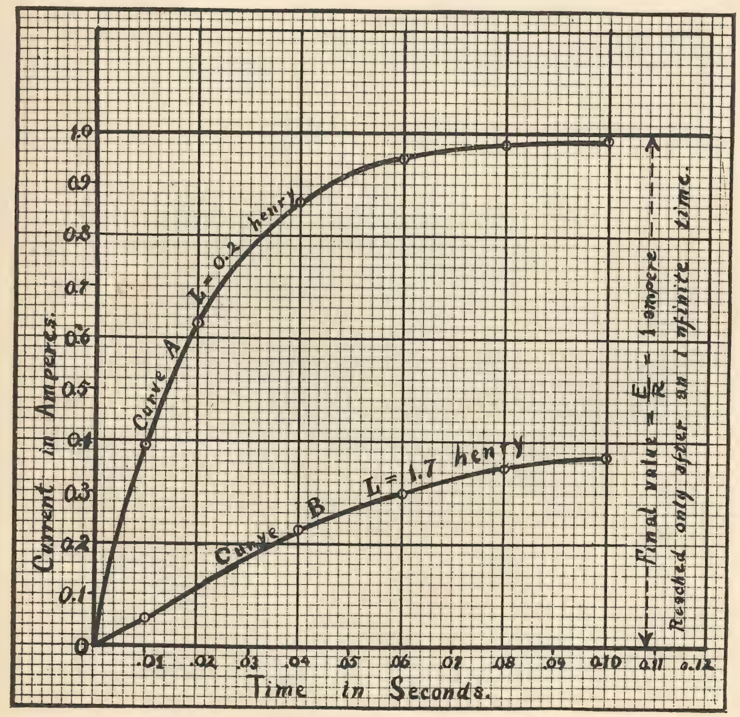


FIG. 39.

in which E denotes the E. M. F. in volts, of the battery employed, R denotes the resistance of the complete circuit, including the coil, battery and connecting wires; L denotes the coefficient of self-inductance of the circuit, which is essentially that of the coil, since the inductance of the coil is relatively very great, and $\epsilon = 2.71828$.

197. As has been already explained, the shape of the current curve may be computed by substituting for t, a number of different numerical values and solving the equation for corresponding values of the current.

198. The following actual cases have been computed and the results plotted in the form of a curve shown in figure 39.

EXAMPLE 8: Given a spark coil having a resistance of 10 ohms and a coefficient of inductance L = 1.7 henry; compute values of current, at the following times in seconds after a pressure of 10 volts is applied to the coil. $t = \frac{L}{R} = .17$ second. $t = 0.1$; .08; .06; .04; .01; .0075; .005; and .001 seconds.

Data.
E = 10 volts.
R = 10 ohms.
L = 1.7 henry.

199. Making the proper substitutions of the given numerical values, in the fundamental equation, will give the following for the value of current at the time $t = \frac{L}{R}$.

If $t = \frac{L}{R}$ then the exponent $\frac{Rt}{L}$ will become equal to $\frac{R}{L} \times \frac{L}{R}$ or equal to 1. Then the current will be found from:

$$i = \frac{10}{10} - \frac{10}{10 \times 2.71828} = 1 - \frac{1}{\epsilon} = 0.6321 \text{ ampere.}$$

200. When the time t is made equal to 0.1 second, the current is found as follows:

$$i = \frac{10}{10} - \frac{10}{10 \times \epsilon^{\frac{10 \times 0.1}{1.7}}} = 1 - 0.5554 = 0.4446 \text{ ampere.}$$

201. The following tabulated values of time and corresponding values of current have been computed according to the fundamental equation, and the curve B in figure 39 plotted according to these values.

Time in fractions of one second.	Corresponding values of current in amperes.
.005	.029
.0075	.0431
.01	.0571
.04	.210
.06	0.2994
.08	0.3754
0.1	0.4446
$\frac{L}{R} = 0.17$	0.6321
0.4	0.8964

EXAMPLE 9: Given a spark coil having a resistance of 10 ohms and a coefficient of inductance L equal to 0.2 henry; compute values of current, at the following times in seconds after a pressure of 10 volts is applied to the terminals of the coil.

$t = 0.4$; 0.1; .08; .06; .04; $\frac{L}{R} = .02$; .01; .0075; .005 seconds.

