Summary

- Ferromagnetic materials are made mostly from iron, cobalt, and nickel.
  - The field lines around terrestrial magnets flow from north to south as indicated by a magnetic compass.
- An electric current can generate a magnetic field.
  - The direction of electromagnetic fields can be determined using right-hand rules.
  - Interacting electromagnetic fields can produce forces on current-carrying wires or on moving electric charges.
  - An electric meter (voltmeter or ammeter) can be developed based on the twisting force on a wire caused by interacting electromagnetic fields.
- A wire moving in a magnetic field can have a current induced in it.
  - The magnetic flux of a current induced in a wire always opposes the magnetic flux of the current that induced it. This is known as Lenz's law.

Practice Exercises

*In each case, select the choice that best answers the question or completes the statement.*

1. Heating a magnet will
   (A) weaken it
   (B) strengthen it
   (C) reverse its polarity
   (D) produce new poles
   (E) have no effect
2. The emf produced by a generator operating at constant speed depends mainly on
   (A) the thickness of the wire on the armature
   (B) the thickness of the wire on the field magnet
   (C) the strength of the magnetic field
   (D) the length of time the generator operates
   (E) the size of the brushes
3. A factory gets its electrical power from a generator 2 kilometers away. The

two wires connecting the generator to the factory terminals have a resistance of 0.03 ohm per kilometer. When the generator supplies 50 amperes to the factory, the terminal voltage at the generator is 120 volts. A voltmeter connected to the factory terminals should then read

(A) 100 V
(B) 110 V
(C) 114 V
(D) 118 V
(E) 120 V
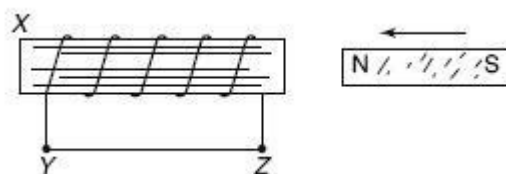
4. In the diagram above, X is a coil wire with a hollow core. The permanent magnet is pushed at constant speed from the right into the core and out again at the left. During the motion

(A) there will be no current in wire YZ
(B) current in wire YZ will be from Y to Z
(C) current in wire YZ will be from Z to Y
(D) current in wire YZ will be from Z to Y and then from Y to Z
(E) current in wire YZ will be from Y to Z and then from Z to Y
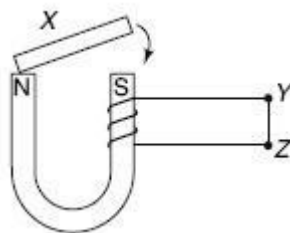
5. The soft-iron armature X in the above diagram is allowed to fall into position on top of the poles of the horseshoe magnet. While it falls,

(A) there will be no current in wire YZ
(B) current in wire YZ will be from Y to Z
(C) current in wire YZ will be from Z to Y
(D) current in wire YZ will be from Z to Y and then from Y to Z
(E) current in wire YZ will be from Y to Z and then from Z to Y
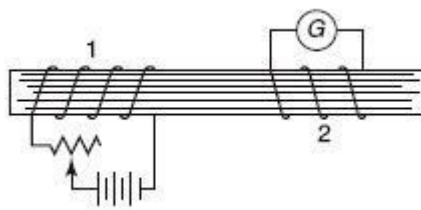
6. In the above diagram, G is a sensitive galvanometer connected to coil 2. Coil 1 is insulated from coil 2. Both coils are wound on the same iron core and are insulated from it. When the variable contact on the rheostat is moved halfway to the left, the needle on the galvanometer
(A) moves to the left
(B) moves to the right
(C) moves momentarily and then returns to its starting position
(D) doesn't move because coils 1 and 2 are insulated from each other
(E) doesn't move because coils 1 and 2 are insulated from the iron
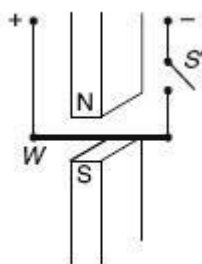
7. A horizontal copper wire W is shown above suspended between two magnetic poles by means of two flexible copper wires that are connected to a dc source through switch S'. A result of closing the switch will be
(A) a force on W toward the front
(B) a force on W toward the back
(C) a force on W toward the left
(D) a force on W toward the right
(E) no additional force on W

8. A 3-centimeter wire is moved at right angles across a uniform magnetic field with a speed of 2.0 meters per second. If the flux density is 5.0 teslas, what is the magnitude of the induced emf?
(A) 0.03 V
(B) 0.3 V
(C) 0.6 V
(D) 10 V
(E) 20 V

9. If a step-up transformer were 100% efficient, the primary and secondary windings would have the same
(A) current

(B) power
(C) number of turns
(D) voltage
(E) direction of winding

Questions 10 and 11

When a transformer is connected to 120-volt alternating current, it supplies 3,000 volts to a device. The current through the secondary winding then is 0.06 ampere, and the current through the primary is 2 amperes. The number of turns in the primary winding is 400.

10. The number of turns in the secondary winding is
   (A) 16
   (B) 30
   (C) 1,000
   (D) 2,000
   (E) 10,000
11. The efficiency of the transformer is
   (A) 75%
   (B) 80%
   (C) 85%
   (D) 90%
   (E) 95%

# Answer Key

1. **(A)**	5. **(B)**	9. **(B)**
2. **(C)**	6. **(C)**	10. **(B)**
3. **(C)**	7. **(B)**	11. **(A)**
4. **(B)**	8. **(B)**	

Answers Explained

1. **A** Heating increases the random motion of the particles in the magnet. This leads to a less orderly arrangement of molecular magnets (or domains) in the magnet, making the magnet weaker.
2. **C** The emf induced in a wire depends on the length of the wire cutting the magnetic field, on the strength of the magnetic field being cut, and on the speed with which the field is being cut at right angles. Of these, only the second is offered as a choice (C). In the practical design of the generator, the thickness of the wire used is important but does not affect directly the

emf produced because it does not affect the three factors mentioned. Once the generator reaches constant speed, the length of time the generator operates does not affect these three factors.

3. **C** Four kilometers of wire are used to connect the generator to the factory terminals. Since the wire has a resistance of 0.03 Ω/km, 4 km will have a resistance of 0.12 Ω. This resistance is in series with the factory load, which gets 50 A. The *IR* drop in the connecting wires = (50 A) × (0.12 Ω) = 6 V. Since the generator supplies 120 V to the circuit and the drop in the connecting wires is 6 V, 114 V will be left for the factory load. (In a series circuit, $V_T = V_1 + V_2$.) A voltmeter should measure this voltage at the factory terminals.

