* 21–14 Resonance in AC Circuits

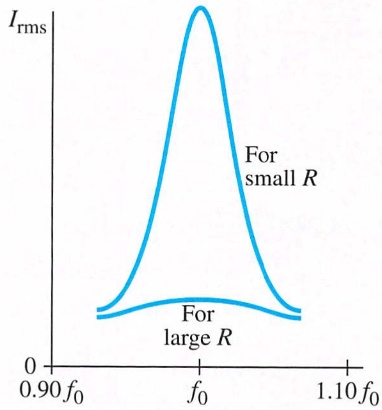

FIGURE 21–42 Current in an LRC circuit as a function of frequency, showing resonance peak at $f = f_0 = (1/2\pi)\sqrt{1/LC}$.

The rms current in an LRC series circuit is given by (see Eqs. 21–14, 21–15, 21–11b, and 21–12b):

$$I_{rms} = \frac{V_{rms}}{Z} = \frac{V_{rms}}{\sqrt{R^2 + \left(2\pi f L - \frac{1}{2\pi f C}\right)^2}}. \qquad \text{(21–18)}$$

Because the reactance of inductors and capacitors depends on the frequency f of the source, the current in an LRC circuit depends on frequency. From Eq. 21–18 we see that the current will be maximum at a frequency that satisfies

$$2\pi f L - \frac{1}{2\pi f C} = 0.$$

We solve this for f, and call the solution f_0:

Resonant frequency

$$f_0 = \frac{1}{2\pi}\sqrt{\frac{1}{LC}}. \qquad \text{(21–19)}$$

When $f = f_0$, the circuit is in resonance, and f_0 is the **resonant frequency** of the circuit. At this frequency, $X_C = X_L$, so the impedance is purely resistive. A graph of I_{rms} versus f is shown in Fig. 21–42 for particular values of R, L, and C. For smaller R compared to X_L and X_C, the resonance peak will be higher and sharper.

LC circuit

When R is very small, we speak of an ***LC* circuit**. The energy in an LC circuit oscillates, at frequency f_0, between the inductor and the capacitor, with some being dissipated in R (some resistance is unavoidable). This is called an ***LC* oscillation** or an **electromagnetic oscillation**. Not only does the charge oscillate back and forth, but so does the energy, which oscillates between being stored in the electric field of the capacitor and in the magnetic field of the inductor.

EM oscillations

Electric resonance is used in many circuits. Radio and TV sets, for example, use resonant circuits for tuning in a station. Many frequencies reach the circuit from the antenna, but a significant current flows only for frequencies at or near the resonant frequency. Either L or C is variable so that different stations can be tuned in (more on this in Chapter 22).

Summary

The **magnetic flux** passing through a loop is equal to the product of the area of the loop times the perpendicular component of the magnetic field strength:

$$\Phi_B = B_\perp A = BA\cos\theta. \qquad \text{(21–1)}$$

If the magnetic flux through a coil of wire changes in time, an emf is induced in the coil. The magnitude of the induced emf equals the time rate of change of the magnetic flux through the loop times the number N of loops in the coil:

$$\mathscr{E} = -N\frac{\Delta\Phi_B}{\Delta t}. \qquad \text{(21–2b)}$$

This is **Faraday's law of induction**.

The induced emf can produce a current whose magnetic field opposes the original change in flux (**Lenz's law**).

Faraday's law also tells us that a changing magnetic field produces an electric field; and that a straight wire of length l moving with speed v perpendicular to a magnetic field of strength B has an emf induced between its ends equal to

$$\mathscr{E} = Blv. \qquad \text{(21–3)}$$

An electric **generator** changes mechanical energy into electrical energy. Its operation is based on Faraday's law: a coil of wire is made to rotate uniformly by mechanical means in a magnetic field, and the changing flux through the coil induces a sinusoidal current, which is the output of the generator.

[*A motor, which operates in the reverse of a generator, acts like a generator in that a **back emf**, or **counter emf**, is induced in its rotating coil. Because this back emf opposes the input voltage, it can act to limit the current in a motor coil. Similarly, a generator acts somewhat like a motor in that a **counter torque** acts on its rotating coil.]

A **transformer**, which is a device to change the magnitude of an ac voltage, consists of a primary coil and a secondary coil. The changing flux due to an ac voltage in the primary coil induces an ac voltage in the secondary coil. In a 100% efficient transformer, the ratio of output to input voltages (V_S/V_P) equals the ratio of the number of turns N_S in the secondary to the number N_P in the primary:

$$\frac{V_S}{V_P} = \frac{N_S}{N_P}. \qquad \text{(21–6)}$$

The ratio of secondary to primary current is in the inverse ratio of turns:

$$\frac{I_S}{I_P} = \frac{N_P}{N_S}. \qquad \text{(21–7)}$$

Microphones, ground fault circuit interrupters, seismographs, and read/write heads for computer drives and tape recorders are applications of electromagnetic induction.

