CHAPTER EIGHT
Inductance

So far the circuits we have studied have been resistive. That is, resistors presented the only opposition to current flow. Two other phenomena—inductance and capacitance—exist in direct-current circuits to some extent, but they are of major importance in alternating-current circuits. Both inductance and capacitance present a kind of opposition to current flow that is called "reactance," which you will study in Chapter Ten. Before we examine reactance, however, we must first study inductance (the subject of this chapter) and capacitance (the subject of Chapter Nine).

Inductance is the property of an electric circuit that opposes any change in the current through that circuit. That is, if the current increases, a self-induced voltage opposes this change and delays the increase. If the current decreases, a self-induced voltage tends to aid (or prolong) the current flow, delaying the decrease. Thus, current can neither increase nor decrease as fast in an inductive circuit as it can in a purely resistive circuit.

This effect becomes very important in a-c circuits, because it affects the phase relationships between voltage and current. You learned in Chapter Seven that voltages (or currents) can be out of phase if they are induced in separate armatures of an alternator. In that case, the voltage and current generated by each armature were in phase. When inductance is a factor in a circuit, the voltage and current generated by the same armature are out of phase. We shall examine these phase relationships later in this book. Your objective in this chapter is to understand the nature and effects of inductance in an electric circuit.

The opposition to the change of current is essentially an effect of electromagnetic induction, or induced electromotive force (emf). In Chapter Seven, you learned that voltage is induced in a conductor when it is moved through a magnetic field. The same thing happens when a magnetic field is moving across a conductor. It is this relative motion between the field and the conductor that produces a self-induced voltage in a conductor. A magnetic field builds up when current begins to flow and collapses when it is shut off. In either case, the field moves, and this effect is the subject of this chapter.

When you have finished this chapter you will be able to:

- explain the factors that affect inductance;
- describe the growth and decay of current in a resistive-inductive circuit;
- distinguish between self-inductance and mutual inductance;
- describe the effects of inductance in an electric circuit;

- calculate the induced voltage when the inductance is known;
- calculate the L/R time constant of a circuit; and,
- calculate the total inductance of a circuit.

Self-Inductance

1. As you have already learned, current flow in a conductor always produces a magnetic field surrounding, or linking with, the conductor. Inductance is a factor in a circuit even when a conductor is perfectly straight, because the magnetic field builds up, or expands, when current begins to flow and deteriorates, or collapses, when current is shut off. Inductance is much more significant when the conductor is in the form of a coil, because each turn of the coil, with its associated magnetic field, affects all other nearby turns, as we shall see later. When the current changes (this change may be an increase, a decrease, or a change of direction), the magnetic field also changes, and an electromotive force (emf) is induced in the conductor. This emf is called a self-induced emf because it is induced in the same conductor carrying the current. The self-induced emf is caused by the magnetic field as it moves across a conductor. Self-inductance results from what characteristic of electric current? ______

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2. When current flows in a conductor, what must be the relationship between the magnetic field and the conductor to cause a self-induced emf?

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3. The strength of a magnetic field about a conductor is directly proportional to the amount of current flow in the conductor. When current flow increases, what happens to the magnetic field strength? ______

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4. The self-induced emf in a conductor is directly proportional to the strength of the magnetic field that causes it. As the current flow in a conductor increases, what happens to the magnetic field strength? ______

What happens to the self-induced emf? ____________________

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5. When current flows in a conductor, how is a self-induced emf produced in the conductor? ____________________

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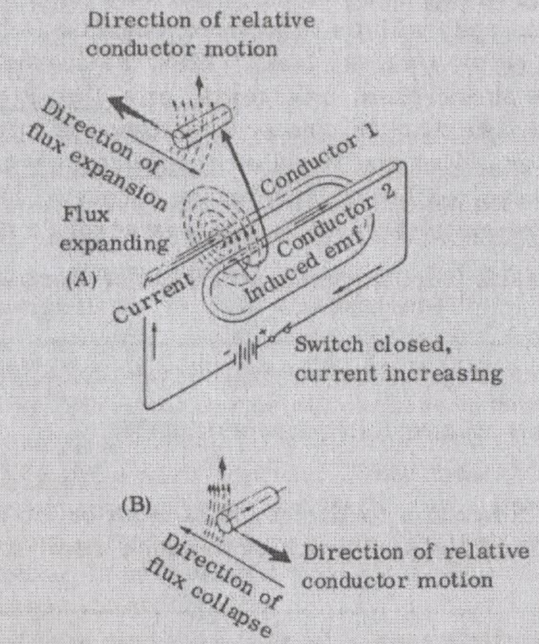

Figure 8-1. Self-inductance.

Refer to Figure 8-1 for Frames 6 through 12.