Data.
E = 10 volts.
R = 10 ohms.
L = $\frac{2}{10}$ henry.

Making the proper numerical substitutions in the fundamental equation gives the following values:

If $t = \frac{L}{R}$ then $i = $ **0.632 ampere.**

In this case $\frac{L}{R} = \frac{2}{100} = 0.02$ second.

The following values have been computed and tabulated.

Values of t in fractions of a second.	Values of current i in amperes.
.001	.048
.005	.221
.0075	.312
.01	.393
.04	.864
.06	.950
.08	.981
.1	.993

The above tabulated values have been plotted as curve A page 47.

PROBLEM 9: *Compute the value of the current, in amperes, at* $\frac{1}{5}$ *of a second after applying a direct pressure of* 10 *volts to the terminals of a spark coil having a resistance of* 5 *ohms and a coefficient of inductance* L = 1 *henry.* Answer: **1.26 ampere.**

Problem 9a: Compute the value of the current, in amperes, at $\frac{1}{5}$ of a second after applying a steady direct pressure of 20 volts to the terminals of a spark coil having a resistance of 5 ohms and a coefficient of inductance L = 1 henry.

202. From these examples it is seen that the current attains a value in a short time that approaches very close to the value expressed by Ohm's law; $= \frac{E}{R}$. The current is slower in approaching this final value, in a coil having a large value for its coefficient of inductance L.

203. It should also be observed that the greater the value of the pressure E that is applied to the terminals of a given coil, the greater will be the final value of the current in the coil and likewise the greater will be the amount of each of the instantaneous values. This fact is a very important one in the operation of such coils when it is desirable to utilize a considerable amount of energy in a very short time.

LESSON XIV.

ENERGY FROM A SPARK COIL.

204. The function of a spark coil such as has been described is really to store up electrical energy during a certain interval and to release this energy during a different interval. The energy, expressed in *joules* or in *watt-seconds*, that can be stored up in a spark coil may be expressed by $W = \frac{1}{2} L i^2$ in which L denotes the coefficient of inductance of the coil, expressed in henrys, and i denotes the value of the current at the end of the interval of time chosen.

205. The value of i after a time t, has been shown to be:

$$i = \frac{E}{R} - \frac{E}{R} \times \frac{1}{\epsilon^{\frac{Rt}{L}}} \text{ which is the same as}$$

$$i = \frac{E}{R}\left(1 - \frac{1}{\epsilon^{\frac{Rt}{L}}}\right)$$

from this the value of i^2 may be expressed as

$$i^2 = \frac{E^2}{R^2}\left(1 - \frac{1}{\epsilon^{\frac{Rt}{L}}}\right)^2$$

hence the expression for the energy in joules stored in a coil during the time the current is increasing from zero to any value denoted by i, is

$$W = \frac{1}{2} L \frac{E^2}{R^2}\left(1 - \frac{1}{\epsilon^{\frac{Rt}{L}}}\right)^2$$

206. Expressed slightly differently, the energy in watt-seconds or joules stored in a coil during any time t after the application of a steady direct pressure, may be computed by substituting any desired value for t in the above equation, together with the known or assumed values for E, R, L and ϵ and solving the equation for W.

207. If a coil has an inductance of L = 1 henry and the current in it is 1.26 ampere at the end of a certain time; say $\frac{1}{5}$ of a second, then the energy stored in the magnetic field of the coil during $\frac{1}{5}$ of a second will be $W = \frac{1}{2} \times 1 \times 1.26^2 = \frac{1}{2} \times 1.587 = 0.793$ joule or watt-second. When the circuit of such a coil is opened after the current has been flowing, the stored energy is evident by the spark produced at the break.

208. The longer the current has been maintained, the greater the stored energy and the larger and brighter the spark at break. The heat of the spark in other words depends upon the amount of stored energy.

209. In the operation of gas engines the heat of the spark must be sufficient to ignite the compressed mixture of gas and air in the cylinder of the engine. The make and break device must therefore be arranged

within the cylinder. It requires at least 0.02 joule or watt-second to ignite a charge under ordinary conditions, therefore a coil employed for such service must be designed so that $.02 = \frac{1}{2} L i^2$. If the inductance is 1 henry then $.02 = \frac{i^2}{2}$ or $i^2 = .04$ or $i = \sqrt{.04} = 0.2$ ampere. That is with a coil having a coefficient of inductance = 1 henry the value of current must reach 0.2 ampere when the circuit is broken within the cylinder, in order to ignite the mixture.