4. **E** When the magnet approaches the coil, conventional current will flow through the coil and from *Y* to *Z*. This follows from Lenz's law. An emf is induced in the coil (because the magnetic field moves with respect to the coil); the direction of the induced current must be such as to oppose the approach of the magnet by producing poles in the coil, as shown. The right-hand rule applied to the coil (thumb pointing in direction of N-pole) then gives the direction of electron flow indicated. When the magnet has moved through the coil and is moving away from it, the direction of the induced current must be reversed; in that case the poles of the coil will be reversed, as needed to oppose the motion. The conventional current will then be from *Z* to *Y*.
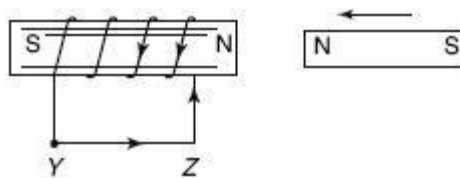
5. **B** The soft-iron armature *X* is magnetized by induction: The part on the left becomes an S-pole; the part on the right, an N-pole. The falling of *X* is then equivalent to a magnet moving near a coil and a current will be induced in the coil. According to Lenz's law, the direction of the current should be such as to oppose the falling of *X*. This will be the case if the top of the coil becomes an N-pole, opposing the falling N-pole. The right-hand rule for the coil indicates that conventional current in wire *YZ* is from *Y* to *Z*.

6. **C** There will be a change of current in coil 1; the resulting change in the magnetic field in the iron core affects coil 2 in spite of any insulation. The current is momentary, because an emf is induced only while there is a change in the magnetic field. We can't tell whether the needle moves momentarily to the left or the right because we don't have enough

information about the connection to the galvanometer.

7. **B** The closing of the switch results in conventional flow through W from left to right. The right-hand rule for a wire tells us the direction of the resulting magnetic field around the wire: in front of the wire downward, behind the wire upward. The magnetic field due to the two poles is thus reinforced in front, weakened in back of the wire. The resulting force on W is toward the back.

8. **B** $V = \mathbf{B}l\,\mathbf{v}$

   $= (5 \text{ teslas})(0.03 \text{ m})(2 \text{ m/s})$

   $= 0.3 \text{ volt}$

9. **B** Efficiency = (work or power output)/(work or power output). In order for this ratio to be equal to 1 (or 100%), the numerator and denominator must be equal; that is, the power supplied to the primary of the transformer equals the power supplied by the secondary to the device connected to it.

10. **E** In such a transformer,

$$\frac{\text{number of turns on the secondary}}{\text{number of turns on the primary}} = \frac{\text{secondary emf}}{\text{primary emf}}$$

$$\frac{N_s}{400} = \frac{3{,}000 \text{ V}}{120 \text{ V}}; \; N_s = 10{,}000$$

A $\text{Efficiency} = \dfrac{V_s I_s}{V_p I_p} = \dfrac{3{,}000 \text{ V} \times 0.06 \text{ A}}{120 \text{ V} \times 2 \text{ A}}$

$= 0.75 = 75\%$

11.

Problems & Exercises

23.1 Induced Emf and Magnetic Flux

1. What is the value of the magnetic flux at coil 2 in **Figure 23.56** due to coil 1?
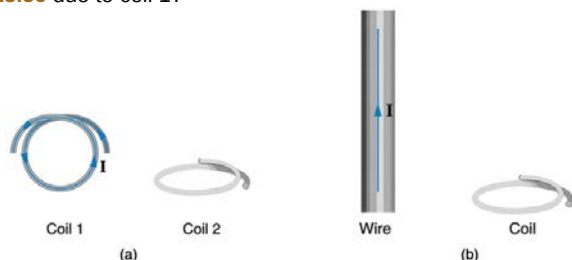

Figure 23.56 (a) The planes of the two coils are perpendicular. (b) The wire is perpendicular to the plane of the coil.

2. What is the value of the magnetic flux through the coil in **Figure 23.56**(b) due to the wire?

23.2 Faraday's Law of Induction: Lenz's Law

3. Referring to **Figure 23.57**(a), what is the direction of the current induced in coil 2: (a) If the current in coil 1 increases? (b) If the current in coil 1 decreases? (c) If the current in coil 1 is constant? Explicitly show how you follow the steps in the **Problem-Solving Strategy for Lenz's Law**.
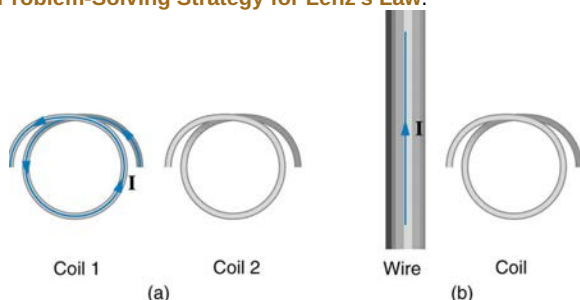

Figure 23.57 (a) The coils lie in the same plane. (b) The wire is in the plane of the coil

4. Referring to **Figure 23.57**(b), what is the direction of the current induced in the coil: (a) If the current in the wire increases? (b) If the current in the wire decreases? (c) If the current in the wire suddenly changes direction? Explicitly show how you follow the steps in the **Problem-Solving Strategy for Lenz's Law**.

5. Referring to **Figure 23.58**, what are the directions of the currents in coils 1, 2, and 3 (assume that the coils are lying in the plane of the circuit): (a) When the switch is first closed? (b) When the switch has been closed for a long time? (c) Just after the switch is opened?
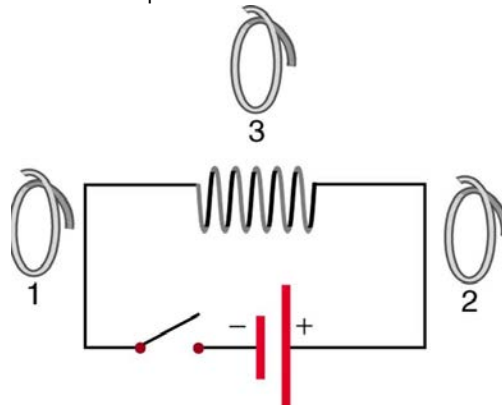

Figure 23.58

6. Repeat the previous problem with the battery reversed.

7. Verify that the units of $\Delta\Phi / \Delta t$ are volts. That is, show that $1 \text{ T} \cdot \text{m}^2 / \text{s} = 1 \text{ V}$.

