# CHAPTER 22 | *Induction*

CONCEPTUAL QUESTIONS & PROBLEMS

Cutnell & Johnson 7E

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76. GO **Concept Questions** A magnetic field passes through a stationary wire loop, and its magnitude changes in time according to the graph in the drawing. The direction of the field remains constant, however. There are three equal time intervals indicated in the graph: 0–3.0 s, 3.0–6.0 s, and 6.0–9.0 s. (a) Is the induced emf equal to zero during any of the intervals? (b) During which interval is the magnitude of the induced emf the largest? (c) If the direction of the current induced during (the first interval is clockwise, what is the direction during the third interval? In all cases, provide a reason for your answer.
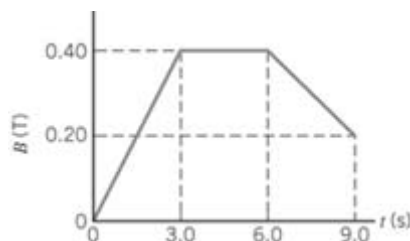
Problem The loop consists of 50 turns of wire and has an area of 0.15 m^2. The magnetic field is oriented parallel to the normal to the loop. For purposes of this problem, this means that $\theta = 0\,°$ in Equation 22.2. (a) For each interval, determine the induced emf. (b) The wire has a resistance of 0.50 Ω. Determine the induced current for the first and third intervals. Make sure your answers are consistent with your answers to the Concept Questions.

76.   *CONCEPT QUESTIONS*

 a. The induced emf is zero during the second interval, 3.0 – 6.0 s. According to Faraday's law of electromagnetic induction, Equation 22.3, an induced emf arises only when the magnetic flux changes. During this interval, the magnetic field, the area of the loop, and the orientation of the field relative to the loop are constant. Thus, the magnetic flux does not change, so there is no induced emf.

 b. An emf is induced during the first and third intervals, because the magnetic field is changing in time. The time interval is the same (3.0 s) for the two cases. However, the magnitude of the field changes more during the first interval. Therefore, the magnetic flux is changing at a greater rate in that interval, which means that the magnitude of the induced emf is greatest during the first interval.

c. During the first interval the magnetic field in increasing with time. During the third interval, the field is decreasing with time. As a result, the induced emfs will have opposite polarities during these intervals. If the direction of the induced current is clockwise during the first interval, it will be counterclockwise during the third interval.

SOLUTION
a. The induced emf is given by Equations 22.3 and 22.3:

0–3.0 s:

$$\xi = -N\frac{\Delta\Phi}{\Delta t} = -N\left(\frac{BA\cos\phi - B_0 A\cos\phi}{t-t_0}\right)$$

$$= -NA\cos\phi\left(\frac{B-B_0}{t-t_0}\right) = -(50)(0.15\text{ m}^2)(\cos 0°)\left(\frac{0.40\text{ T}-0\text{ T}}{3.0\text{ s}-0\text{ s}}\right) = \boxed{-1.0\text{ V}}$$

3.0–6.0 s:

$$\xi = -NA\cos\phi\left(\frac{B-B_0}{t-t_0}\right) = -(50)(0.15\text{ m}^2)(\cos 0°)\left(\frac{0.40\text{ T}-0.40\text{ T}}{6.0\text{ s}-3.0\text{ s}}\right) = \boxed{0\text{ V}}$$

6.0–9.0 s:

$$\xi = -NA\cos\phi\left(\frac{B-B_0}{t-t_0}\right) = -(50)(0.15\text{ m}^2)(\cos 0°)\left(\frac{0.20\text{ T}-0.40\text{ T}}{9.0\text{ s}-6.0\text{ s}}\right) = \boxed{+0.50\text{ V}}$$

b. The induced current is given by Equation 20.2 as $I = (\text{Emf})/R$.