[*A changing current in a coil of wire will produce a changing magnetic field that induces an emf in a second coil placed nearby. The **mutual inductance**, M, is defined by

$$\mathscr{E}_2 = -M\frac{\Delta I_1}{\Delta t}. \qquad \textbf{(21–8)]}$$

[*Within a single coil, the changing B due to a changing current induces an opposing emf, $\mathscr{E}$, so a coil has a **self-inductance** L defined by

$$\mathscr{E} = -L\frac{\Delta I}{\Delta t}. \qquad \textbf{(21–9)]}$$

[*The energy stored in an inductance L carrying current I is given by $U = \frac{1}{2}LI^2$. This energy can be thought of as being stored in the magnetic field of the inductor. The energy density u in any magnetic field B is given by

$$u = \frac{1}{2}\frac{B^2}{\mu_0}. \qquad \textbf{(21–10)]}$$

[*When an inductance L and resistor R are connected in series to a source of emf, V, the current rises as

$$I = \frac{V}{R}\left(1 - e^{-t/\tau}\right),$$

where $\tau = L/R$ is the time constant. If the battery is suddenly switched out of the LR circuit, the current drops exponentially, $I = I_{max}e^{-t/\tau}$.]

[*Inductive and capacitive **reactance**, X, defined as for resistors, is the proportionality constant between voltage and current (either the rms or peak values). Across an inductor,

$$V = IX_L, \qquad \textbf{(21–11a)}$$

and across a capacitor,

$$V = IX_C. \qquad \textbf{(21–12a)}$$

The reactance of an inductor increases with frequency

$$X_L = 2\pi fL, \qquad \textbf{(21–11b)}$$

whereas the reactance of a capacitor decreases with frequency f,

$$X_C = \frac{1}{2\pi fC}. \qquad \textbf{(21–12b)}$$

The current through a resistor is always in phase with the voltage across it, but in an inductor, the current lags the voltage by 90°, and in a capacitor the current leads the voltage by 90°.]

[*In an LRC series circuit, the total **impedance** Z is defined by the equivalent of $V = IR$ for resistance, namely,

$$V_0 = I_0 Z \quad \text{or} \quad V_{rms} = I_{rms}Z; \qquad \textbf{(21–14)}$$

Z is given by

$$Z = \sqrt{R^2 + (X_L - X_C)^2}. \qquad \textbf{(21–15a)]}$$

[*An LRC series circuit **resonates** at a frequency given by

$$f_0 = \frac{1}{2\pi}\sqrt{\frac{1}{LC}}. \qquad \textbf{(21–19)}$$

The rms current in the circuit is largest when the applied voltage has a frequency equal to f_0.]

Questions

1. What would be the advantage, in Faraday's experiments (Fig. 21–1), of using coils with many turns?
2. What is the difference between magnetic flux and magnetic field?
3. Suppose you are holding a circular ring of wire and suddenly thrust a magnet, south pole first, away from you toward the center of the circle. Is a current induced in the wire? Is a current induced when the magnet is held steady within the ring? Is a current induced when you withdraw the magnet? In each case, if your answer is yes, specify the direction.
4. Two loops of wire are moving in the vicinity of a very long straight wire carrying a steady current as shown in Fig. 21–43. Find the direction of the induced current in each loop.

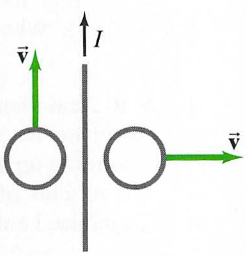

FIGURE 21–43 Question 4.

5. Suppose you are looking along a line through the centers of two circular (but separate) wire loops, one behind the other. A battery is suddenly connected to the front loop, establishing a clockwise current. (*a*) Will a current be induced in the second loop? (*b*) If so, when does this current start? (*c*) When does it stop? (*d*) In what direction is this current? (*e*) Is there a force between the two loops? (*f*) If so, in what direction?
6. In Fig. 21–44, determine the direction of the induced current in resistor R_A when (*a*) coil B is moved toward coil A, (*b*) when coil B is moved away from A, (*c*) when the resistance R_B is increased.