210. The important question is the element of time, when operating gas or gasolene engines. These usually operate at high speeds, hence a spark coil must be so designed as to furnish sufficient current at the highest speeds.

If the maximum speed is 1000 revolutions per minute, this is a speed of $\frac{1000}{60} = 16\frac{2}{3} = \frac{50}{3}$ revolutions per second. One revolution takes place in $\frac{3}{50}$ of one second (.06 second).

If the time allowed for the spark is $\frac{2}{100}$ or $\frac{1}{50}$ of a second this allows $\frac{4}{100}$ (.04) or $\frac{2}{50}$ of a second during which energy may be stored in the coil. That is, according to the assumption that 0.2 of an ampere is required to produce the necessary heat, this must be reached $\frac{2}{50}$ of a second after the mechanism completes the circuit. The coil must be so designed that this condition is realized.

211. This may be indicated by the following:

$$0.2 = \frac{E}{R}\left(1 - \frac{1}{\epsilon^{\frac{R\,2}{L\,50}}}\right)$$

From this it may be seen there are three unknowns or variables, E, R, and L. If any two of these have numerical values assigned to them then the third may be computed from the equation. R and L are in reality the quantities pertaining to the design of the coil. R may be reduced or kept at a minimum by employing the best conductor, such as silver, while L may be increased by increasing the number of turns on the coil or better by increasing the size and quality of the iron core.

212. A very important fact to be noted is that with any given coil should sufficient current not be obtained at the highest speeds with the battery employed, it may be sufficiently increased by adding a few cells to the battery. Where the question is one of weight or one of economic operation, then the design of the coil is of prime importance. In other words a coil that would furnish sufficient current at low engine speeds might not be able to furnish sufficient current at high engine speeds.

213. With a make and break system such as described, *only one spark* is obtained at each break; whereas with an *induction coil* a number of sparks jump between the spark plug terminals when the primary is closed by the engine mechanism.

214. So far as expense of operating is concerned, the make and break type of spark coil is more desirable than the induction-coil operated jump spark.

LESSON XV.

TESLA COILS.

215. In considering the general subject of induction coils it is fitting to mention briefly so-called Tesla coils, or *Oscillation Transformers*. This class of induction coil has no iron core whatever and when in operation should be carefully removed from all kinds of objects made of iron or steel. Another term applied to such coils is "*air core transformers.*"

216. The function of such coils or transformers, is to transform from a high pressure to a much higher one and at the same time from a given frequency to a much greater frequency.

217. The secondary discharge from a Tesla coil or oscillation transformer is at a much greater pressure and frequency than is the primary pressure.

Such a coil is constructed with very few turns on its primary and comparatively few turns on its secondary. The oscillations are produced by the discharge of a condenser connected in series with the primary coil as shown in figure 40.

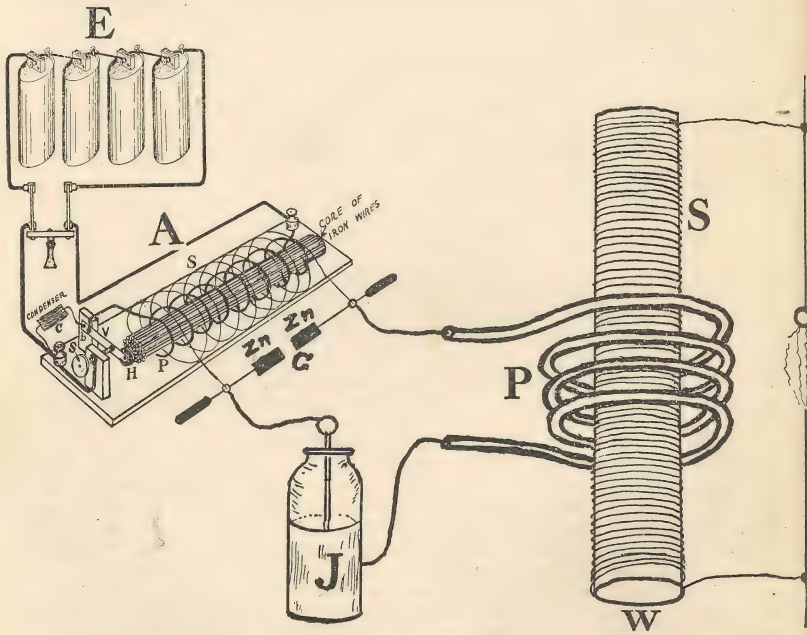


Fig. 40.

