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.

For the ring on the left side of the current-carrying wire there is no induced current. As the ring moves along parallel to the wire, the magnetic flux through the ring does not change, which means there is no induced emf and no induced current.

For the ring on the right side of the current-carrying wire, the induced current is clockwise. As the ring moves away from the wire, the magnetic flux through the ring is decreasing (there are fewer magnetic field lines pointing into the loop). In an attempt to oppose this decrease (Lenz’s law), and emf and current will be induced in the ring in a clockwise direction (using the right-hand rule).

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) coil B is moved away from A, (c) when the resistance $R_B$ is increased.

(a) The induced current in $R_A$ is to the right as coil B is moved toward coil A. As B approaches A, the magnetic flux through coil A increased. Coil A attempts to oppose this increase in flux, and the induced emf creates a current to produce a magnetic field pointing to the right through the center of the coil. A current through $R_A$ to the right will produce this opposing field.

(b) The induced current in $R_A$ is to the left as coil B is moved away from coil A.

(c) The induced current in $R_A$ is to the left as $R_B$ in coil B is increased. As $R_B$ increases, the current in coil B decreased, which also decreased the magnetic field coil B produces. As the magnetic field from coil B decreases, the magnetic flux through coil A decreases. Coil A attempts to oppose this decrease in flux, and the induced emf creates a current to produced a magnetic field pointing to the left through the center of the coil. A current through $R_A$ to the left will produce this opposing field.

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.

As a magnet falls through a metal tube, an increase in the magnetic flux is created in the areas ahead of it in the tube. This flux change induces a current to flow around the tube walls to create an opposing magnetic field in the tube (Lenz’s law). This induced magnetic field pushes against the falling magnet and causes it to slow down. The opposing magnetic field cannot cause the magnet to actually come to a stop, since then the flux would become constant and the induced current would disappear and so would the opposing magnetic field. Thus the magnet reaches a state of equilibrium and falls at a constant terminal velocity.

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

Higher voltages, such as 600 V or 1200 V, would be dangerous if they were used in household wires. Such a large potential difference between household wires and anything that is grounded would more easily cause electrical breakdown of the air and then much more sparking would occur. Basically, this would supply each of the charges in the household wires with much more energy than the lower voltages, which would allow them to arc to other conductors. This would increases the possibility of more short circuits, as well as accidental electrocutions and fires.
(8) 10 points  (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?

(a) As the resistance is increased, the current in the outer loop will decrease. Thus the flux through the inner loop, which is out of the page, will decrease. To oppose this decrease, the induced current in the inner loop will produce a flux out of the page, so the direction of the induced current will be counterclockwise.

(b) If the small loop is placed to the left, the flux through the small loop will be into the page and will decrease. To oppose this decrease, the induced current in the inner loop will produce a flux into the page, so the direction of the induced current will be clockwise.

(12) 10 points  (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.

(a) The magnitude of the emf developed is

\[ \varepsilon = \frac{\Delta \Phi_B}{\Delta t} = \frac{BA \Delta A}{\Delta t} = B\ell v \frac{\Delta t}{\Delta t} = B\ell v = (0.800 \text{ T})(12.0 \times 10^{-2} \text{ m})(15.0 \times 10^{-2} \text{ m/s}) = 1.44 \times 10^{-2} \text{ V}. \]

(b) Because the upward flux is increasing, the induced flux will be into the page, so the induced current is clockwise. Thus the induced emf in the rod is down, which means that the electric field will be down. The magnitude of the electric field is

\[ E = \frac{\varepsilon}{\ell} = \frac{1.44 \times 10^{-2} \text{ V}}{0.120 \text{ m}} = 0.120 \text{ V/m}. \]

(18) 10 points  (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 $8.65 \times 10^{-3} \text{ T/s}$. Determine (a) the current in the loop, and (b) the rate at which thermal energy is produced.

(a) There is an emf induced in the coil since the flux through the coil changes. The current in the coil is the induced emf divided by the resistance of the coil

\[ |\varepsilon| = \frac{NA_{\text{coil}} \Delta B}{\Delta t} \]

where

\[ R = \frac{\rho L}{A_{\text{wire}}} \]

Therefore, the current in the loop is

\[ I = \frac{\varepsilon}{R} = \frac{NA_{\text{coil}}A_{\text{wire}} \Delta B/\Delta t}{\rho L} = \frac{(20) [\pi(0.11 \text{ m})^2] [\pi(1.3 \times 10^{-3} \text{ m})^2] (8.65 \times 10^{-3} \text{ T/s})}{(1.68 \times 10^{-8} \text{ Ω} \cdot \text{m})(20)(2\pi)(0.11 \text{ m})} = 0.15 \text{ A}. \]

(b) The rate at which thermal energy is produced in the wire is the power dissipated in the wire

\[ P = I^2R = 9.9 \times 10^{-4} \text{ W}. \]
(30) 6 points  (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?