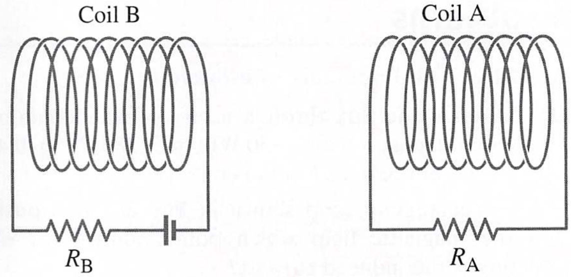

FIGURE 21–44 Question 6.

7. In situations where a small signal must travel over a distance, a "shielded cable" is used in which the signal wire is surrounded by an insulator and then enclosed by a cylindrical conductor carrying the return current. Why is a "shield" necessary?
8. What is the advantage of placing the two insulated electric wires carrying ac close together or even twisted about each other?

*9. Explain why, exactly, the lights may dim briefly when a refrigerator motor starts up. When an electric heater is turned on, the lights may stay dimmed as long as the heater is on. Explain the difference.

* **10.** Use Figs. 21–15 and 21–17 plus the right-hand rules to show why the counter torque in a generator *opposes* the motion.

* **11.** Will an eddy current brake (Fig. 21–20) work on a copper or aluminum wheel, or must the wheel be ferromagnetic? Explain.

* **12.** It has been proposed that eddy currents be used to help sort solid waste for recycling. The waste is first ground into tiny pieces and iron removed with a dc magnet. The waste then is allowed to slide down an incline over permanent magnets. How will this aid in the separation of nonferrous metals (Al, Cu, Pb, brass) from nonmetallic materials?

* **13.** The pivoted metal bar with slots in Fig. 21–45 falls much more quickly through a magnetic field than does a solid bar. Explain.

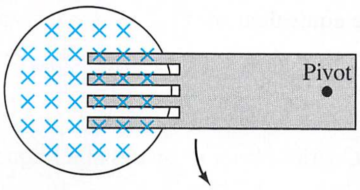

FIGURE 21–45 Question 13.

* **14.** If an aluminum sheet is held between the poles of a large bar magnet, it requires some force to pull it out of the magnetic field even though the sheet is not ferromagnetic and does not touch the pole faces. Explain.

* **15.** A bar magnet falling inside a vertical metal tube reaches a terminal velocity even if the tube is evacuated so that there is no air resistance. Explain.

* **16.** A metal bar, pivoted at one end, oscillates freely in the absence of a magnetic field; but in a magnetic field, its oscillations are quickly damped out. Explain. (This *magnetic damping* is used in a number of practical devices.)

17. An enclosed transformer has four wire leads coming from it. How could you determine the ratio of turns on the two coils without taking the transformer apart? How would you know which wires paired with which?

18. The use of higher-voltage lines in homes—say, 600 V or 1200 V—would reduce energy waste. Why are they not used?

19. A transformer designed for a 120-V ac input will often "burn out" if connected to a 120-V dc source. Explain. [*Hint*: the resistance of the primary coil is usually very low.]

* **20.** How would you arrange two flat circular coils so that their mutual inductance was (*a*) greatest, (*b*) least (without separating them by a great distance)?

* **21.** Does the emf of the battery in Fig. 21–33 affect the time needed for the *LR* circuit to reach (*a*) a given fraction of its maximum possible current, (*b*) a given value of current? Explain.

* **22.** In an *LRC* circuit, can the rms voltage across (*a*) an inductor, (*b*) a capacitor, be greater than the rms voltage of the ac source? Explain.

* **23.** Describe briefly how the frequency of the source emf affects the impedance of (*a*) a pure resistance, (*b*) a pure capacitance, (*c*) a pure inductance, (*d*) an *LRC* circuit near resonance (*R* small), (*e*) an *LRC* circuit far from resonance (*R* small).

* **24.** Describe how to make the impedance in an *LRC* circuit a minimum.

Problems

21–1 to 21–4 Faraday's Law of Induction

1. (I) The magnetic flux through a coil of wire containing two loops changes from −50 Wb to +38 Wb in 0.42 s. What is the emf induced in the coil?

2. (I) The rectangular loop shown in Fig. 21–46 is pushed into the magnetic field which points inward. In what direction is the induced current?

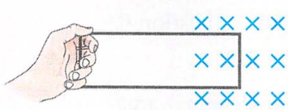

FIGURE 21–46 Problem 2.

3. (I) The north pole of the magnet in Fig. 21–47 is being inserted into the coil. In which direction is the induced current flowing through the resistor *R*?

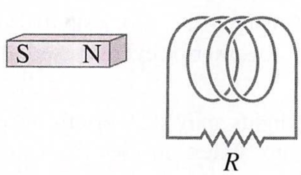

FIGURE 21–47 Problem 3.