8. Suppose a 50-turn coil lies in the plane of the page in a uniform magnetic field that is directed into the page. The coil originally has an area of 0.250 m^2. It is stretched to have no area in 0.100 s. What is the direction and magnitude of the induced emf if the uniform magnetic field has a strength of 1.50 T?

9. (a) An MRI technician moves his hand from a region of very low magnetic field strength into an MRI scanner's 2.00 T field with his fingers pointing in the direction of the field. Find the average emf induced in his wedding ring, given its diameter is 2.20 cm and assuming it takes 0.250 s to move it into the field. (b) Discuss whether this current would significantly change the temperature of the ring.

10. Integrated Concepts

Referring to the situation in the previous problem: (a) What current is induced in the ring if its resistance is 0.0100 Ω ? (b) What average power is dissipated? (c) What magnetic field is induced at the center of the ring? (d) What is the direction of the induced magnetic field relative to the MRI's field?

11. An emf is induced by rotating a 1000-turn, 20.0 cm diameter coil in the Earth's $5.00 \times 10^{-5} \text{ T}$ magnetic field. What average emf is induced, given the plane of the coil is originally perpendicular to the Earth's field and is rotated to be parallel to the field in 10.0 ms?

12. A 0.250 m radius, 500-turn coil is rotated one-fourth of a revolution in 4.17 ms, originally having its plane perpendicular to a uniform magnetic field. (This is 60 rev/s.) Find the magnetic field strength needed to induce an average emf of 10,000 V.

13. Integrated Concepts

Approximately how does the emf induced in the loop in **Figure 23.57**(b) depend on the distance of the center of the loop from the wire?

14. Integrated Concepts

(a) A lightning bolt produces a rapidly varying magnetic field. If the bolt strikes the earth vertically and acts like a current in a long straight wire, it will induce a voltage in a loop aligned like that in **Figure 23.57**(b). What voltage is induced in a 1.00 m diameter loop 50.0 m from a 2.00×10^6 A lightning strike, if the current falls to zero in $25.0 \, \mu s$? (b) Discuss circumstances under which such a voltage would produce noticeable consequences.

23.3 Motional Emf

15. Use Faraday's law, Lenz's law, and RHR-1 to show that the magnetic force on the current in the moving rod in **Figure 23.11** is in the opposite direction of its velocity.

16. If a current flows in the Satellite Tether shown in **Figure 23.12**, use Faraday's law, Lenz's law, and RHR-1 to show that there is a magnetic force on the tether in the direction opposite to its velocity.

17. (a) A jet airplane with a 75.0 m wingspan is flying at 280 m/s. What emf is induced between wing tips if the vertical component of the Earth's field is 3.00×10^{-5} T ? (b) Is an emf of this magnitude likely to have any consequences? Explain.

18. (a) A nonferrous screwdriver is being used in a 2.00 T magnetic field. What maximum emf can be induced along its 12.0 cm length when it moves at 6.00 m/s? (b) Is it likely that this emf will have any consequences or even be noticed?

19. At what speed must the sliding rod in **Figure 23.11** move to produce an emf of 1.00 V in a 1.50 T field, given the rod's length is 30.0 cm?

20. The 12.0 cm long rod in **Figure 23.11** moves at 4.00 m/s. What is the strength of the magnetic field if a 95.0 V emf is induced?

21. Prove that when B , ℓ , and v are not mutually perpendicular, motional emf is given by $\mathrm{emf} = B\ell v \sin\theta$. If v is perpendicular to B , then θ is the angle between ℓ and B . If ℓ is perpendicular to B , then θ is the angle between v and B .

22. In the August 1992 space shuttle flight, only 250 m of the conducting tether considered in **Example 23.2** could be let out. A 40.0 V motional emf was generated in the Earth's 5.00×10^{-5} T field, while moving at 7.80×10^3 m/s . What was the angle between the shuttle's velocity and the Earth's field, assuming the conductor was perpendicular to the field?

23. Integrated Concepts

Derive an expression for the current in a system like that in **Figure 23.11**, under the following conditions. The resistance between the rails is R , the rails and the moving rod are identical in cross section A and have the same resistivity ρ . The distance between the rails is l, and the rod moves at constant speed v perpendicular to the uniform field B . At time zero, the moving rod is next to the resistance R .

24. Integrated Concepts

The Tethered Satellite in **Figure 23.12** has a mass of 525 kg and is at the end of a 20.0 km long, 2.50 mm diameter cable with the tensile strength of steel. (a) How much does the cable stretch if a 100 N force is exerted to pull the satellite in? (Assume the satellite and shuttle are at the same altitude above the Earth.) (b) What is the effective force constant of the cable? (c) How much energy is stored in it when stretched by the 100 N force?

25. Integrated Concepts

The Tethered Satellite discussed in this module is producing 5.00 kV, and a current of 10.0 A flows. (a) What magnetic drag force does this produce if the system is moving at 7.80 km/s? (b) How much kinetic energy is removed from the system in 1.00 h, neglecting any change in altitude or velocity during that time? (c) What is the change in velocity if the mass of the system is 100,000 kg? (d) Discuss the long term consequences (say, a week-long mission) on the space shuttle's orbit, noting what effect a decrease in velocity has and assessing the magnitude of the effect.

23.4 Eddy Currents and Magnetic Damping

26. Make a drawing similar to **Figure 23.14**, but with the pendulum moving in the opposite direction. Then use Faraday's law, Lenz's law, and RHR-1 to show that magnetic force opposes motion.
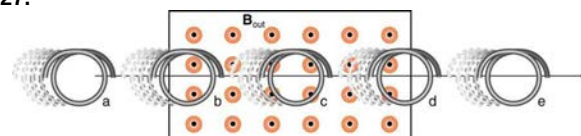
27.

Figure 23.59 A coil is moved into and out of a region of uniform magnetic field. A coil is moved through a magnetic field as shown in **Figure 23.59**. The field is uniform inside the rectangle and zero outside. What is the direction of the induced current and what is the direction of the magnetic force on the coil at each position shown?