218. The discharge of a condenser through such a circuit as shown in figure 40 is oscillatory. As is shown in the figure the primary P of the oscillation transformer consisting of four or five turns is wound outside of the secondary, and is connected in series with a Leyden jar condenser J and in series with a spark gap G. Each terminal of the spark gap G is connected with one of the secondary terminals of a one or two inch induction coil. The spark gap should be made adjustable by allowing one or both terminals to slide or move toward each other. These terminals may be made of ordinary zinc rods $\frac{3}{8}$ inch in diameter; such as are used for battery zincs.

219. The secondary of the induction coil A charges the Leyden jar condenser through the primary of the air core transformer and when the charge reaches a certain value the jar discharges with a powerful spark through the spark gap G. This spark discharge is oscillatory and there are many oscillations per second.

220. The number of the oscillations may be varied by varying the capacity of the condenser. As many as 1,000,000 oscillations per second may be obtained by a proper relation of the inductance of the primary of the oscillation transformer, and the capacity of the condenser.

The general equation expressing the relation of frequency, capacity and inductance is:

$$f=\frac{1}{2\pi\sqrt{LC}} \text{ and since } \frac{1}{2\pi}=\frac{1}{2\times3.14159}=0.15915,$$

the equation becomes:

$$f=\frac{0.15915}{\sqrt{LC}};$$

in which f denotes the frequency of the current in the primary P of the oscillation transformer, L denotes the inductance of the primary P in henrys, and C denotes the capacity of the jar condenser J in *farads.*

Suppose, for example, the capacity of the condenser is $\frac{1}{100,000,000}$ farad and the inductance of the primary P is $\frac{1}{10,000}$ henry; then

$$f=\frac{0.15915}{\sqrt{\frac{1}{100,000,000}\times\frac{1}{10,000}}}$$

$$=\frac{0.15915}{\sqrt{\frac{1}{1,000,000,000,000}}}=1,000,000\times0.15915$$

$$=159,150 \text{ cycles per second.}$$

221. The relation between the frequency and the *wave length* of the discharge from an oscillation transformer may be shown by the following explanation.

The expression for the frequency just given is obtained from:

$$2\pi f L=\frac{1}{2\pi f C}$$

from which is obtained

$$f^2=\frac{1}{4\pi^2 LC} \text{ or } f=\sqrt{\frac{1}{4\pi^2 LC}}$$

$$=\frac{1}{2\pi\sqrt{LC}}=\frac{1}{2\pi\sqrt{L}\sqrt{C}}.$$

222. The velocity of electrical discharge is assumed to be about 300,000,000 meters per second, and the relation between velocity of propagation, frequency and wave length is $V=f\lambda$; in which V denotes velocity of wave propagation; equal to 300,000,000 metres per second; f denotes the frequency of vibration of discharge and λ denotes the wave length of each wave, in meters. The velocity might be expressed in miles per second as about 186,000 miles; then the wave length will be in miles. The Greek letter *lambda* λ is usually employed to denote wave length.

223. From the last equation the value of f is $f=\frac{V}{\lambda}$. By substituting this value in the equation in solving L and C, the following is obtained:

$$\frac{V}{\lambda}=\frac{1}{2\pi\sqrt{L}\sqrt{C}}$$

from which is obtained:

$$\lambda=2\pi V\sqrt{L}\sqrt{C}$$
$$=6.28318\times300{,}000{,}000\sqrt{L}\sqrt{C}$$
$$=1884954000\sqrt{L}\sqrt{C}\text{ meters.}$$

If C is expressed in microfarads and L in microhenrys:

$$\lambda=1{,}884{,}954{,}000\sqrt{\frac{L}{1{,}000{,}000}}\sqrt{\frac{C}{1{,}000{,}000}}=1884.9\sqrt{L}\sqrt{C}\text{ meters.}$$

224. The oscillation transformer has numerous applications in practice. It forms a connecting link in wireless operation between the source of energy supply and the aerial or the delivery of the energy. The energy input is at a certain frequency which is stepped up to a sufficiently high frequency to reduce the wave length to a proper value for practical use. The discharge from the secondary of this coil is employed to some extent in electro therapeutics, as a remedy for rheumatism and other disorders. The discharge from such a coil being at a very high frequency does not penetrate the tissues of the human body, even though the pressure is very great.