4. (I) A 9.6-cm-diameter circular loop of wire is in a 1.10-T magnetic field. The loop is removed from the field in 0.15 s. What is the average induced emf?

5. (I) A 12.0-cm-diameter loop of wire is initially oriented perpendicular to a 1.5-T magnetic field. The loop is rotated so that its plane is parallel to the field direction in 0.20 s. What is the average induced emf in the loop?

6. (II) A 10.2-cm-diameter wire coil is initially oriented so that its plane is perpendicular to a magnetic field of 0.63 T pointing up. During the course of 0.15 s, the field is changed to one of 0.25 T pointing down. What is the average induced emf in the coil?

7. (II) A 15-cm-diameter circular loop of wire is placed in a 0.50-T magnetic field. (*a*) When the plane of the loop is perpendicular to the field lines, what is the magnetic flux through the loop? (*b*) The plane of the loop is rotated until it makes a 35° angle with the field lines. What is the angle θ in Eq. 21–1 for this situation? (*c*) What is the magnetic flux through the loop at this angle?

8. (II) (*a*) If the resistance of the resistor in Fig. 21–48 is slowly increased, what is the direction of the current induced in the small circular loop inside the larger loop? (*b*) What would it be if the small loop were placed outside the larger one, to the left?

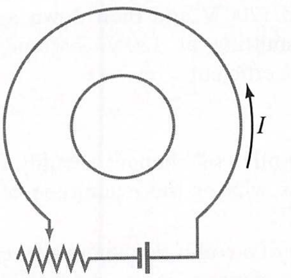

FIGURE 21–48 Problem 8.

9. (II) What is the direction of the induced current in the circular loop due to the current shown in each part of Fig. 21–49?

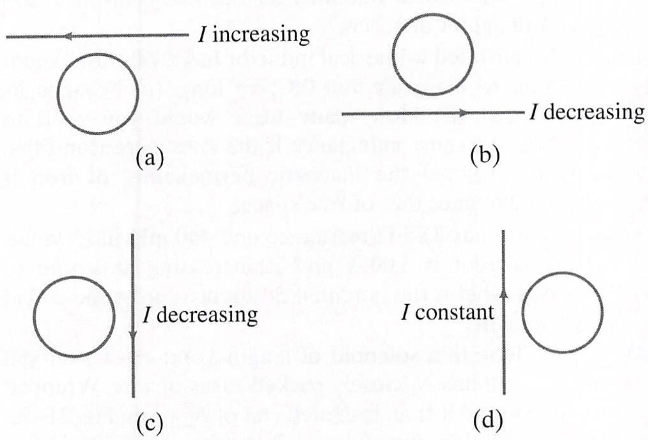

FIGURE 21–49 Problem 9.

10. (II) If the solenoid in Fig. 21–50 is being pulled away from the loop shown, in what direction is the induced current in the loop?

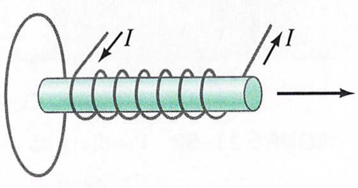

FIGURE 21–50 Problem 10.

11. (II) The magnetic field perpendicular to a circular wire loop 12.0 cm in diameter is changed from +0.52 T to −0.45 T in 180 ms, where + means the field points away from an observer and − toward the observer. (*a*) Calculate the induced emf. (*b*) In what direction does the induced current flow?

12. (II) The moving rod in Fig. 21–12 is 12.0 cm long and is pulled at a speed of 15.0 cm/s. If the magnetic field is 0.800 T, calculate (*a*) the emf developed, and (*b*) the electric field felt by electrons in the rod.

13. (II) A circular loop in the plane of the paper lies in a 0.75-T magnetic field pointing into the paper. If the loop's diameter changes from 20.0 cm to 6.0 cm in 0.50 s, (*a*) what is the direction of the induced current, (*b*) what is the magnitude of the average induced emf, and (*c*) if the coil resistance is 2.5 Ω, what is the average induced current?

14. (II) The moving rod in Fig. 21–12 is 13.2 cm long and generates an emf of 120 mV while moving in a 0.90-T magnetic field. (*a*) What is its speed? (*b*) What is the electric field in the rod?

15. (II) Part of a single rectangular loop of wire with dimensions shown in Fig. 21–51 is situated inside a region of uniform magnetic field of 0.550 T. The total resistance of the loop is 0.230 Ω. Calculate the force required to pull the loop from the field (to the right) at a constant velocity of 3.40 m/s. Neglect gravity.