23.5 Electric Generators

28. Calculate the peak voltage of a generator that rotates its 200-turn, 0.100 m diameter coil at 3600 rpm in a 0.800 T field.

29. At what angular velocity in rpm will the peak voltage of a generator be 480 V, if its 500-turn, 8.00 cm diameter coil rotates in a 0.250 T field?

30. What is the peak emf generated by rotating a 1000-turn, 20.0 cm diameter coil in the Earth's 5.00×10^{-5} T magnetic field, given the plane of the coil is originally perpendicular to the Earth's field and is rotated to be parallel to the field in 10.0 ms?

31. What is the peak emf generated by a 0.250 m radius, 500-turn coil is rotated one-fourth of a revolution in 4.17 ms, originally having its plane perpendicular to a uniform magnetic field. (This is 60 rev/s.)

32. (a) A bicycle generator rotates at 1875 rad/s, producing an 18.0 V peak emf. It has a 1.00 by 3.00 cm rectangular coil in a 0.640 T field. How many turns are in the coil? (b) Is this number of turns of wire practical for a 1.00 by 3.00 cm coil?

33. Integrated Concepts

This problem refers to the bicycle generator considered in the previous problem. It is driven by a 1.60 cm diameter wheel that rolls on the outside rim of the bicycle tire. (a) What is the velocity of the bicycle if the generator's angular velocity is 1875 rad/s? (b) What is the maximum emf of the generator when the bicycle moves at 10.0 m/s, noting that it was 18.0 V under the original conditions? (c) If the sophisticated generator can vary its own magnetic field, what field strength will it need at 5.00 m/s to produce a 9.00 V maximum emf?

34.
(a) A car generator turns at 400 rpm when the engine is idling. Its 300-turn, 5.00 by 8.00 cm rectangular coil rotates in an adjustable magnetic field so that it can produce sufficient voltage even at low rpms. What is the field strength needed to produce a 24.0 V peak emf? (b) Discuss how this required field strength compares to those available in permanent and electromagnets.

35.
Show that if a coil rotates at an angular velocity ω, the period of its AC output is $2\pi/\omega$.

36.
A 75-turn, 10.0 cm diameter coil rotates at an angular velocity of 8.00 rad/s in a 1.25 T field, starting with the plane of the coil parallel to the field. (a) What is the peak emf? (b) At what time is the peak emf first reached? (c) At what time is the emf first at its most negative? (d) What is the period of the AC voltage output?

37.
(a) If the emf of a coil rotating in a magnetic field is zero at $t = 0$, and increases to its first peak at $t = 0.100 \text{ ms}$, what is the angular velocity of the coil? (b) At what time will its next maximum occur? (c) What is the period of the output? (d) When is the output first one-fourth of its maximum? (e) When is it next one-fourth of its maximum?

38. Unreasonable Results

A 500-turn coil with a 0.250 m^2 area is spun in the Earth's $5.00 \times 10^{-5} \text{ T}$ field, producing a 12.0 kV maximum emf. (a) At what angular velocity must the coil be spun? (b) What is unreasonable about this result? (c) Which assumption or premise is responsible?

23.6 Back Emf

39.
Suppose a motor connected to a 120 V source draws 10.0 A when it first starts. (a) What is its resistance? (b) What current does it draw at its normal operating speed when it develops a 100 V back emf?

40.
A motor operating on 240 V electricity has a 180 V back emf at operating speed and draws a 12.0 A current. (a) What is its resistance? (b) What current does it draw when it is first started?

41.
What is the back emf of a 120 V motor that draws 8.00 A at its normal speed and 20.0 A when first starting?

42.
The motor in a toy car operates on 6.00 V, developing a 4.50 V back emf at normal speed. If it draws 3.00 A at normal speed, what current does it draw when starting?

43. Integrated Concepts

The motor in a toy car is powered by four batteries in series, which produce a total emf of 6.00 V. The motor draws 3.00 A and develops a 4.50 V back emf at normal speed. Each battery has a $0.100 \text{ }\Omega$ internal resistance. What is the resistance of the motor?

23.7 Transformers

44.
A plug-in transformer, like that in **Figure 23.29**, supplies 9.00 V to a video game system. (a) How many turns are in its secondary coil, if its input voltage is 120 V and the primary coil has 400 turns? (b) What is its input current when its output is 1.30 A?

45.
An American traveler in New Zealand carries a transformer to convert New Zealand's standard 240 V to 120 V so that she can use some small appliances on her trip. (a) What is the ratio of turns in the primary and secondary coils of her transformer? (b) What is the ratio of input to output current? (c) How could a New Zealander traveling in the United States use this same transformer to power her 240 V appliances from 120 V?

46.
A cassette recorder uses a plug-in transformer to convert 120 V to 12.0 V, with a maximum current output of 200 mA. (a) What is the current input? (b) What is the power input? (c) Is this amount of power reasonable for a small appliance?

47.
(a) What is the voltage output of a transformer used for rechargeable flashlight batteries, if its primary has 500 turns, its secondary 4 turns, and the input voltage is 120 V? (b) What input current is required to produce a 4.00 A output? (c) What is the power input?

48.
(a) The plug-in transformer for a laptop computer puts out 7.50 V and can supply a maximum current of 2.00 A. What is the maximum input current if the input voltage is 240 V? Assume 100% efficiency. (b) If the actual efficiency is less than 100%, would the input current need to be greater or smaller? Explain.

49.
A multipurpose transformer has a secondary coil with several points at which a voltage can be extracted, giving outputs of 5.60, 12.0, and 480 V. (a) The input voltage is 240 V to a primary coil of 280 turns. What are the numbers of turns in the parts of the secondary used to produce the output voltages? (b) If the maximum input current is 5.00 A, what are the maximum output currents (each used alone)?

50.
A large power plant generates electricity at 12.0 kV. Its old transformer once converted the voltage to 335 kV. The secondary of this transformer is being replaced so that its output can be 750 kV for more efficient cross-country transmission on upgraded transmission lines. (a) What is the ratio of turns in the new secondary compared with the old secondary? (b) What is the ratio of new current output to old output (at 335 kV) for the same power? (c) If the upgraded transmission lines have the same resistance, what is the ratio of new line power loss to old?

51.
If the power output in the previous problem is 1000 MW and line resistance is $2.00 \text{ }\Omega$, what were the old and new line losses?