6. When current flows in a conductor, it produces a magnetic field (flux) that cuts across the conductor and induces an emf. The induced emf causes current flow that is in the opposite direction to the current flow already present in the conductor. This effect is summarized by Lenz's Law: The induced emf in any circuit is always in a direction to oppose the effect that produced it. Don't try to visualize a flow of emf; rather, think of the current flow resulting from the emf. Inductance is increased by shaping a conductor so that the electromagnetic field around each portion of the conductor cuts across some other portion of the same conductor. This is shown in its simplest form in Figure 8-1. A length of conductor is looped

so that two portions of the conductor lie adjacent and parallel to one another. These portions are labeled Conductor 1 and Conductor 2. When the switch in the circuit is closed, electron flow through the conductor establishes a typical concentric field around all portions of the conductor. For simplicity, the field is shown in a single plane that is perpendicular to both conductors. Although the field originates simultaneously in both conductors, it is considered here as originating in Conductor 1, and its effect on Conductor 2 will be shown. When the switch in the circuit is closed, the flux begins to (expand/contract) ____________________.

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7. When the flux expands, there is relative motion between it and the conductor, and the effect is the same as if the conductor were moving. You have already learned that when a conductor moves in a magnetic field, a voltage (emf) is induced in the conductor. A small section of Conductor 2 is shown in View A of Figure 8-1. The direction of the expanding flux from Conductor 1 is shown as well as the direction of the relative motion of Conductor 2. The current flow in Conductor 2 that is produced by the battery is shown in the larger drawing. (You can locate the arrow that indicates this current flow by following the arrows from the negative terminal of the battery.) A dashed-line arrow in the small segment of Conductor 2 shows the current flow resulting from the induced emf. The induced emf causes current flow in Conductor 2 that is in a direction that is (the same as/ opposite to) ____________________ the current flow produced by the battery.

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8. The effect of inductance in a circuit is to oppose any change in the current through that circuit. Current in a purely resistive circuit is normally thought of as starting and stopping instantly when the circuit is closed or opened. To understand the effect of inductance, you must realize that changes in current flow are not quite instantaneous. To visualize this, review what happens when an inductance is present in the circuit, as it is in Figure 8-1. When the switch is closed, current begins to flow in the circuit. The current flows in all parts of the circuit, of course, but examine the portions of the circuit labeled Conductor 1 and Conductor 2. When current begins to flow in Conductor 1, the resulting magnetic field begins to expand, cutting across Conductor 2. An emf is induced in Conductor 2, and this self-induced emf causes an additional current flow that is in a direction opposite to the main current flow. Thus, when the switch is closed, the inductance of Conductor 1 acts to (aid/oppose) __________

the buildup of current in Conductor 2.

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9. Although the effect is not illustrated in Figure 8-1, a magnetic field also begins to expand around Conductor 2 when the circuit switch is closed. As current from the battery begins to flow in Conductor 1, the expanding magnetic field from Conductor 2 induces an emf. How does this emf affect the current flow in Conductor 1? ______________________________

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10. View B shows what happens when the circuit switch is opened. When the current that produces the magnetic field is turned off, the field begins to collapse. Therefore, its direction of movement is reversed, and the apparent direction of movement of Conductor 2 in that field is also reversed. Now the direction of current flow in Conductor 2 is in the same direction as that of the battery current. Although the battery current tries to stop (because the switch is opened), the collapsing magnetic field induces an emf in Conductor 2 that tries to keep the current moving. This continues only for the tiny length of time during which the magnetic field is collapsing, but the effect is real. Therefore, how does inductance act to influence the current in the circuit? ______________________________

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11. How does inductance act on the <u>battery</u> current, (a) when the switch is closed and, (b) when the switch is opened? ______________________________

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12. When the circuit switch is closed, there is a <u>change</u> in current from zero to its normal value. When the switch is opened, there is again a change back to zero. It is important to note that the voltage of self-inductance opposes <u>both</u> changes in current. It delays the initial buildup of current by opposing the battery voltage, and it delays the breakdown of current by exerting an induced voltage that causes current flow in the same direction

as the battery current. When current flows in any circuit, how does self-inductance affect the current flow? ______________________________

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If you intend to take a break pretty soon, this is a good place to stop.

13. The unit for measuring inductance, L, is the henry (named for an American physicist, Joseph Henry), abbreviated h. You have now encountered five parameters, or things measured, in electric circuits. (You will learn others later.) Complete the table below.

Parameter	Mathematical Symbol	Unit	Abbreviation
voltage	E	volt	v.
current	____	____	____
resistance	____	____	____
power	____	____	____
inductance	____	____	____

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14. The henry is a large unit of inductance, so you need to learn two other abbreviations used with inductance. "Milli-," as you have learned, means a thousandth; that is, 1/1000, or 0.001. One milliampere equals 0.001 a. A common unit of inductance is the millihenry, abbreviated mh. One millihenry equals __________ h.

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15. An easier way to express 0.001 h. is __________.