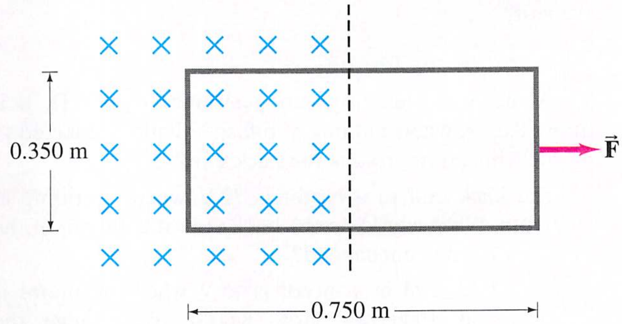

FIGURE 21–51 Problem 15.

16. (II) A 500-turn solenoid, 25 cm long, has a diameter of 2.5 cm. A 10-turn coil is wound tightly around the center of the solenoid. If the current in the solenoid increases uniformly from 0 to 5.0 A in 0.60 s, what will be the induced emf in the short coil during this time?

17. (II) In Fig. 21–12, the rod moves with a speed of 1.6 m/s, is 30.0 cm long, and has a resistance of 2.5 Ω. The magnetic field is 0.35 T, and the resistance of the U-shaped conductor is 25.0 Ω at a given instant. Calculate (*a*) the induced emf, (*b*) the current in the U-shaped conductor, and (*c*) the external force needed to keep the rod's velocity constant at that instant.

18. (III) A 22.0-cm-diameter coil consists of 20 turns of circular copper wire 2.6 mm in diameter. A uniform magnetic field, perpendicular to the plane of the coil, changes at a rate of 8.65×10^{-3} T/s. Determine (*a*) the current in the loop, and (*b*) the rate at which thermal energy is produced.

19. (III) The magnetic field perpendicular to a single 13.2-cm-diameter circular loop of copper wire decreases uniformly from 0.750 T to zero. If the wire is 2.25 mm in diameter, how much charge moves past a point in the coil during this operation?

21–5 Generators

20. (I) A simple generator is used to generate a peak output voltage of 24.0 V. The square armature consists of windings that are 6.0 cm on a side and rotates in a field of 0.420 T at a rate of 60.0 rev/s. How many loops of wire should be wound on the square armature?

21. (II) The generator of a car idling at 1100 rpm produces 12.4 V. What will the output be at a rotation speed of 2500 rpm, assuming nothing else changes?

22. (II) Show that the rms output (Section 18–7) of an ac generator is $V_{rms} = NAB\omega/\sqrt{2}$, where $\omega = 2\pi f$.

23. (II) A simple generator has a 320-loop square coil 21.0 cm on a side. How fast must it turn in a 0.650-T field to produce a 120-V peak output?

24. (II) A 450-loop circular armature coil with a diameter of 8.0 cm rotates at 120 rev/s in a uniform magnetic field of strength 0.55 T. (*a*) What is the rms voltage output of the generator? (*b*) What would you do to the rotation frequency in order to double the rms voltage output?

25. (II) A generator rotates at 85 Hz in a magnetic field of 0.030 T. It has 1000 turns and produces an rms voltage of 150 V and an rms current of 70.0 A. (*a*) What is the peak current produced? (*b*) What is the area of each turn of the coil?

* 21–6 Back EMF and Torque

***26.** (I) A motor has an armature resistance of 3.25 Ω. If it draws 8.20 A when running at full speed and connected to a 120-V line, how large is the back emf?

***27.** (I) The back emf in a motor is 72 V when operating at 1800 rpm. What would be the back emf at 2500 rpm if the magnetic field is unchanged?

***28.** (II) The back emf in a motor is 95 V when the motor is operating at 1000 rpm. How would you change the motor's magnetic field if you wanted to reduce the back emf to 65 V when the motor was running at 2500 rpm?

***29.** (II) What will be the current in the motor of Example 21–9 if the load causes it to run at half speed?

21–7 Transformers

[Assume 100% efficiency, unless stated otherwise.]

30. (I) A transformer is designed to change 120 V into 10,000 V, and there are 164 turns in the primary coil. How many turns are in the secondary coil?

31. (I) A transformer has 320 turns in the primary coil and 120 in the secondary coil. What kind of transformer is this, and by what factor does it change the voltage? By what factor does it change the current?

32. (I) A step-up transformer increases 25 V to 120 V. What is the current in the secondary coil as compared to the primary coil?

33. (I) Neon signs require 12 kV for their operation. To operate from a 240-V line, what must be the ratio of secondary to primary turns of the transformer? What would the voltage output be if the transformer were connected backward?