52. Unreasonable Results

The 335 kV AC electricity from a power transmission line is fed into the primary coil of a transformer. The ratio of the number of turns in the secondary to the number in the primary is $N_s / N_p = 1000$. (a) What voltage is induced in the secondary? (b) What is unreasonable about this result? (c) Which assumption or premise is responsible?

53. Construct Your Own Problem

Consider a double transformer to be used to create very large voltages. The device consists of two stages. The first is a transformer that produces a much larger output voltage than its input. The output of the first transformer is used as input to a second transformer that further increases the voltage. Construct a problem in which you calculate the output voltage of the final stage based on the input voltage of the first stage and the number of turns or loops in both parts of both transformers (four coils in all). Also calculate the maximum output current of the final stage based on the input current. Discuss the possibility of power losses in the devices and the effect on the output current and power.

23.8 Electrical Safety: Systems and Devices

54. Integrated Concepts

A short circuit to the grounded metal case of an appliance occurs as shown in **Figure 23.60**. The person touching the case is wet and only has a $3.00 \text{ k}\Omega$ resistance to earth/ground. (a) What is the voltage on the case if 5.00 mA flows through the person? (b) What is the current in the short circuit if the resistance of the earth/ground wire is $0.200 \text{ }\Omega$? (c) Will this trigger the 20.0 A circuit breaker supplying the appliance?
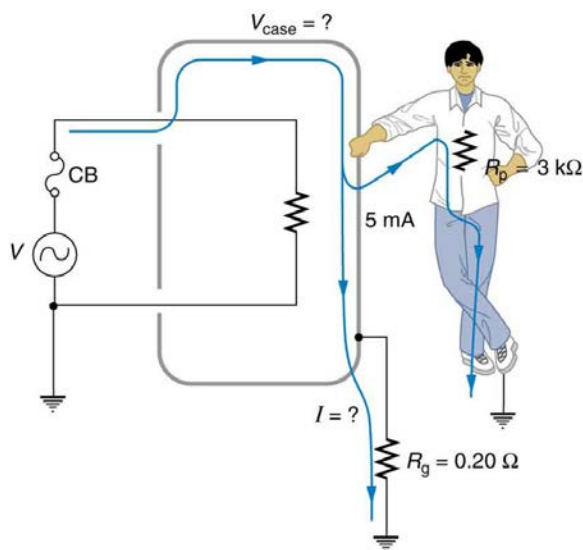

Figure 23.60 A person can be shocked even when the case of an appliance is grounded. The large short circuit current produces a voltage on the case of the appliance, since the resistance of the earth/ground wire is not zero.

23.9 Inductance

55. Two coils are placed close together in a physics lab to demonstrate Faraday's law of induction. A current of 5.00 A in one is switched off in 1.00 ms, inducing a 9.00 V emf in the other. What is their mutual inductance?

56. If two coils placed next to one another have a mutual inductance of 5.00 mH, what voltage is induced in one when the 2.00 A current in the other is switched off in 30.0 ms?

57. The 4.00 A current through a 7.50 mH inductor is switched off in 8.33 ms. What is the emf induced opposing this?

58. A device is turned on and 3.00 A flows through it 0.100 ms later. What is the self-inductance of the device if an induced 150 V emf opposes this?

59. Starting with $\text{emf}_2 = -M\dfrac{\Delta I_1}{\Delta t}$, show that the units of inductance are $(\text{V} \cdot \text{s})/\text{A} = \text{ }\Omega \text{ } \cdot \text{s}$.

60. Camera flashes charge a capacitor to high voltage by switching the current through an inductor on and off rapidly. In what time must the 0.100 A current through a 2.00 mH inductor be switched on or off to induce a 500 V emf?

61. A large research solenoid has a self-inductance of 25.0 H. (a) What induced emf opposes shutting it off when 100 A of current through it is switched off in 80.0 ms? (b) How much energy is stored in the inductor at full current? (c) At what rate in watts must energy be dissipated to switch the current off in 80.0 ms? (d) In view of the answer to the last part, is it surprising that shutting it down this quickly is difficult?

62. (a) Calculate the self-inductance of a 50.0 cm long, 10.0 cm diameter solenoid having 1000 loops. (b) How much energy is stored in this inductor when 20.0 A of current flows through it? (c) How fast can it be turned off if the induced emf cannot exceed 3.00 V?

63. A precision laboratory resistor is made of a coil of wire 1.50 cm in diameter and 4.00 cm long, and it has 500 turns. (a) What is its self-inductance? (b) What average emf is induced if the 12.0 A current through it is turned on in 5.00 ms (one-fourth of a cycle for 50 Hz AC)? (c) What is its inductance if it is shortened to half its length and counter-wound (two layers of 250 turns in opposite directions)?

64. The heating coils in a hair dryer are 0.800 cm in diameter, have a combined length of 1.00 m, and a total of 400 turns. (a) What is their total self-inductance assuming they act like a single solenoid? (b) How much energy is stored in them when 6.00 A flows? (c) What average emf opposes shutting them off if this is done in 5.00 ms (one-fourth of a cycle for 50 Hz AC)?

65. When the 20.0 A current through an inductor is turned off in 1.50 ms, an 800 V emf is induced, opposing the change. What is the value of the self-inductance?

66. How fast can the 150 A current through a 0.250 H inductor be shut off if the induced emf cannot exceed 75.0 V?

67. Integrated Concepts

A very large, superconducting solenoid such as one used in MRI scans, stores 1.00 MJ of energy in its magnetic field when 100 A flows. (a) Find its self-inductance. (b) If the coils "go normal," they gain resistance and start to dissipate thermal energy. What temperature increase is produced if all the stored energy goes into heating the 1000 kg magnet, given its average specific heat is 200 J/kg·°C ?

68. Unreasonable Results

A 25.0 H inductor has 100 A of current turned off in 1.00 ms. (a) What voltage is induced to oppose this? (b) What is unreasonable about this result? (c) Which assumption or premise is responsible?

23.10 RL Circuits

69. If you want a characteristic *RL* time constant of 1.00 s, and you have a $500 \text{ }\Omega$ resistor, what value of self-inductance is needed?

70. Your *RL* circuit has a characteristic time constant of 20.0 ns, and a resistance of $5.00 \text{ M}\Omega$. (a) What is the inductance of the circuit? (b) What resistance would give you a 1.00 ns time constant, perhaps needed for quick response in an oscilloscope?