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16. An even smaller unit of inductance is also common. You have already learned that "micro-" means a millionth, or 0.000001. The Greek letter μ (pronounced mu) is used to represent "micro-," so a millionth of a henry is called a ____________________, abbreviated _____.

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17. Inductance opposes a <u>change</u> in current. The Greek letter Δ (pronounced delta) means "a change in." The expression for "a change in time" is Δt.

What do you think would be the expression for "a change in current"? ___

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18. An inductance of 1 henry exists if an emf of 1 volt is induced when the current is changing at the rate of 1 ampere per second. The relationships of induced voltage, inductance, and rate of change of current with respect to time can be stated mathematically:

$$E = L\,\frac{\Delta I}{\Delta t}$$

where E is the induced emf in volts, L is the inductance in henries, and ΔI is the change in current in amperes that occurs in a given amount of time (Δt). You can find the value of the voltage induced in a conductor such as that shown in Figure 8-1 if you know the other values. If all units are of the same order of magnitude, such as milli- or micro-, the induced voltage will be of the same order of magnitude; that is, it will have the same prefix. For example, to solve for induced voltage where the inductance is 5 μh, the change in current is 4 microamperes, and the time required to effect the change is 2 microseconds, substitute those values in the equation:

$$\begin{aligned} E &= 5 \times (4 \div 2) \\ &= 5 \times 2 \\ &= 10 \end{aligned}$$

The induced voltage is 10 (volts/microvolts/millivolts) _______________.

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19. Try working another problem yourself. The inductance is 10 mh, the change in current is 2 ma., and the change in time is 1 millisecond. What is the induced voltage? ____________________

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20. L = 2 μh; I = 3 microamperes; and Δt = 2 microseconds. E = ________

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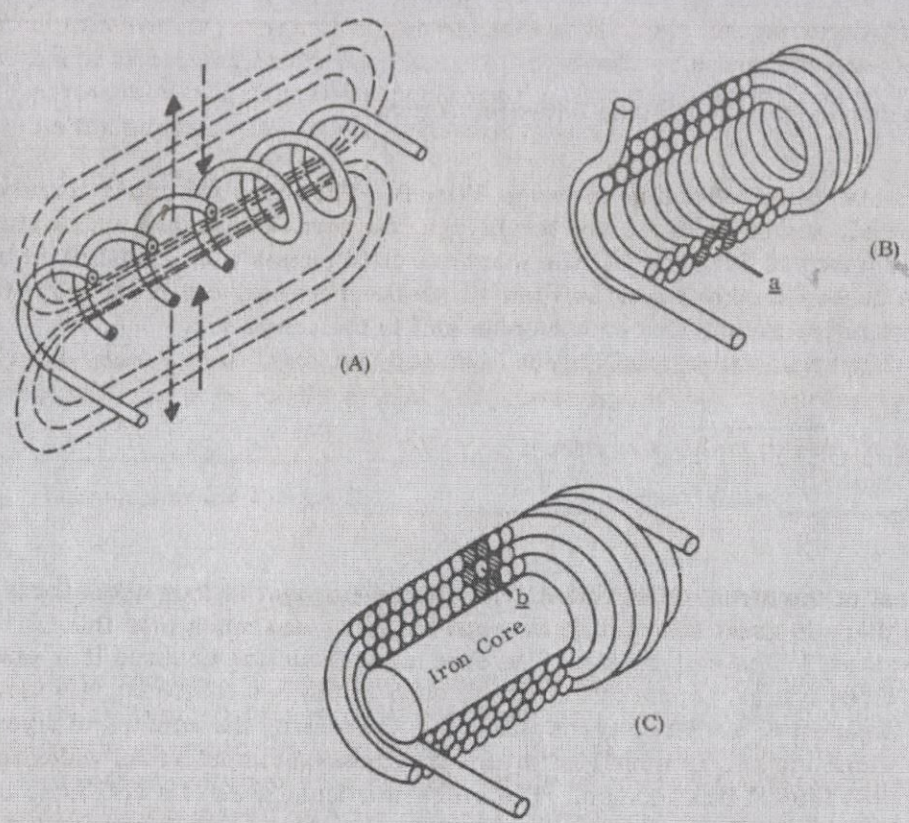

Figure 8-2. Coils of various inductors.

Refer to Figure 8-2 for Frames 21 through 26.

21. Many things affect the self-inductance of a circuit. One important factor is the degree of linkage, or interaction, between the circuit conductors and the associated magnetic flux. In a straight length of conductor, there is very little flux linkage between one part of the conductor and another. Therefore, its inductance is extremely small. Conductors become much more inductive when they are wound into coils, as shown in Figure 8-2. This is true because there is maximum flux linkage between the conductor turns, which lie side by side in the coil. Of the three coils (A, B, and C) shown in Figure 8-2, which one do you think has the poorest flux linkage?

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22. The coil in View A is a poor inductor compared to the others, because its turns are widely spaced, thus decreasing the flux linkage between its turns. (Remember that a magnetic field becomes weaker as it moves out in space.) How could you increase the flux linkage of the coil in View A?