34. (II) A model-train transformer plugs into 120-V ac and draws 0.35 A while supplying 7.5 A to the train. (*a*) What voltage is present across the tracks? (*b*) Is the transformer step-up or step-down?

35. (II) The output voltage of a 95-W transformer is 12 V, and the input current is 22 A. (*a*) Is this a step-up or a step-down transformer? (*b*) By what factor is the voltage multiplied?

36. (II) A transformer has 330 primary turns and 1340 secondary turns. The input voltage is 120 V and the output current is 15.0 A. What are the output voltage and input current?

37. (II) If 30 MW of power at 45 kV (rms) arrives at a town from a generator via 4.0-Ω transmission lines, calculate (*a*) the emf at the generator end of the lines, and (*b*) the fraction of the power generated that is wasted in the lines.

38. (III) 65 kW is to arrive at a town over two 0.100-Ω lines. Estimate how much power is saved if the voltage is stepped up from 120 V to 1200 V and then down again, rather than simply transmitting at 120 V. Assume the transformers are each 99% efficient.

* 21–9 Inductance

***39.** (I) If the current in a 180-mH coil changes steadily from 25.0 A to 10.0 A in 350 ms, what is the magnitude of the induced emf?

***40.** (I) What is the inductance of a coil if the coil produces an emf of 2.50 V when the current in it changes from −28.0 mA to +31.0 mA in 12.0 ms?

***41.** (I) What is the inductance L of a 0.60-m-long air-filled coil 2.9 cm in diameter containing 10,000 loops?

***42.** (I) How many turns of wire would be required to make a 130-mH inductance out of a 30.0-cm-long air-filled coil with a diameter of 5.2 cm?

***43.** (II) An air-filled cylindrical inductor has 2800 turns, and it is 2.5 cm in diameter and 28.2 cm long. (*a*) What is its inductance? (*b*) How many turns would you need to generate the same inductance if the core were iron-filled instead? Assume the magnetic permeability of iron is about 1200 times that of free space.

***44.** (II) A coil has 2.25-Ω resistance and 440-mH inductance. If the current is 3.00 A and is increasing at a rate of 3.50 A/s, what is the potential difference across the coil at this moment?

***45.** (III) A long thin solenoid of length l and cross-sectional area A contains N_1 closely packed turns of wire. Wrapped tightly around it is an insulated coil of N_2 turns, Fig. 21–52. Assume all the flux from coil 1 (the solenoid) passes through coil 2, and calculate the mutual inductance.

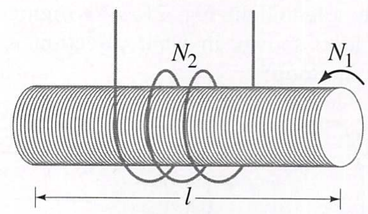

FIGURE 21–52 Problem 45.

***46.** (III) The wire of a tightly wound solenoid is unwound and used to make another tightly wound solenoid of twice the diameter. By what factor does the inductance change?

* 21–10 Magnetic Energy Storage

***47.** (I) The magnetic field inside an air-filled solenoid 36 cm long and 2.0 cm in diameter is 0.80 T. Approximately how much energy is stored in this field?

***48.** (II) At a given instant the current through an inductor is 50.0 mA and is increasing at the rate of 115 mA/s. What is the initial energy stored in the inductor if the inductance is known to be 60.0 mH, and how long does it take for the energy to increase by a factor of 10 from the initial value?

* 49. (II) Assuming the Earth's magnetic field averages about 0.50×10^{-4} T near the surface of the Earth, estimate the total energy stored in this field in the first 10 km above the Earth's surface.

* 21–11 *LR* Circuit

* 50. (II) Determine $\Delta I/\Delta t$ at $t = 0$ (when the battery is connected) for the *LR* circuit of Fig. 21–33 and show that if I continued to increase at this rate, it would reach its maximum value in one time constant.

* 51. (III) After how many time constants does the current in Fig. 21–33 reach within (*a*) 10%, (*b*) 1.0%, and (*c*) 0.1% of its maximum value?

* 52. (III) Two tightly wound solenoids have the same length and circular cross-sectional area. But solenoid 1 uses wire that is half as thick as solenoid 2. (*a*) What is the ratio of their inductances? (*b*) What is the ratio of their inductive time constants (assuming no other resistance in the circuits)?

* 21–12 AC Circuits and Reactance

* 53. (I) What is the reactance of a 7.20-μF capacitor at a frequency of (*a*) 60.0 Hz, (*b*) 1.00 MHz?