71. A large superconducting magnet, used for magnetic resonance imaging, has a 50.0 H inductance. If you want current through it to be adjustable with a 1.00 s characteristic time constant, what is the minimum resistance of system?

72. Verify that after a time of 10.0 ms, the current for the situation considered in **Example 23.9** will be 0.183 A as stated.

73. Suppose you have a supply of inductors ranging from 1.00 nH to 10.0 H, and resistors ranging from $0.100 \; \Omega$ to $1.00 \text{ M}\Omega$. What is the range of characteristic *RL* time constants you can produce by connecting a single resistor to a single inductor?

74. (a) What is the characteristic time constant of a 25.0 mH inductor that has a resistance of $4.00 \; \Omega$? (b) If it is connected to a 12.0 V battery, what is the current after 12.5 ms?

75. What percentage of the final current I_0 flows through an inductor L in series with a resistor R, three time constants after the circuit is completed?

76. The 5.00 A current through a 1.50 H inductor is dissipated by a $2.00 \; \Omega$ resistor in a circuit like that in **Figure 23.44** with the switch in position 2. (a) What is the initial energy in the inductor? (b) How long will it take the current to decline to 5.00% of its initial value? (c) Calculate the average power dissipated, and compare it with the initial power dissipated by the resistor.

77. (a) Use the exact exponential treatment to find how much time is required to bring the current through an 80.0 mH inductor in series with a $15.0 \; \Omega$ resistor to 99.0% of its final value, starting from zero. (b) Compare your answer to the approximate treatment using integral numbers of τ. (c) Discuss how significant the difference is.

78. (a) Using the exact exponential treatment, find the time required for the current through a 2.00 H inductor in series with a $0.500 \; \Omega$ resistor to be reduced to 0.100% of its original value. (b) Compare your answer to the approximate treatment using integral numbers of τ. (c) Discuss how significant the difference is.

23.11 Reactance, Inductive and Capacitive

79. At what frequency will a 30.0 mH inductor have a reactance of $100 \; \Omega$?

80. What value of inductance should be used if a $20.0 \text{ k}\Omega$ reactance is needed at a frequency of 500 Hz?

81. What capacitance should be used to produce a $2.00 \text{ M}\Omega$ reactance at 60.0 Hz?

82. At what frequency will an 80.0 mF capacitor have a reactance of $0.250 \; \Omega$?

83. (a) Find the current through a 0.500 H inductor connected to a 60.0 Hz, 480 V AC source. (b) What would the current be at 100 kHz?

84. (a) What current flows when a 60.0 Hz, 480 V AC source is connected to a $0.250 \; \mu\text{F}$ capacitor? (b) What would the current be at 25.0 kHz?

85. A 20.0 kHz, 16.0 V source connected to an inductor produces a 2.00 A current. What is the inductance?

86. A 20.0 Hz, 16.0 V source produces a 2.00 mA current when connected to a capacitor. What is the capacitance?

87. (a) An inductor designed to filter high-frequency noise from power supplied to a personal computer is placed in series with the computer. What minimum inductance should it have to produce a $2.00 \text{ k}\Omega$ reactance for 15.0 kHz noise? (b) What is its reactance at 60.0 Hz?

88. The capacitor in **Figure 23.55**(a) is designed to filter low-frequency signals, impeding their transmission between circuits. (a) What capacitance is needed to produce a $100 \text{ k}\Omega$ reactance at a frequency of 120 Hz? (b) What would its reactance be at 1.00 MHz? (c) Discuss the implications of your answers to (a) and (b).

89. The capacitor in **Figure 23.55**(b) will filter high-frequency signals by shorting them to earth/ground. (a) What capacitance is needed to produce a reactance of $10.0 \text{ m}\Omega$ for a 5.00 kHz signal? (b) What would its reactance be at 3.00 Hz? (c) Discuss the implications of your answers to (a) and (b).

90. Unreasonable Results

In a recording of voltages due to brain activity (an EEG), a 10.0 mV signal with a 0.500 Hz frequency is applied to a capacitor, producing a current of 100 mA. Resistance is negligible. (a) What is the capacitance? (b) What is unreasonable about this result? (c) Which assumption or premise is responsible?

91. Construct Your Own Problem

Consider the use of an inductor in series with a computer operating on 60 Hz electricity. Construct a problem in which you calculate the relative reduction in voltage of incoming high frequency noise compared to 60 Hz voltage. Among the things to consider are the acceptable series reactance of the inductor for 60 Hz power and the likely frequencies of noise coming through the power lines.

23.12 RLC Series AC Circuits

92. An *RL* circuit consists of a $40.0 \; \Omega$ resistor and a 3.00 mH inductor. (a) Find its impedance Z at 60.0 Hz and 10.0 kHz. (b) Compare these values of Z with those found in **Example 23.12** in which there was also a capacitor.

93. An *RC* circuit consists of a $40.0 \; \Omega$ resistor and a $5.00 \; \mu\text{F}$ capacitor. (a) Find its impedance at 60.0 Hz and 10.0 kHz. (b) Compare these values of Z with those found in **Example 23.12**, in which there was also an inductor.

94. An *LC* circuit consists of a 3.00 mH inductor and a $5.00 \; \mu\text{F}$ capacitor. (a) Find its impedance at 60.0 Hz and 10.0 kHz. (b) Compare these values of Z with those found in **Example 23.12** in which there was also a resistor.

95. What is the resonant frequency of a 0.500 mH inductor connected to a $40.0 \; \mu\text{F}$ capacitor?

96. To receive AM radio, you want an *RLC* circuit that can be made to resonate at any frequency between 500 and 1650 kHz. This is accomplished with a fixed $1.00\ \mu H$ inductor connected to a variable capacitor. What range of capacitance is needed?

97. Suppose you have a supply of inductors ranging from 1.00 nH to 10.0 H, and capacitors ranging from 1.00 pF to 0.100 F. What is the range of resonant frequencies that can be achieved from combinations of a single inductor and a single capacitor?

98. What capacitance do you need to produce a resonant frequency of 1.00 GHz, when using an 8.00 nH inductor?

99. What inductance do you need to produce a resonant frequency of 60.0 Hz, when using a $2.00\ \mu F$ capacitor?

100. The lowest frequency in the FM radio band is 88.0 MHz. (a) What inductance is needed to produce this resonant frequency if it is connected to a 2.50 pF capacitor? (b) The capacitor is variable, to allow the resonant frequency to be adjusted to as high as 108 MHz. What must the capacitance be at this frequency?