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23. A more inductive coil is shown in View B. The turns are more closely spaced, and since there are two layers, the turns are linked with a greater number of flux loops as the magnetic field moves out, as indicated by the dashed arrows shown in View A. In other words, there are more opportunities for the flux to induce an emf in the conductor.

The turn labeled a in View B is directly adjacent to how many other turns? __________

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24. Most of the turns of the coil in View B are adjacent to four other turns, so there is great interaction between the turns and much less flux is "wasted." The coil in View C is even more inductive because it is wound in three layers. Some of the turns, such as the one labeled b, are directly adjacent to six other turns (shaded). Increasing the number of layers in which the coil is wound increases its cross-sectional area, which improves lateral flux linkage. The cross-sectional area of a coil is an important factor in its inductance. To make a coil more inductive would you increase or decrease its cross-sectional area? ________________

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25. We have seen that the inductance of a coil is affected by the number of turns, the spacing between the turns, and the cross-sectional area of the coil. The spacing of the turns and the cross-sectional area are actually considered together as one factor: the ratio of the cross-sectional area to the length of the coil. Summarize the two major factors affecting inductance that you have learned so far. ______________________

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26. One other important factor affecting inductance is illustrated by the coil in View C of Figure 8-2, which is the most inductive of the three shown. Not only does it have the greatest number of turns and the greatest ratio of cross-sectional area to length, but it has an iron core. (The other two coils have air cores.) As you learned in Chapter Six, permeability (symbol μ) is related to the core material of a coil. An iron core is highly permeable, which greatly increases the inductance of the coil in View C. As the permeability of the core material is increased, what happens to the inductance? ______________________________

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27. The Greek letter mu (μ) stands for two things in electricity. (1) As the symbol for a characteristic of a magnetic material, it represents ____________________. (2) As a numerical prefix, it is an abbreviation for the prefix ____________, which means ____________.

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28. There are several equations in advanced electricity that take permeability into account. While you will not study them in this book, you should know that the permeability of a magnetic material (μ) is assigned a numerical value that represents its relative ability to conduct magnetic lines of force as compared with air, which is arbitrarily assigned a μ of 1. The magnetic materials commonly used in electrical applications have μ values that are much greater than 1. In an air-core coil, what is the value of μ? ________

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29. The inductance of a coil increases very rapidly as the number of turns is increased. It also increases as the coil is made shorter, the cross-sectional area is made larger, or the permeability of the core is increased. The four major factors affecting inductance are:

(1) ______________________________

(2) ______________________________

(3) ______________________________

(4) ______________________________

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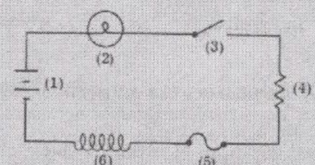
(Note: If you listed the ratio of the cross-sectional area to the length, you accounted for two of the factors.)

30. As you have learned, any electrical device has resistance, but sometimes resistors are used in a circuit for the simple purpose of limiting current flow. There is the same relationship between the terms <u>inductance</u> and <u>inductor</u>. Any current-carrying conductor has inductance, but a device manufactured to introduce inductance into a circuit is called an inductor. For example, there are inductors in a radio circuit that help to tune the radio to a certain station. As you might expect, there is a schematic symbol for inductance (whether it is planned or unplanned). Here is a simple schematic diagram that includes some symbols you have already learned as well as the symbol for an inductor.



The symbols in the above schematic are numbered. Write the meaning of each symbol.

(1) ____________________ (4) ____________________

(2) ____________________ (5) ____________________

(3) ____________________ (6) ____________________

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or

Growth and Decay of Current in an R-L Series Circuit

31. If a battery is connected across an inductor, the current builds up to its final value at a rate that is determined by the battery voltage and the circuit resistance. The current buildup is gradual because of the opposing emf (counter emf) resulting from the self-inductance of the coil.

How does the counter emf affect the buildup of current? __________

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32. When the current starts to flow, the magnetic lines of force move out, cut the turns of wire on the inductor, and build up a counter emf. What do you think this counter emf opposes? ____________________

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33. This opposition causes a delay in the time it takes the current to build up to a steady value. Later, when the battery is disconnected, the lines of force collapse, again cutting the turns of the inductor and building up an emf. What does this emf tend to do? ____________________

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34. Although the analogy is not exact, electrical inductance is somewhat like mechanical inertia. A large truck begins to move forward in a very low gear, because the inertia of a heavy weight at rest must be overcome. As the heavy truck begins to pick up speed, the driver changes to successively higher gears as the load becomes easier to move. The reverse occurs when the driver wishes to stop the truck. He must gear down to overcome the tendency of forward inertia to keep the load moving forward. In the case of inductance, it is electrical "inertia" that must be overcome. Figure 8-3, on the next page, shows a circuit that includes two switches, a battery, and a voltage divider containing containing a resistor (R) and an inductor (L). (The voltage dividers we have studied so far have consisted of resistors only; however, an inductor may be used as a component.) Switches S_1 and S_2 are "ganged," as indicated by the dashed line, so that when one is closed, the other is opened at exactly the same instant. Such an arrangement is called an R-L (resistive-inductive) series circuit. The source voltage of the battery is applied across the R-L combination (the resistor and inductor) when (S_1/S_2) __________ is closed.