0–3.0 s:

$$I = \frac{\xi}{R} = \frac{-1.0\text{ V}}{0.50\ \Omega} = \boxed{-2.0\text{ A}}$$

6.0–9.0 s:

$$I = \frac{\xi}{R} = \frac{+0.50\text{ V}}{0.50\ \Omega} = \boxed{+1.0\text{ A}}$$

As expected, the currents are in opposite directions.

77. **Concept Questions** The drawing shows a straight wire carrying a current I. Above the wire is a rectangular loop that contains a resistor R. (a) Does the magnetic field produced by the current I penetrate the loop and generate a magnetic flux? (b) When is there an induced current in the loop, if the current I is constant or if it is decreasing in time? (c) When there is an induced magnetic field produced by the loop, does it always have a direction that is opposite to the direction of the magnetic field produced by the current I? Provide a reason for each answer.
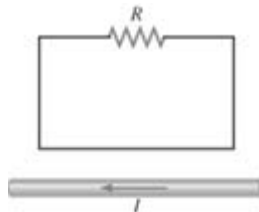
Problem If the current I is decreasing in time, what is the direction of the induced current through the resistor R—left to right or right to left? Give your reasoning.

77.   *CONCEPT QUESTIONS*
        a. The magnetic field produced by I extends throughout the space surrounding the loop. Using RHR-2, it can be shown that the magnetic field is parallel to the normal to the loop. Thus, the magnetic field penetrates the loop and generates a magnetic flux.

b. According to Faraday's law of electromagnetic induction, an emf is induced when the magnetic flux through the loop is changing in time. If the current I is constant, the magnetic flux is constant, and no emf is induced in the loop. However, if the current is decreasing in time, the magnetic flux is decreasing and an induced current exists in the loop.

c. No. Lenz's law states that the induced magnetic field opposes the *change* in the magnetic field produced by the current I. The induced magnetic field does not necessarily oppose the magnetic field itself. Thus, the induced magnetic field does not always have a direction that is opposite to the direction of the field produced by I.

SOLUTION At the location of the loop, the magnetic field produced by the current I is directed into the page (this can be verified by using RHR-2). The current is decreasing, so the magnetic field is decreasing. Therefore, the magnetic flux that penetrates the loop is decreasing. According to Lenz's law, the induced emf has a polarity that leads to an induced current whose direction is such that the induced magnetic field opposes this flux change. The induced magnetic field will oppose this decrease in flux by pointing into the page, in the same direction as the field produced by I. According to RHR-2, the induced current must flow clockwise around the loop in order to produce such an induced field. The current then flows from $\boxed{\text{left-to-right}}$ through the resistor.

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78. **Concept Questions** A flat coil of wire has an area A, N turns, and a resistance R. It is situated in a magnetic field such that the normal to the coil is parallel to the magnetic field. The coil is then rotated through an angle of 90°, so that the normal becomes perpendicular to the magnetic field. (a) Why is an emf induced in the coil? (b) What determines the amount of induced current in the coil? (c) How is the amount of charge Dq that flows related to the induced current I and the time interval $t - t_0$ during which the coil rotates?

    Problem The coil has an area of 1.5×10^{-3} m^2, 50 turns, and a resistance of 140 Ω During the time when it is rotating, a charge of 8.5×10^{-5} C flows in the coil. What is the magnitude of the magnetic field?

78.   *CONCEPT QUESTIONS*
        a. An emf is induced in the coil because the magnetic flux through the coil is changing in time. The flux is changing because the angle ϕ between the normal to the coil and the magnetic field is changing.

b. The amount of induced current is equal to the induced emf divided by the resistance of the coil (see Equation 20.2).

c. According to Equation 20.1, the amount of charge Δq that flows is equal to the induced current I multiplied by the time interval $\Delta t = t - t_0$ during which the coil rotates, or $\Delta q = I(t - t_0)$.