* 54. (I) At what frequency will a 22.0-mH inductor have a reactance of 660 Ω?

* 55. (I) At what frequency will a 2.40-μF capacitor have a reactance of 6.70 kΩ?

* 56. (II) Plot a graph of the reactance of a 1.0-μF capacitor as a function of frequency from 10 to 1000 Hz.

* 57. (II) Plot a graph of the reactance of a 1.0-mH inductor as a function of frequency from 100 to 10,000 Hz.

* 58. (II) Calculate the reactance of, and rms current in, a 160-mH radio coil connected to a 240-V (rms) 10.0-kHz ac line. Ignore resistance.

* 59. (II) An inductance coil operates at 240 V and 60.0 Hz. It draws 12.8 A. What is the coil's inductance?

* 60. (II) (*a*) What is the reactance of a well-insulated 0.030-μF capacitor connected to a 2.0-kV (rms) 720-Hz line? (*b*) What will be the peak value of the current?

* 21–13 *LRC* Circuits

* 61. (I) A 30-kΩ resistor is in series with a 45-mH inductor and an ac source. Calculate the impedance of the circuit if the source frequency is (*a*) 50 Hz, and (*b*) 3.0×10^4 Hz.

* 62. (I) A 3.5-kΩ resistor and a 4.0-μF capacitor are connected in series to an ac source. Calculate the impedance of the circuit if the source frequency is (*a*) 60 Hz, and (*b*) 60,000 Hz.

* 63. (I) For a 120-V rms 60-Hz voltage, an rms current of 70 mA passing through the human body for 1.0 s could be lethal. What must be the impedance of the body for this to occur?

* 64. (II) What is the resistance of a coil if its impedance is 235 Ω and its reactance is 135 Ω?

* 65. (II) What are the total impedance, phase angle, and rms current in an *LRC* circuit connected to a 10.0-kHz, 725-V (rms) source if $L = 22.0$ mH, $R = 8.70$ kΩ, and $C = 6250$ pF?

* 66. (III) A 2.5-kΩ resistor in series with a 420-mH inductor is driven by an ac power supply. At what frequency is the impedance double that of the impedance at 60 Hz?

* 67. (III) (*a*) What is the rms current in an *RL* circuit when a 60.0-Hz 120-V rms ac voltage is applied, where $R = 1.80$ kΩ, and $L = 350$ mH? (*b*) What is the phase angle between voltage and current? (*c*) What are the rms voltage readings across R and L?

* 68. (III) (*a*) What is the rms current in an *RC* circuit if $R = 8.80$ kΩ, $C = 1.80\ \mu$F, and the rms applied voltage is 120 V at 60.0 Hz? (*b*) What is the phase angle between voltage and current? (*c*) What are the voltmeter readings across R and C?

* 21–14 Resonance in AC Circuits

* 69. (I) A 3500-pF capacitor is connected to a 55.0-μH coil of resistance 3.00 Ω. What is the resonant frequency of this circuit?

* 70. (I) The variable capacitor in the tuner of an AM radio has a capacitance of 2800 pF when the radio is tuned to a station at 580 kHz. (*a*) What must be the capacitance for a station at 1600 kHz? (*b*) What is the inductance (assumed constant)?

* 71. (II) An *LRC* circuit has $L = 14.8$ mH and $R = 4.40\ \Omega$. (*a*) What value must C have to produce resonance at 3600 Hz? (*b*) What will be the maximum current at resonance if the peak external voltage is 150 V?

General Problems

72. Suppose you are looking at two current loops in the plane of the page as shown in Fig. 21–53. When switch S is thrown in the left-hand coil, (*a*) what is the direction of the induced current in the other loop? (*b*) What is the situation after a "long" time? (*c*) What is the direction of the induced current in the right-hand loop if that loop is quickly pulled horizontally to the right?

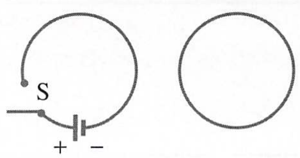

FIGURE 21–53 Problem 72.

73. A square loop 24.0 cm on a side has a resistance of 5.20 Ω. It is initially in a 0.665-T magnetic field, with its plane perpendicular to $\vec{\mathbf{B}}$, but is removed from the field in 40.0 ms. Calculate the electric energy dissipated in this process.

74. A high-intensity desk lamp is rated at 45 W but requires only 12 V. It contains a transformer that converts 120-V household voltage. (*a*) Is the transformer step-up or step-down? (*b*) What is the current in the secondary coil when the lamp is on? (*c*) What is the current in the primary coil? (*d*) What is the resistance of the bulb when on?