Burned-out electric lamp bulbs may be held in the hand and when brought near either of the secondary terminals of one of these coils in operation will glow with a greenish or bluish light.

The secondary terminals when the coil is operating glow all over with a bluish brush discharge.

225. A Tesla coil or air core transformer for producing a secondary discharge of four or five inches, using a two-inch induction coil, may be made by carefully winding double wound, cotton covered, copper magnet wire No. 32 B. & S. gauge around a well-dried wooden cylinder two inches in diameter and two feet long, carefully spacing the windings, winding about 36 turns to the inch, and winding to within ½ inch of either end of the wooden cylinder. This means a total of about 828 turns. Wind only one layer. This constitutes the secondary of the coil.

226. For the primary wind 5 turns of ordinary twisted lamp cord about a wooden frame about 6 inches in diameter, so as to encircle the secondary as indicated in figure 40. The five turns should be spaced about 1½ inch apart, and should encircle the secondary at its center; that is midway between the ends of the secondary. Double reenforced window cord serves very well as a primary, and may be tied in place with ordinary twine if the primary frame work is made of wooden strips.

227. If desired, such a coil may be immersed in oil, which will greatly increase its output. Very good results may, however, be obtained when used in air.

INDUCTION COILS FOR TELEPHONES.

228. A small induction coil for use in telephone transmission may be made by gluing wooden discs to a cardboard tube having a ¼-inch hole, so that the distance between the discs is be 3 inches. These wooden discs should be 1 inch in diameter and may be ½ inch thick. The winding space is 3 inches long between the discs. It is not necessary that these discs be circular, as square blocks will answer as well.

229. For a primary wind on the spool thus formed, two evenly wound layers of No. 22 B. & S. gauge copper magnet wire, double cotton-covered. Over this wind evenly No. 36 double cotton-covered magnet wire to a depth of about ¼ inch. This constitutes the secondary. The primary of such a coil is connected in series with the transmitter and the battery, while the secondary is connected in series with the receivers.

The whole matter of telephone coils and their use is explained more at length in "*How to Make Telephones.*"

LESSON XVI.

CHOKE COILS.

230. The writer is constantly receiving so many enquiries regarding the construction and operation of so-called "*choke coils,*" it is thought advisable to add to the consideration of induction coils a limited discussion of choke coils.

The choke coil can only be used on alternating-current circuits; its function being to reduce the line pressure to a much lower value, in order to operate various classes of apparatus requiring comparatively low pressures.

The alternating-current choke coil operates because of a counter electromotive force induced in its turns due to the varying or alternating magnetic field produced through its center, by the alternating current passing through the turns of wire of which the coil is wound. The coil shown in figure 15 may be used as a choke coil.

231. Regulation of Arc Lights by Choke Coils.

For example, it is often desired to operate an arc light, that requires only about 45 volts, from an alternating current supply circuit having a pressure of 110 volts. In such a case $110-45=65$ volts must be counter-

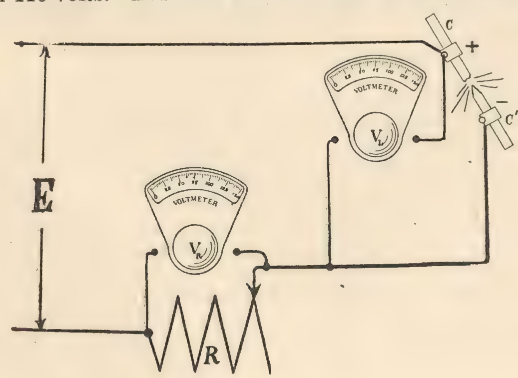


FIG. 41.

acted by some means. This could be accomplished on alternating-current circuits as it is on direct-current circuits, by introducing a simple resistance into the circuit in series with the arc, as indicated in figure 41, so that the R I pressure drop across the added resistance R may equal 65 volts. This would be indicated by a voltmeter connected as at V_r. The power loss in such a case may be denoted by RI^2 and if the current is considerable the loss will be expensive as may be appreciated from a study of the following example and problems.