SOLUTION According to Equation 20.1, the amount of charge that flows is $\Delta q = I\Delta t$. The current is related to the emf ξ in the coil and the resistance R by Equation 20.2 as $I = \xi /R$. The amount of charge that flows can, therefore, be written as

$$\Delta q = I\,\Delta t = \left(\frac{\xi}{R}\right)\Delta t$$

The emf is given by Faraday's law of electromagnetic induction as

$$\xi = - N\left(\frac{\Delta \Phi}{\Delta t}\right) = - N\left(\frac{BA\cos \phi - BA\cos \phi_0}{\Delta t}\right)$$

where we have also used Equation 22.2, which gives the definition of magnetic flux as $\Phi = BA\cos \phi$. With this emf, the expression for the amount of charge becomes

$$\Delta q = I\,\Delta t = \left[\frac{- N\left(\dfrac{BA\cos \phi - BA\cos \phi_0}{\Delta t}\right)}{R}\right]\Delta t = \frac{- NBA\left(\cos \phi - \cos \phi_0\right)}{R}$$

Solving for the magnitude of the magnetic field yields

$$B = \frac{- R\,\Delta q}{NA\left(\cos \phi - \cos \phi_0\right)} = \frac{-\left(140\,\Omega\right)\left(8.5\times 10^{-5}\ \text{C}\right)}{\left(50\right)\left(1.5\times 10^{-3}\ \text{m}^2\right)\left(\cos 90° - \cos 0°\right)} = \boxed{0.16\ \text{T}}$$

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79. **Concept Questions** A constant current I exists in a solenoid whose inductance is L. The current is then reduced to zero in a certain amount of time. (a) If the wire from which the solenoid is made has no resistance, is there a voltage across the solenoid during the time when the current is constant? (b) If the wire from which the solenoid is made has no resistance, is there an emf across the solenoid during the time that the current is being reduced to zero? (c) Does the solenoid store electrical energy when the current is constant? If so, express this energy in terms of the current and the inductance. (d) When the current is reduced from its constant value to zero, what is the rate at which energy is removed from the solenoid? Express your answer in terms of the initial current, the inductance, and the time during which the current goes to zero.

Problem A solenoid has an inductance of $L = 3.1$ H and carries a current of $I = 15$ A. (a) If the current goes from 15 to 0 A in a time of 75 ms, what is the emf induced in the solenoid? (b) How much electrical energy is stored in the solenoid? (c) At what rate must the electrical energy be removed from the solenoid when the current is reduced to zero in

75 ms?

79.   *CONCEPT QUESTIONS*

a. If the wire has no resistance, there is no voltage across the solenoid. This conclusion follows from Equation 20.2, $V = IR$. If $R = 0\ \Omega$, then $V = 0$ V.

b. Yes. According to Faraday's law of electromagnetic induction, expressed as $\xi = -L(\Delta I / \Delta t)$, an emf is induced in the solenoid as long as the current is changing in time.

c. Yes. The amount of electrical energy E stored by an inductor is given by Equation 22.10 as $E = \frac{1}{2} L I^2$, where L is the inductance and I is the current.

d. The power is equal to the energy removed divided by the time (Equation 6.10b),
$$P = \frac{E}{t} = \frac{\frac{1}{2} L I^2}{t}.$$

SOLUTION

a. The emf induced in the solenoid is

$$\text{Emf} = -L\left(\frac{\Delta I}{\Delta t}\right) = -(3.1\,\text{H})\left(\frac{0\,\text{A} - 15\,\text{A}}{75 \times 10^{-3}\,\text{s}}\right) = \boxed{+620\,\text{V}} \tag{22.9}$$

b. The energy stored in the solenoid is

$$E = \frac{1}{2} L I^2 = \frac{1}{2}(3.1\,\text{H})(15\,\text{A})^2 = \boxed{350\,\text{J}} \tag{22.10}$$

c. The rate (or power, P) at which the energy is removed is

$$P = \frac{E}{t} = \frac{\frac{1}{2} L I^2}{t} = \frac{\frac{1}{2}(3.1\,\text{H})(15\text{A})^2}{75 \times 10^{-3}\,\text{s}} = \boxed{4700\,\text{W}} \tag{6.10b}$$