Using \( V_S/V_P = N_S/N_P \) and solving for \( N_S \) we find that

\[
N_S = N_P \frac{V_S}{V_P} = (164) \frac{10,000 \text{ V}}{120 \text{ V}} = 13,700 \text{ turns.}
\]

(44) 8 points  (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?

We can think of the coil as two elements in series: a pure resistance and a pure inductance. There is a voltage drop due to the resistance of the coil, given by Ohm's law, and an induced emf due to the inductance of the coil. Since the current is increasing, the inductance will create a potential difference to oppose the increasing current, and so there is a drop in the potential due to the inductance. The potential difference across the coil is the sum of the two potential drops

\[
\Delta V = IR + L \frac{\Delta I}{\Delta t} = (3.00 \text{ A})(2.25 \text{ Ω}) + (0.440 \text{ H})(3.50 \text{ A/s}) = 8.29 \text{ V.}
\]

(72) 12 points  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?

(a) The clockwise current in the left-hand loop produces a magnetic field which is into the page within the loop and out of the page outside the loop. Thus the right-hand loop is in a magnetic field that is directed out of the page. Before the current in the left-hand loop reaches its steady state, there will be an induced current in the right-hand loop that will produce a magnetic field into the page to oppose the increase of the field from the left-hand loop. Thus the induced current will be clockwise.

(b) After a long time, the current in the left-hand loop is constant, so there will be no induced current in the right-hand coil.

(c) If the second loop is pulled to the right, the magnetic field out of the page from the left-hand loop through the second loop will decrease. During the motion, there will be an induced current in the right-hand loop that will produce a magnetic field out of the page to oppose the decrease of the field from the left-hand loop. Thus the induced current will be counterclockwise.
A loop with a resistance of 200 Ω is pulled at constant velocity through a region where there is a magnetic field of 2 T out of the screen and into a region of no magnetic field (position is given in meters and time is given in seconds).

During the time shown in the animation,

a. What are the direction and magnitude of the current in the loop?

The current in the loop has a magnitude of

\[ I = \frac{\varepsilon}{R} = \frac{B \Delta A}{R \Delta t} = \frac{B \ell v}{R}, \]

where \( \ell \) is the vertical length of the loop and \( v \) is the speed at which it is exiting the magnitude field \( B \). From the animation, we find that the loop is moving with a constant speed \( v = 3 \text{ m/s} \). The vertical length of the loop is measured to be \( \ell = 5 \text{ m} \). Therefore, the current in the loop is

\[ I = \frac{(2 \text{ T})(5 \text{ m})(3 \text{ m/s})}{200 \Omega} = 0.15 \text{ A}; \]

using the right-hand rules (and Lenz’s law), we conclude that this current is in the counterclockwise direction.

b. A force is necessary to pull the loop out of the magnetic field. Why? (Draw a free-body diagram of the loop and explain the origination of each force.)

Due to the current in the loop, there will be a magnetic force exerted on the loop to the left (Lenz’s law). However, the loop is pulled at a constant velocity. Therefore, the net force acting on it must be zero and so there must be an applied force exerted on the loop to the right that exactly cancels the leftward magnetic force.

c. Find the magnitude of the force that was exerted by the hand on the loop in the animation.

The magnetic force exerted on the loop has a magnitude

\[ F_B = I \ell B = (0.15 \text{ A})(5 \text{ m})(2 \text{ T}) = 1.5 \text{ N}. \]

Therefore, by the argument given in part b, the force exerted by the hand must also have a magnitude of 1.5 N.

d. Describe the subsequent motion of the loop if the same force continues to act on the loop when it is in the region of no magnetic field.

Once the loop leaves the magnetic field, the magnetic force acting on it will be zero. Therefore, if the same force found in part c continued to act on the loop, it will begin accelerate to the right (Newton’s second law). The magnitude of this acceleration will be directly proportional to the force (1.5 N), and indirectly proportional to the mass of the loop (unknown).