EXAMPLE 10: If electric power costs 15 cents per kilowatt hour, what will be the cost of operating during one hour, the regulating resistance of an arc light that requires 45 volts and 10 amperes, if the supply pressure is 110 volts.

Data.
$E = 110$ volts.
$I = 10$ amperes.
$E - E_A = 65$ volts.

If the arc requires 45 volts and the supply pressure is 110, the pressure applied to the regulating resistance is $110 - 45 = 65$ volts.

The current is 10 amperes in the regulating resistance as well as in the arc, so the power radiated by the resistance in the form of heat is expressed by $E^1I = 65 \times 10 = 650$ watts; or $\frac{650}{1000} = 0.65$ kilowatt. One kilowatt is equal to one thousand watts. If the current passes through the resistance during one hour, the number of kilowatt hours will be 1×0.65 or 0.65 kilowatt hour. The hourly cost will therefore be

$$15 \times 0.65 = \mathbf{9.75\ cents.}$$

The cost of the energy used in the arc itself is only $45 \times 10 \times \frac{15}{1000} = 0.45 \times 15 = 6.75$ cents. The total cost of operating the light per hour will therefore amount to $9.75 + 6.75 = 16.5$ cents.

PROBLEM 10: *What will it cost per hour, to operate an arc light that requires* 15 *amperes at* 50 *volts from* 110 *volt mains,* at 15 cents *per kilowatt hour?*

Answer. **23.25 cents.**

Problem 10a: What will it cost per hour to operate a regulating resistance for an arc light that requires 20 amperes at 55 volts, if the light is operated from 110 volt mains? Cost of electric energy being 20 cents per kilowatt hour.

232. A much less expensive method of counteracting pressure is possible in alternating-current circuits by means of choke coils. If a choke coil is connected *in series* with any device, as indicated at R, figure 41, it is evident that the wire of which the choke coil is wound must be of sufficient size to safely conduct the current required by the device. The following table will serve as a guide as to the sizes of copper wire to be used for different currents:

B. & S. gauge number.	Area in circular mils.	Current in amperes.
18	1624	2
16	2583	4
14	4107	10
12	6530	18
10	10380	20
8	16510	28

233. A brief consideration regarding the theory of the operation of choke coils is now in order. As has been shown in explaining the fundamental principles underlying the operation of induction coils, whenever there is *relative* motion between an electrical circuit and a magnetic field, an electrical pressure is induced in the circuit, according to the right-hand rule; which shows the induced pressure to be in a direction opposite to that of any external applied pressure. Given a coil consisting of a number of turns of winding, whenever a varying current flows in one turn it produces a varying magnetic field that threads through the adjacent turn, inducing in it a counter pressure to that which is applied. This interaction between contiguous turns is a mutual one so that each turn adds its increment to the counter electromotive force of the whole coil. The fundamental principles also show that if all of the magnetic field produced by one turn can pass through the next turn, the induced counter pressure in the second turn will be the same as the applied pressure of the first turn.

According to well-established laws of efficiency the counter pressure can never be exactly equal to the applied pressure producing it. However, by employing a soft iron core to cause a maximum number of magnetic lines to thread through all of the turns on a coil, the counter electromotive force of the coil can be kept at a relatively high value.

234. Whenever a coil is connected with an alternating source of supply, the alternating pressure applied to the terminals of the coil sends an alternating current through the coil according to the following expression:

$$I_{AC} = \frac{E}{\sqrt{R^2 + (2\pi f L)^2}};$$

in which I_{AC} denotes the current, in amperes, passing through the wire of the coil, E denotes the pressure, in volts, applied to the terminals of the coil, R denotes the simple ohmic resistance of the wire of the coil, in ohms, $2\pi = 2 \times 3.1416 = 6.2832$, f denotes the frequency, in cycles per second, of the applied alternating pressure, and L denotes the coefficient of inductance of the coil, measured in henrys.