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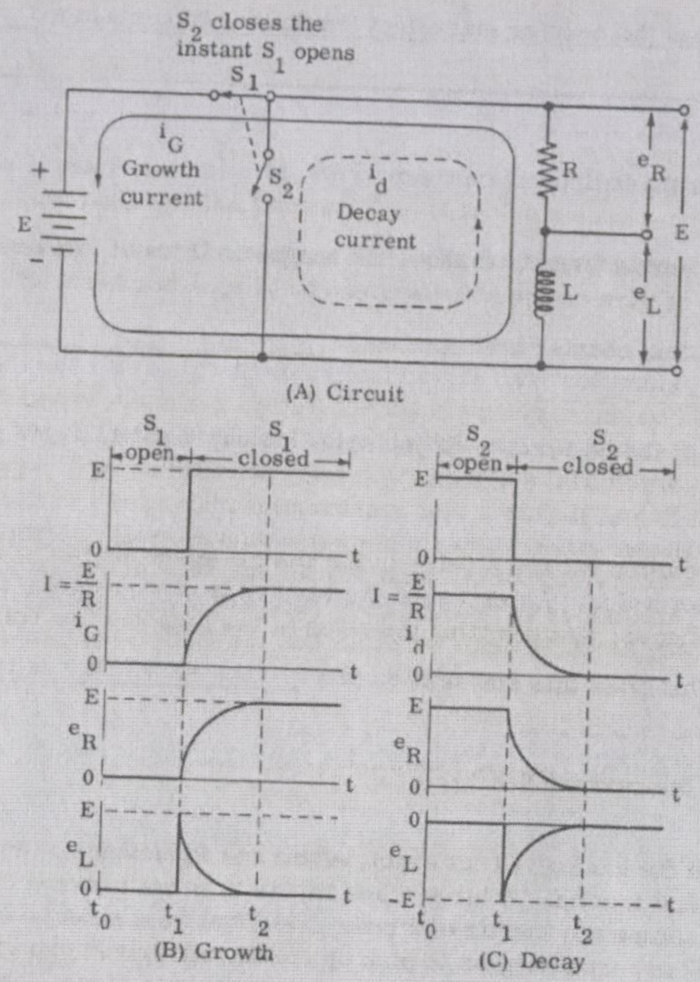

Figure 8-3. Growth and decay of current in an R-L series circuit.

Refer to Figure 8-3 for Frames 34 through 43.

35. As soon as S_1 is closed, as shown in View A of Figure 8-3, a voltage (E) appears across the R-L combination. A current attempts to flow, but the inductor opposes this current by building up a counter emf. At the first instant S_1 is closed, the counter emf (sometimes called "back emf") exactly equals the battery emf, and its polarity is opposite. Under this condition, will current flow in resistor R? ______

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36. Because no current can flow when the counter emf is exactly equal to the battery voltage, no voltage is dropped across R. View B shows this situation. The growth current (i_G), voltage across R (e_R), and voltage

across L (e_L) are all plotted along a time line. S_1 is first closed at time ($t_0/t_1/t_2$) ________.

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37. At time t_1, the growth current i_G (the current through R) is (zero/maximum) ________________, e_R is (zero/maximum) ________________, and e_L is (zero/maximum) ________________.

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38. At t_1, all of the battery voltage is dropped across L. Since the sum of all voltage drops in a series circuit must be equal to the source voltage, there is no voltage dropped across R. As current overcomes the opposition of the inductance and starts to flow, a voltage (e_R) appears across R; and e_L, the voltage across L, is reduced by the same amount. As i_G increases, (e_L/e_R) ________ also increases.

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39. The growth current i_G reaches maximum shortly before time ______.

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40. The curves in View B show that e_L finally reaches zero when i_G reaches maximum. At this point, all of the source voltage is dropped across the ________________.

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41. Under the steady-state condition (when there is no counter emf and "normal" current flows in the circuit), only the resistor limits the size of the current. Any conductor is considered to have some resistance, but wire resistance is usually ignored. Therefore, the resistance of the coil in Figure 8-3 is regarded as zero. The inductance of the coil opposed the growth of current in View A of Figure 8-3. View C shows that it also opposes the <u>decay</u> of current when the battery switch S_1 is opened. S_1 is

opened, and S_2 is closed, at time ($t_0/t_1/t_2$) ______.