75. Power is generated at 24 kV at a generating plant located 118 km from a town that requires 50 MW of power at 12 kV. Two transmission lines from the plant to the town each have a resistance of 0.10 Ω/km. What should the output voltage of the transformer at the generating plant be for an overall transmission efficiency of 98.5%, assuming a perfect transformer?

76. The primary windings of a transformer which has an 80% efficiency are connected to 110-V ac. The secondary windings are connected across a 2.4-Ω, 75-W lightbulb. (*a*) Calculate the current through the primary windings of the transformer. (*b*) Calculate the ratio of the number of primary windings of the transformer to the number of secondary windings of the transformer.

77. A pair of power transmission lines each have a 0.80-Ω resistance and carry 740 A over 9.0 km. If the rms input voltage is 42 kV, calculate (*a*) the voltage at the other end, (*b*) the power input, (*c*) power loss in the lines, and (*d*) the power output.

78. Two resistanceless rails rest 32 cm apart on a 6.0° ramp. They are joined at the bottom by a 0.60-Ω resistor. At the top a copper bar of mass 0.040 kg (ignore its resistance) is laid across the rails. The whole apparatus is immersed in a vertical 0.55-T field. What is the terminal (steady) velocity of the bar as it slides frictionlessly down the rails?

79. Show that the power loss in transmission lines, P_L, is given by $P_L = (P_T)^2 R_L/V^2$, where P_T is the power transmitted to the user, V is the delivered voltage, and R_L is the resistance of the power lines.

80. A coil with 150 turns, a radius of 5.0 cm, and a resistance of 12 Ω surrounds a solenoid with 230 turns/cm and a radius of 4.5 cm; see Fig. 21–54. The current in the solenoid changes at a constant rate from 0 to 2.0 A in 0.10 s. Calculate the magnitude and direction of the induced current in the coil.

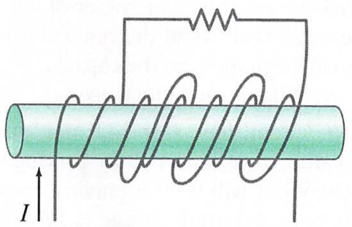

FIGURE 21–54 Problem 80.

81. A certain electronic device needs to be protected against sudden surges in current. In particular, after the power is turned on the current should rise no more than 7.5 mA in the first 120 μs. The device has resistance 150 Ω and is designed to operate at 55 mA. How would you protect this device?

82. A 25-turn 12.5-cm-diameter coil is placed between the pole pieces of an electromagnet. When the magnet is turned on, the flux through the coil changes, inducing an emf. At what rate (in T/s) must the field produced by the magnet change if the emf is to be 120 V?

* **83.** Calculate the peak output voltage of a simple generator whose square armature windings are 6.60 cm on a side; the armature contains 155 loops and rotates in a field of 0.200 T at a rate of 120 rev/s.

* **84.** Typical large values for electric and magnetic fields attained in laboratories are about 1.0×10^4 V/m and 2.0 T. (*a*) Determine the energy density for each field and compare. (*b*) What magnitude electric field would be needed to produce the same energy density as the 2.0-T magnetic field?

* **85.** What is the inductance L of the primary of a transformer whose input is 220 V at 60.0 Hz if the current drawn is 5.8 A? Assume no current in the secondary.

* **86.** A 130-mH coil whose resistance is 18.5 Ω is connected to a capacitor C and a 1360-Hz source voltage. If the current and voltage are to be in phase, what value must C have?

* **87.** An inductance coil draws 2.5-A dc when connected to a 36-V battery. When connected to a 60-Hz 120-V (rms) source, the current drawn is 3.8 A (rms). Determine the inductance and resistance of the coil.

* **88.** A 135-mH inductor with 2.0-Ω resistance is connected in series to a 20-μF capacitor and a 60-Hz, 45-V source. Calculate (*a*) the rms current, and (*b*) the phase angle.

* **89.** The **Q factor** of a resonance circuit can be defined as the ratio of the voltage across the capacitor (or inductor) to the voltage across the resistor, at resonance. The larger the Q factor, the sharper the resonance curve will be and the sharper the tuning. (*a*) Show that the Q factor is given by the equation $Q = (1/R)\sqrt{L/C}$. (*b*) At a resonant frequency $f_0 = 1.0$ MHz, what must be the values of L and R to produce a Q factor of 550? Assume that $C = 0.010\ \mu$F.

Answers to Exercises

A: 0.0102 Wb.

B: (*a*) Counterclockwise; (*b*) clockwise; (*c*) zero; (*d*) counterclockwise.

C: Counterclockwise.

D: 10 turns.