101. An *RLC* series circuit has a $2.50\ \Omega$ resistor, a $100\ \mu H$ inductor, and an $80.0\ \mu F$ capacitor.(a) Find the circuit's impedance at 120 Hz. (b) Find the circuit's impedance at 5.00 kHz. (c) If the voltage source has $V_{\rm rms} = 5.60\ V$, what is $I_{\rm rms}$ at each frequency? (d) What is the resonant frequency of the circuit? (e) What is $I_{\rm rms}$ at resonance?

102. An *RLC* series circuit has a $1.00\ k\Omega$ resistor, a $150\ \mu H$ inductor, and a 25.0 nF capacitor. (a) Find the circuit's impedance at 500 Hz. (b) Find the circuit's impedance at 7.50 kHz. (c) If the voltage source has $V_{\rm rms} = 408\ V$, what is $I_{\rm rms}$ at each frequency? (d) What is the resonant frequency of the circuit? (e) What is $I_{\rm rms}$ at resonance?

103. An *RLC* series circuit has a $2.50\ \Omega$ resistor, a $100\ \mu H$ inductor, and an $80.0\ \mu F$ capacitor. (a) Find the power factor at $f = 120\ Hz$. (b) What is the phase angle at 120 Hz? (c) What is the average power at 120 Hz? (d) Find the average power at the circuit's resonant frequency.

104. An *RLC* series circuit has a $1.00\ k\Omega$ resistor, a $150\ \mu H$ inductor, and a 25.0 nF capacitor. (a) Find the power factor at $f = 7.50\ Hz$. (b) What is the phase angle at this frequency? (c) What is the average power at this frequency? (d) Find the average power at the circuit's resonant frequency.

105. An *RLC* series circuit has a $200\ \Omega$ resistor and a 25.0 mH inductor. At 8000 Hz, the phase angle is $45.0°$. (a) What is the impedance? (b) Find the circuit's capacitance. (c) If $V_{\rm rms} = 408\ V$ is applied, what is the average power supplied?

106. Referring to **Example 23.14**, find the average power at 10.0 kHz.

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23.1 Induced Emf and Magnetic Flux

1. To produce current with a coil and bar magnet you can:
   a.   move the coil but not the magnet.
   b.   move the magnet but not the coil.
   c.   move either the coil or the magnet.
   d.   It is not possible to produce current.

2. Calculate the magnetic flux for a coil of area 0.2 m^2 placed at an angle of θ=60º (as shown in the figure above) to a magnetic field of strength 1.5×10^{-3} T. At what angle will the flux be at its maximum?

23.5 Electric Generators

3. The emf induced in a coil that is rotating in a magnetic field will be at a maximum when
   a.   the magnetic flux is at a maximum.
   b.   the magnetic flux is at a minimum.
   c.   the change in magnetic flux is at a maximum.
   d.   the change in magnetic flux is at a minimum.

4. A coil with circular cross section and 20 turns is rotating at a rate of 400 rpm between the poles of a magnet. If the magnetic field strength is 0.6 T and peak voltage is 0.2 V, what is the radius of the coil? If the emf of the coil is zero at t = 0 s, when will it reach its peak emf?

23.7 Transformers

5. Which of the following statements is true for a step-down transformer? Select *two* answers.
   a.   Primary voltage is higher than secondary voltage.
   b.   Primary voltage is lower than secondary voltage.
   c.   Primary current is higher than secondary current.
   d.   Primary current is lower than secondary current.

6. An ideal step-up transformer with turn ratio 1:30 is supplied with an input power of 120 W. If the output voltage is 210 V, calculate the output power and input current.

23.8 Electrical Safety: Systems and Devices

7. Which of the following statements is true for an isolation transformer?
   a.   It has more primary turns than secondary turns.
   b.   It has fewer primary turns than secondary turns.
   c.   It has an equal number of primary and secondary turns.
   d.   It can have more, fewer, or an equal number of primary and secondary turns.

8. Explain the working of a ground fault interrupter (GFI).

Chapter 23

Problems & Exercises

1
Zero
3

(a) CCW

(b) CW

(c) No current induced

5

(a) 1 CCW, 2 CCW, 3 CW

(b) 1, 2, and 3 no current induced

(c) 1 CW, 2 CW, 3 CCW

9
(a) 3.04 mV
(b) As a lower limit on the ring, estimate R = 1.00 mΩ. The heat transferred will be 2.31 mJ. This is not a significant amount of heat.
11
0.157 V
13

proportional to $\frac{1}{r}$

17

(a) 0.630 V

(b) No, this is a very small emf.

19
2.22 m/s
25

(a) 10.0 N

(b) 2.81×10^8 J

(c) 0.36 m/s

(d) For a week-long mission (168 hours), the change in velocity will be 60 m/s, or approximately 1%. In general, a decrease in velocity would cause the orbit to start spiraling inward because the velocity would no longer be sufficient to keep the circular orbit. The long-term consequences are that the shuttle would require a little more fuel to maintain the desired speed, otherwise the orbit would spiral slightly inward.

28
474 V
30
0.247 V
32

(a) 50

(b) yes

Answer Key

34

(a) 0.477 T

(b) This field strength is small enough that it can be obtained using either a permanent magnet or an electromagnet.

36

(a) 5.89 V

(b) At t=0

(c) 0.393 s

(d) 0.785 s

38

(a) 1.92×10^6 rad/s

(b) This angular velocity is unreasonably high, higher than can be obtained for any mechanical system.

(c) The assumption that a voltage as great as 12.0 kV could be obtained is unreasonable.

39

(a) $12.00 \, \Omega$

(b) 1.67 A

41

72.0 V

43

$0.100 \, \Omega$

44

(a) 30.0

(b) 9.75×10^{-2} A

46

(a) 20.0 mA

(b) 2.40 W

(c) Yes, this amount of power is quite reasonable for a small appliance.

48

(a) 0.063 A

(b) Greater input current needed.

50

(a) 2.2

(b) 0.45

(c) 0.20, or 20.0%

52

(a) 335 MV

(b) way too high, well beyond the breakdown voltage of air over reasonable distances

(c) input voltage is too high

54

(a) 15.0 V

(b) 75.0 A

(c) yes

55

1.80 mH

57

3.60 V

61

(a) 31.3 kV

(b) 125 kJ

(c) 1.56 MW

(d) No, it is not surprising since this power is very high.