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42. When S_2 is closed, the battery voltage is removed from the circuit, and another circuit is provided for the flow of the decay current i_d. When the battery voltage is removed from the circuit, the magnetic field of L collapses, and lines of force again cut the turns of the coil. The induced voltage e_L is maximum at time (t_1/t_2) ______, as shown in View C. (Note the new position of the zero line, which was moved for easier comparison of the growth and decay curves.)

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43. At the first instant S_2 is closed, e_L is essentially the same value as the battery voltage, which is now disconnected. The decay current i_d flows through R in the same direction as did current i_G when the battery was in the circuit. At time t_1, e_R is maximum, but it rapidly falls to zero as e_L reaches zero shortly before time ______.

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44. The growth of current in a circuit when the circuit is completed by a switch closure and the decay of current when a switch is opened are almost instantaneous. We have traced the growth and decay of current to show how an inductance opposes any change in current. When a circuit is closed, inductance tries to keep current from flowing. Its opposition is shortlived, however, because a moving magnetic field is necessary for a counter emf to be produced. Once the circuit current reaches its steady state, the field no longer moves, and no counter emf is produced.

When a circuit is opened, inductance again opposes a change in current flow and tries to keep it flowing by means of the counter emf, which is now produced by the collapsing magnetic field. But the opposition to a decrease in circuit current is only momentary, because there is no motion of the magnetic field (in fact, it does not exist) once it completely collapses.

How does inductance affect circuit current when a switch is first closed to complete a circuit? ______________________________

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45. How does inductance affect circuit current when a switch is opened?

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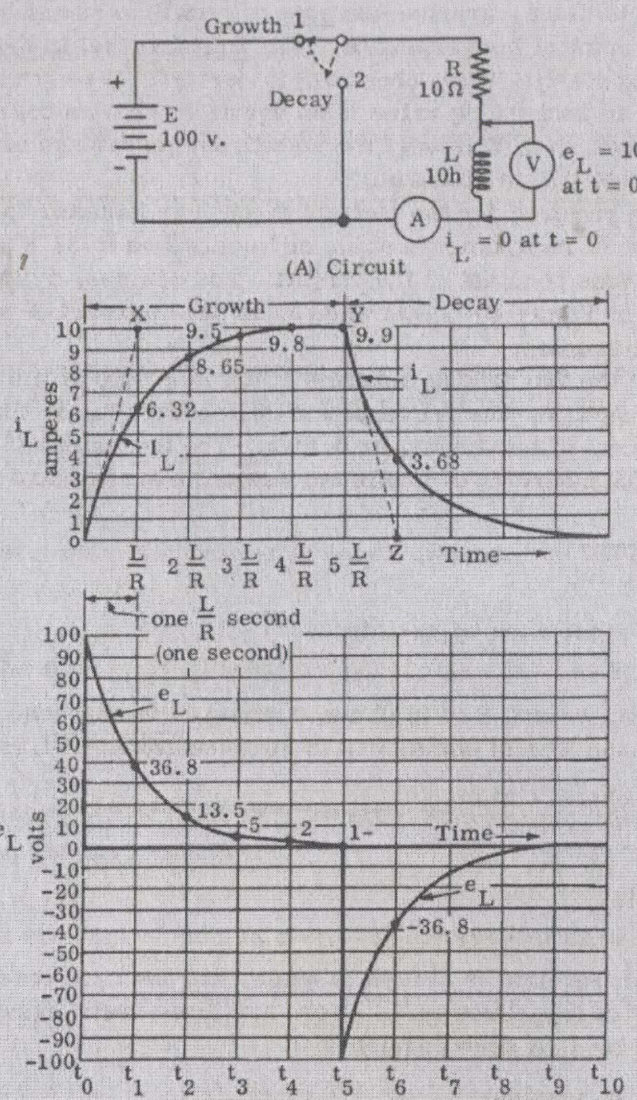

(A) Circuit

(B) Growth and Decay Graphs

Figure 8-4. L/R time constant.

Refer to Figure 8-4 for Frames 46 through 54.

<u>L/R Time Constant</u>

46. The time required for the growth or decay of current in an R-L circuit is important in many electronic circuits. These applications are beyond the scope of this book, but if you plan to go on to advanced electricity, you

will want to learn the fundamentals of the L/R time constant.

As the curves in Figure 8-3 indicate, growth and decay are rapid at first, and then the curves flatten out. The top graph of Figure 8-4 shows the growth of current through the inductor (i_L), while the bottom graph shows the corresponding decay of induced voltage (e_L). After several intervals of time—which are labeled L/R, 2L/R, etc. on the i_L graph and t_1, t_2, etc. on the e_L graphs—the rate of growth or decay has slowed down to the point of insignificance. The first interval is the one from which the expression "time constant" is derived. We normally think of a constant as an unchanging value in an equation. In this case, the constant has to be calculated; it is only the significant percentage of maximum current or voltage that is constant.