235. The fundamental equation just explained may be rearranged as follows:

$$I_{AC}\sqrt{R^2 + (2\pi f L)^2} = E;$$

or by putting I_{AC} under the radical sign, as:

$$\sqrt{R^2I^2_{AC} + I^2_{AC}(2\pi f L)^2} = E.$$

The last form, if closely observed, will prove to be according to the famous Pythagorean theorem in Geometry, which stated in simple English, is to the effect that the square of the hypotenuse of any right angled tri-

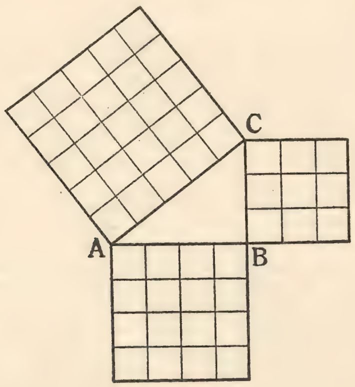


FIG. 42.

angle is equal to the sum of the squares of the other two sides. This is illustrated by figure 42.

236. Suppose a triangle A B C is constructed as shown in figure 43, having its hypotenuse A B of such a number of units in length as to denote 110 volts.

For example, A B might be drawn 11 inches long. If the resistance of the wire of the coil is say 3 ohms and the current in it is 20 amperes, then R I = 3×20 = 60 volts, and A C will be drawn 60 units long; say 6 inches.

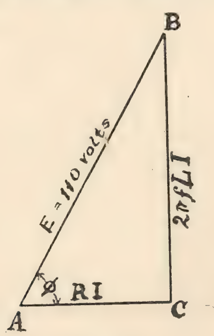


FIG. 43.

If the frequency of the supply pressure is known and the coefficient of inductance L of the coil is known, then the length of the side C B may be

computed. The application of the Pythagorean principle may be seen from the values of the sides of the triangle A B C, figure 43, as follows:

$$E^2 = (R\,I)^2 + (2\pi f\,L\,I)^2$$

which is the same as

$$E = \sqrt{R^2 I^2 + (2\pi f\,L\,I)^2}.$$

The side denoted by $2\pi f L I$ represents the *counter electromotive force*, of the coil. The application of the foregoing geometrical relation to the design of a choke coil will be outlined.

237. Suppose it is desired to construct a choke coil to carry 5 amperes and to reduce the pressure from 110 to 40 volts. This means that the pressure across the terminals of the coil will be 110−40 = 70 volts.

Draw a straight line 7 inches long as A B, figure 44. With a compass bisect the line A B at O, as indicated by the intersecting arcs at *D D′* and

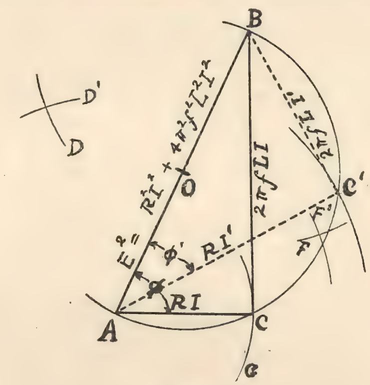


FIG. 44.

at *FF.′* With O B as a radius draw the semicircle A C C′ B. Suppose the resistance of the choke coil is to be 5 ohms. Then R I must be equal to 5×5 = 25 volts. With A as a center and a radius = 2.5 inches, to represent 25 volts, intersect the semicircle A B C at point C, by arc C G.

The line joining C and B will by its length represent the counter electromotive force $2\pi f L I$ of the coil in volts. The frequency of the alternating supply will of course be known, and the current I has been assumed. The unknown is therefore L. It is evident then that:

$$2\pi f\,L\,I = \text{length of B C in inches} \times \text{scale multiplication.}$$

Let it be supposed that the frequency of the supply is 60 cycles. Then the following will be true:

$$L = \frac{\text{length of B C in inches} \times \text{scale multiplication}}{6.2832 \times 60 \times 5}.$$

Suppose C B by careful measurement is found to be 6.5 inches, which corresponds to 65 volts in accordance with the assumed scale relation.

Then

$$L = \frac{65}{6.2832 \times 60 \times 5} = .034 \text{ henry.}$$

The size of the wire must be large enough to carry 5 amperes without overheating, and the coil must contain sufficient turns to give the required value for L of .034 henry. By consulting the table given in paragraph **232**, it will be seen that No. 14 wire wlll be amply safe.

238. To find the required number of turns, a very simple equation to use, when there is no iron core in the coil, is:

$$L=\frac{4\pi n^2 A}{b\times 10^9}.$$

In which n denotes the number of turns on the coil, A denotes the area of the central hole through the coil, expressed in *square centimeters*, and b denotes the length of the coil (not of the wire) in centimeters.