63

(a) 1.39 mH

(b) 3.33 V

(c) Zero

65
60.0 mH
67

(a) 200 H

(b) 5.00ºC

69
500 H
71
50.0 Ω
73
1.00×10^{-18} s to 0.100 s
75
95.0%
77

(a) 24.6 ms

(b) 26.7 ms

(c) 9% difference, which is greater than the inherent uncertainty in the given parameters.

79
531 Hz
81
1.33 nF
83

(a) 2.55 A

(b) 1.53 mA

85
63.7 μH
87

(a) 21.2 mH

(b) 8.00 Ω

89

(a) 3.18 mF

(b) 16.7 Ω

92

(a) 40.02 Ω at 60.0 Hz, 193 Ω at 10.0 kHz

(b) At 60 Hz, with a capacitor, $Z = 531$ Ω, over 13 times as high as without the capacitor. The capacitor makes a large difference at low frequencies. At 10 kHz, with a capacitor $Z = 190$ Ω, about the same as without the capacitor. The capacitor has a smaller effect at high frequencies.

94

(a) $529\ \Omega$ at 60.0 Hz, $185\ \Omega$ at 10.0 kHz

(b) These values are close to those obtained in **Example 23.12** because at low frequency the capacitor dominates and at high frequency the inductor dominates. So in both cases the resistor makes little contribution to the total impedance.

96
9.30 nF to 101 nF
98
3.17 pF
100

(a) $1.31\ \mu H$

(b) 1.66 pF

102

(a) $12.8\ k\Omega$

(b) $1.31\ k\Omega$

(c) 31.9 mA at 500 Hz, 312 mA at 7.50 kHz

(d) 82.2 kHz

(e) 0.408 A

104

(a) 0.159

(b) $80.9°$

(c) 26.4 W

(d) 166 W

106
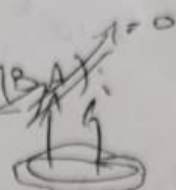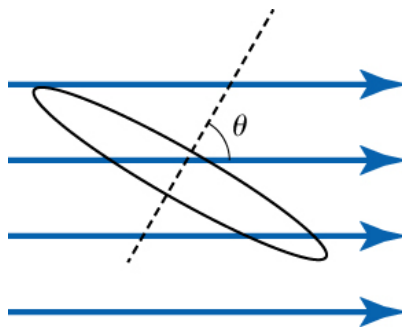16.0 W

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1
(c)

Figure 23.6.

3
(c)
5
(a), (d)
7
(c)
Chapter 24

9/14 $\mathcal{E} = \dfrac{\Delta\Phi}{\Delta t} = \dfrac{\Delta(B.A)}{\Delta t} = \dfrac{BA}{}$ ~~...~~

~~$\dfrac{m\left(\dfrac{2.2}{4} \times B^2\right)^2}{0.25}$~~ $= B.5 \times 10^{-2}V = 5.06\,mV$

11/ $\mathcal{E} = -N\dfrac{\Delta\Phi}{\Delta t} = -N\dfrac{\Phi_f - \Phi_i}{\Delta t} \quad (\cos\theta = 0) = \dfrac{-1000 \cdot -5\times10^{-5}\,\pi\,0.1^2}{0.01}$

$\mathcal{E} = 0.157 V$

17/ $\mathcal{E} = vBl = 0.63 V$.

28/ $\mathcal{E} = vBl = r\omega Bl$

→ if v was at an angle with B then $\mathcal{E} = r\omega Bl\sin\theta$

Or $\omega = \dfrac{\theta}{t} \longrightarrow \theta = \omega t \rightarrow \mathcal{E} = r\omega Bl\sin(\omega t)$

$r\,l = A \rightarrow \mathcal{E} = AB\omega\sin(\omega t)$

if we got N turns $\rightarrow \mathcal{E} = NAB\omega\sin(\omega t)$

$\underset{\mathcal{E}_0}{\underbrace{\qquad}}$

$\rightarrow \mathcal{E}_0 = NAB\omega = 200\,\pi\,0.05^2 \cdot 0.8 \cdot \dfrac{2\pi\,3600}{60} = 474 V$

$30/$ $\mathcal{E}_o = NAB\omega = NAB\dfrac{D\theta}{Dt}$ $\quad\uparrow \overset{D\theta=45°=\frac{\pi}{2}rad}{\underset{\longrightarrow}{\longrightarrow}}$

$\mathcal{E}_o = 1000 \cdot \pi \cdot 0.1^2 \cdot 5 \cdot 10^{-5} \cdot \dfrac{\pi/2}{10\cdot 10^{-3}} = 0.247$

$46/a/$ $e = \dfrac{P_D}{P_P} = \dfrac{U_D}{U_P} = \dfrac{I_P}{I_D} \rightarrow I_P = \dfrac{U_D}{U_P}I_D = \dfrac{12}{120}\cdot 0.2\cdot 8 = 20\,mA$

$b/$ $P_P = I_P U_P = 2.4\,\omega$.

$48/a/$ $I_P = \dfrac{U_D}{U_P}\cdot I_D = 0.625\,A$

$b/$ $e = \dfrac{I_P}{I_D} \rightarrow$ for more ~~the if~~ efficiency, more input

current is needed.

$55/$ $\mathcal{E}_2 = -M\dfrac{DI_1}{Dt} \rightarrow$ ~~$\mathcal{H}=\mathcal{E}_2Dt$~~

$\longrightarrow M = -\dfrac{\mathcal{E}_2 Dt}{DI_1} = $ ~~$\mathcal{E}(0-8)$~~ $\underset{M=R.D}{} = \dfrac{-9\cdot 10^{-3}}{(0-5)} = 1.8\overset{-3}{10}\,M$

$= 1.8\,mH$

$57/$ $\mathcal{E}_2 = -M\dfrac{DI_1}{Dt} = -\dfrac{7.5\cdot 10^{-3}\cdot (6-4)}{8.33\cdot 10^{-3}} = $ ~~3.64~~ $3.6\,U$

$65/$ $\mathcal{E} = -L\dfrac{DI}{Dt} \rightarrow$ ~~8~~ $L = -\mathcal{E}\dfrac{Dt}{DI} = \dfrac{-800\cdot 1.5\cdot 10^{-3}}{0-20}$

$\qquad\qquad\qquad\qquad L = 0.06M = 60\,mH$