The time required for the current through an inductor to increase to 63.2 percent of its maximum value or to decrease to 36.8 percent is known as the L/R time constant of the circuit. You can see, by comparing the two graphs in Figure 8-4, that when i_L is 63.2 percent of maximum, e_L is 36.8 of maximum.

Compare the two graphs in terms of the intervals of time. At time t_1 on the e_L graph, e_L has decreased to 36.8 percent as i_L has increased to 63.2 percent of maximum, or 6.32 a. The increment of time during which this 63.2 percent of maximum was achieved is found by dividing

______ by ______.

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47. If L is in henries and R is in ohms, t (time) is in seconds. If L is in microhenries and R is in ohms, t is in microseconds. If L is in millihenries and R is in ohms, t is in ____________________.

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48. R in the L/R equation is always in ohms, and the time constant is of the same order of magnitude as L. Here are three useful relations used in calculating the L/R time constant:

$$\frac{\text{L (in henries)}}{\text{R (in ohms)}} = \text{t (in seconds)}$$

$$\frac{\text{L (in millihenries)}}{\text{R (in ohms)}} = \text{t (in milliseconds)}$$

$$\frac{\text{L (in microhenries)}}{\text{R (in ohms)}} = \text{t (in microseconds)}$$

In Figure 8-4, R = 10Ω and L = 10 h. How long does it take i_L to reach 63.2 percent of its maximum value? ____________________

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49. If L = 15 mh and R = 5Ω, how long does it take e_L to decay to 36.8 percent of its maximum value? ____________________

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50. Given the values of L and R, how would you find the time between t_0 and t_1? ____________________

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51. The current through the inductor (i_L) in Figure 8-4 takes 1 microsecond to grow from 0 to 6.32 a. How long does it take i_L to grow from 0 to 9.8 a.? ____________

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(At the end of 4 L/R intervals on the graph, the current i_L is 9.8 a.)

52. During the time i_L increases to 6.32 a., as shown in Figure 8-4, e_L decreases to ________ v.

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(This is the value at t_1 on the bottom graph, which corresponds to L/R on the top graph.)

53. The time constant of an L-R circuit is always expressed as a ratio between ________________ and ________________.

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54. What is the L/R time constant of an R-L circuit? ____________
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Mutual Inductance

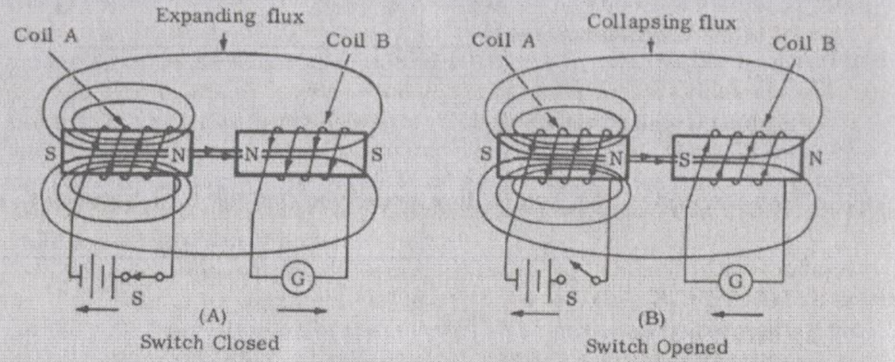

Figure 8-5. Mutual inductance.

Refer to Figure 8-5 for Frames 55 through 63.

55. Only one coil or conductor is involved in self-inductance. Whenever two coils are located so that the flux from one coil links with the turns of the other, a change of flux in one coil will cause an emf to be induced in the other. The two coils have mutual inductance. The amount of mutual inductance depends on the relative position of the two coils. If the coils are separated by a considerable distance, the amount of flux common to both coils is small, and the mutual inductance is low. On the other hand, if the coils are close together, so that nearly all the flux of one coil links the turns of the other, the mutual inductance is high. If we wind the two coils on the same iron core, would the mutual inductance be increased or decreased? ______________

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56. The two coils shown in Figure 8-5 are placed close together with their north-south axes in the same plane (that is, so that a single imaginary line could be extended through both coils). Coil A is connected to a battery through switch S, and Coil B is connected to a galvanometer (one kind of meter that measures current). When the switch is closed (View A), there is a momentary movement of the galvanometer needle to indicate current flow. What does this indicate? ______________

____

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57. The magnetic field associated with a conductor expands (moves out from its source) when current is turned on, then collapses (moves in toward its source) when current is turned off. In other words, the field is moving as it expands or collapses. The current is induced in Coil B because the magnetic field generated by Coil A is (expanding/collapsing)

__________________.

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58. When the current in Coil A reaches a steady value, the associated magnetic field is no longer expanding. Will the galvanometer now indicate current flow? ______

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59. When does current flow in Coil B? ______________________________

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60. In View B, the switch is opened. The galvanometer will momentarily indicate current flow in Coil B. Why? ______________________

____

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61. When current begins to flow in Coil B, an expanding magnetic field cuts the turns of Coil A. This causes a current opposite to battery current to be induced in Coil A. Thus, the buildup of current in Coil A is somewhat

__________________.

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62. When the switch is opened in the circuit of Coil A, current does not stop flowing instantly because the collapsing field of Coil B tends to ________ the current flow in Coil A.