Suppose it is decided to make the central hole 2 inches in diameter and the coil 8 inches long, then solving the given equation for n, gives:

$$n=\sqrt{\frac{10^9\times b\times L}{4\pi A}},$$

and making the proper numerical substitutions gives:

$$n=\sqrt{\frac{10^9\times 8\times 2.54\times .034}{4\pi\times\pi\times 2.54^2}}$$

$$n=\frac{1}{2\pi}\sqrt{\frac{10^9\times 8\times .034}{2.54}}$$

$$=.1591\sqrt{107080000}=1646 \textbf{ turns} \text{ (nearly)}.$$

Data.
$b=8\times 2.54$ cms.
$A=\pi r^2=\pi 2.54^2$.
$L=.034$ henry.

239. If a core $1\frac{1}{8}$ inch in diameter made of about No. 16 or No. 18 iron wires and about 14 inches in length, is inserted into the coil the number of turns may be reduced considerably. The equation, with a core, will be:

$$n=0.1591\sqrt{\frac{10^9\times b\times L}{4\pi\,\mu\, A}} \text{ in which } \mu$$

denotes the permeability of the iron, and its numerical value depends upon the particular grade of iron used. Suppose μ is 500.
Then for the assumed case;

$$n=0.1591\sqrt{\frac{10^9\times 8\times .034}{2.54\times 500}}=74 \textbf{ turns.}$$

240. The foregoing shows the increased choking effect when an iron core is employed, and the choking effect of the coil having 74 turns without the iron core may be computed from the equation for n, without μ, in it.

241. The maximum choking effect occurs when the iron core is wholly within the coil; as it is gradually withdrawn, the choking effect, or the counter electromotive force of the coil decreases, as indicated by B C′, figure 44, and the ohmic pressure drop indicated by R I′ or A C′, figure 44. It is evident that any number of right-angled triangles may be inscribed in the semicircle A C C′ B, and as the B C side decreases the A C side increases.

242. The ohmic resistance of a choke coil provides a very small proportion of the choking effect of the coil, so that its numerical value needs but small consideration compared with the safe current carrying capacity of the wire of which the coil is made.

243. If the design is to be exacting the dimensions of the coil may be slightly varied after the number of turns has been determined, so as to wind the length of wire, of the necessary size for safe conductivity, in such a space as to have the number of turns.

244. In using a choke coil always insert its iron core before closing the circuit, so as to start with the *maximum* choking effect. After the circuit is closed, by gradually withdrawing the iron core, the current in the circuit is gradually increased.

245. Figure 45 may serve to explain how the relation of ohmic pressure drop and inductive pressure drop may be shown by experiment.

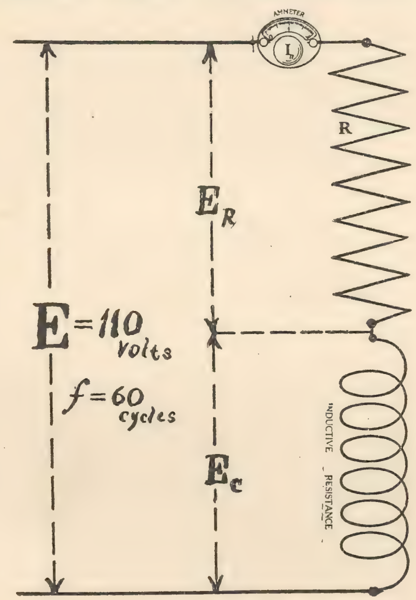


FIG. 45.

Suppose R denotes a resistance of any kind of wire that is not coiled up, while the portion called inductive resistance denotes a coil of wire such as that shown in figure 15. These two portions of the circuit are connected together in series, so that the ammeter will indicate the current in each. There can be but one current in both portions. Suppose a volt meter be connected across the portion R, its indication will be E_R. Another volt meter connected across the inductive portion will indicate the pressure E_C. The pressure of the supply mains may be E. It will not be true that the applied pressure is the sum of the other two; that is, that $E=E_R+E_C$. The sum of the indications of the two volt meters will be *greater* than the applied pressure. There is an *angular relation* between E_R and E_C which renders it necessary to obtain their geometric resultant.

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