- - - - - - - - - - -

63. There would still be mutual inductance between the two coils in Figure 8-5 if they were placed side by side instead of end to end; but the degree of inductance would be different, because the magnetic fields would cut the turns of the coils in a different manner. For simplicity, we have discussed current flow in Coil B as it is related to the magnetic field of Coil A. Naturally, Coil A also has self-inductance because of its own current flow.

Remember that the magnetic field associated with Coil A induces a voltage (and thus causes current flow) in Coil B only when the magnetic field of Coil A is expanding or collapsing. The power source for Coil A is a battery, so the current must be turned on or off before there is mutual inductance. If the power source were a-c, the current would be changing direction constantly, and the field would be alternately expanding and collapsing as long as current flowed. As long as the magnetic field has motion in either direction, there is mutual inductance. Explain, in terms of the magnetic field of Coil A, how a voltage is induced in Coil B.

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Calculation of Total Inductance

64. If inductors in series are well shielded, or located far enough apart to make the effects of mutual inductance negligible, the total inductance is calculated in the same manner as for resistances in series; you merely add them:

$$L_t = L_1 + L_2 + L_3 \ldots \text{(etc.)}$$

What is the total inductance in a series circuit containing three coils (totally shielded) whose values are 50 μh, 30 μh, and 20 μh? __________

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65. If there is no mutual inductance between coils in a parallel circuit, the total inductance is again calculated in the same manner as for resistances in parallel:

$$\frac{1}{L_t} = \frac{1}{L_1} + \frac{1}{L_2} + \frac{1}{L_3} \ldots \text{(etc.)}$$

A portion of a circuit contains three totally shielded inductors in parallel. The values of the three inductances are: 5 mh, 10 mh, and 30 mh.

What is the total inductance? __________

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ely)

66. Two inductances in parallel (with no mutual inductance) have values of 3 μh and 6 μh. What is L_t? (Hint: Use the product-over-sum method.)

____

In this chapter, you have learned how inductance opposes any change in current flow, through the principles of self-inductance, and how, through mutual inductance, current can be made to flow in a circuit that has no power source of its own.

You have learned how the motion of a magnetic field associated with an inductor causes a voltage to be induced in either the same inductor or some other inductor within the field.

You have learned to calculate the induced voltage when the inductance is known, the L/R time constant of a circuit, and the total inductance of both series and parallel inductors.

When you feel that you understand the material in this chapter, go on to the Self-Test.

Self-Test

The following questions will test your understanding of Chapter Eight. Write your answers on a separate sheet of paper and check them with the answers provided following the test.

1. Self-inductance results from what characteristic of electric current?
2. When current flows in a conductor, how is a self-induced emf produced in the conductor?

3. How does inductance act to influence the current flowing in a conductor?

4. For inductance, what are (a) the mathematical symbol, (b) the unit of measurement, and (c) the abbreviation of the unit of measurement?

5. Assume that an inductance of 5 μh exists when the current in a conductor is changing at the rate of 12 microamperes every 3 microseconds. What voltage is induced in the conductor?

6. List the four major factors affecting the inductance of a coil and state whether an increase in each factor will increase or decrease inductance.

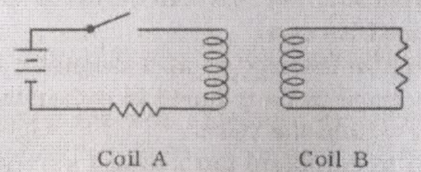
7. Draw the schematic symbol for an inductor.

8. How does inductance affect circuit current in each of the following cases? (Include the action of the magnetic field in your answers.)
   (a) When a switch is first closed to complete a circuit.
   (b) When a switch is first opened to interrupt current flow.

9. The inductance of an R-L circuit is 15 mh and the resistance is 3 Ω. What is the L/R time constant of the circuit?

10. The current through an inductor in an R-L circuit reaches 40 percent of its maximum value in 1 microsecond, 63.2 percent in 2 microseconds, and 95 percent in 6 microseconds. What is the L/R time constant of the circuit?

11. In the following diagram, there will be mutual inductance between Coil A and Coil B for a short time when the switch is closed and again when the switch is opened.



Explain, in terms of the magnetic field of Coil A, how a voltage is induced in Coil B.

12. Three inductors in series, but placed too far apart for mutual inductance, have values of 50 μh, 25 μh, and 15 μh. What is the total inductance?

13. Three inductors in parallel have inductances of 20 μh, 25 μh, and 100 μh. What is the total inductance if there is no mutual inductance?