Chapter 13: Electromagnetic Induction

Mini Investigation: Electric Current from Motion?, page 587

A. Answers may vary. Sample answer:
Moving the magnet with a fast motion near the loop of wire caused a current in the wire. When the magnet was moved quickly through the loop of wire, brought quickly near the wire, or moved past the wires outside of the loop, the galvanometer showed a current in the wire.
B. Answers may vary. Sample answer:
Moving the magnet quickly through the wire was the most effective motion at producing current. The galvanometer consistently showed a significant current in the wire when the magnet was quickly moved through the loop's centre.

Section 13.1: Electromagnetic Induction

Mini Investigation: Faraday's Ring, page 588

A. Answers may vary. Sample answers:
When the primary circuit switch was closed, the galvanometer needle moved to the right, indicating that there was an electric current in the secondary circuit. The galvanometer needle then quickly returned to its original position.
B. Answers may vary. Sample answers:
When the primary circuit switch was opened, the galvanometer needle moved to the left, indicating that there was an electric current in the secondary circuit. The galvanometer needle then quickly returned to its original position.
C. Answers may vary. Sample answers:
The direction of the current in Step 3 was opposite to the direction of the current in Step 2.

Section 13.1 Questions, page 591

1. (a) The galvanometer would indicate a small current in the wire while the magnet is moved toward it, but would indicate no current in the wire once the magnet is placed on top of it.
(b) The galvanometer would indicate no current in the wire while the magnet is resting on top of it, but would then indicate a small current in the direction opposite to that of part (a) while the magnet is being moved away from it.
(c) The galvanometer would indicate a small current in the wire.
(d) The galvanometer would indicate a large current in the wire.
(e) The galvanometer would indicate a large current in the wire that changes direction each time the magnet changes direction.
(f) The galvanometer would indicate a large current in the wire.
2. Answers may vary. Sample answer:
To maximize the amount of induced current in a coiled conductor with a permanent magnet design, I would include a coil with a great number of loops and a strong permanent magnet. I would also have the strong permanent magnet move quickly in and out of the coil. To maximize the amount of induced current for a Faraday's ring design, I would include a great number of loops around the ring and a large amount of electric current in the primary circuit. I would also have the current in the primary circuit rapidly increase and decrease.
3. An induction cooker cannot induce an electric current in the glass, so the pot would remain at room temperature. The cooker can induce an electric current in the iron handle, so the handle would be at a very high temperature.
4. Answers may vary. Sample answer:
No, you cannot design a non-metal detector that uses electromagnetic induction because a magnetic field cannot induce current in a non-conductor, and many non-metals are non-conductors.
5. I may have to remove my belt, empty my pockets, and remove my shoes because these items contain metal that will be detected by the metal detector.
6. Answers may vary. Sample answer:
Induction charges could be used for electric toothbrushes, electric razors, cellphones, digital audio players, handheld gaming consoles, and any other portable electric devices that use batteries. Induction charging is highly useful for electric devices that are exposed to water, such as electric toothbrushes and razors, because it is safer than charging with wires. For other electric devices, the main benefit of induction charging is convenience. The main disadvantage of induction charging is that it is less efficient than direct wired contact. It has an increased resistive heating relative to direct contact. Induction charging also requires drive electronics and coils that increase the cost and complexity of manufacturing if used in a device. Whether induction charging is better than direct wired contact depends on the electric device.

Section 13.2: Lenz's Law

Mini Investigation: Observing the Direction of an Induced Current, page 592

A. Answers may vary. Sample answer:
The direction of the current in Step 3 was opposite to the direction of the current in Step 2.

B. Answers may vary. Sample answer:
When repeating Step 2 with the south pole of the magnet, the direction of the current was opposite to the direction when the north pole of the magnet was used. When repeating Step 3 with the south pole of the magnet, the direction of the current was again opposite to the direction when the north pole of the magnet was used.

C. Using the south pole instead of the north pole changed the order in which the direction of the current changed. It did not affect how quickly the current changed or how much current was produced.

D. Using the right-hand rule for a coiled conductor, I predicted that the end of the coil nearest to the magnet was a north magnetic pole in Step 2 and a south magnetic pole in Step 3.

Section 13.2 Questions, page 594

1. (a) The north pole of a permanent magnet is being forced into the coil. By Lenz's Law, the coil must oppose that with a north pole on the right side of the coil. If the right side of the coil is north, then the left side of the coil must be south. The right-hand rule for a solenoid determines the direction of the electric current to be down the coil at the front.

(b) The north pole of a permanent magnet is being pulled out of the coil. By Lenz's Law, the coil must oppose the north pole with a south pole on the right side of the coil. If the right side of the coil is south, then the left side of the coil must be north The right-hand rule for a solenoid determines the direction of the electric current to be up the coil at the front.

(c) The south pole of a permanent magnet is being pulled out of the coil. By Lenz's Law, the coil must oppose the south pole with a north pole on the right side of the coil. If the right side of the coil is north, then the left side of the coil must be south. The right-hand rule for a solenoid determines the direction of the electric current to be down the coil at the front.

(d) The south pole of a permanent magnet is being forced into the coil. By Lenz's Law, the coil must oppose the south pole with a south pole on the right side of the coil. If the right side of the coil must be south, then the left side of the coil must be north. The right-hand rule for a solenoid determines the direction of the electric current to be up the coil at the front.

2. The answers to Question 1 would not change if the coils were moved instead of the magnets, because the coils would experience a changing magnetic field that is the same as if the magnets are moved and the coils are stationary. By Lenz's law, the electric current in each coil would have to be in a direction such that its own magnetic field opposes the change that produced it, which in this case is the movement of the coil itself. For this to happen, each coil must have the same direction of induced current and magnetic poles as in Question 1.

3. When a magnet is pushed into a coil, the kinetic energy of the magnet is transformed into electrical energy in the electric current in the coil. If the magnetic field that is created by the induced current were to attract the magnet into the coil, both the kinetic energy of the magnet and the electrical energy in the electric current would increase without any work being done by the person pushing the magnet. This increase in energy of the system without any work being done would violate the law of conservation of energy.

4. Using electromagnets in the carts instead of permanent magnets would work equally well since the braking system would still function in the same way. It would not be as reliable because electromagnets can only generate a magnetic field when they are connected to a power source, so if the power failed the electromagnets would not produce a magnetic field and the braking system would not work. Permanent magnets always produce a magnetic field so they avoid this problem.

Section 13.3: Alternating Current

Section 13.3 Questions, page 598

1. No, electrons move back and forth about the same spot at every point along the conductors from the power plant to my home to provide the electrical energy.

2. Yes, the voltage is proportional to the current. In alternating current electricity, as the voltage increases, the conventional current in the wire increases in the positive direction and as the voltage decreases, the conventional current in the wire decreases. This shows that the voltage is proportional to the current.

3. (a) Yes, if the frequency of the alternating current were reduced to 2 Hz it would be noticeable, particularly in the operation of light bulbs. A frequency of 2 Hz means that the current goes in a positive direction, reverses, and then goes in a negative direction two times each second. Any light bulb connected to the circuit would become brighter and dimmer twice each second, which would be very noticeable.

(b) The frequency may have been increased to reduce the flicker in electric lights.

4. A 120 V plug has three prongs and supplies appliances with an effective voltage of 120 V.
A 240 V plug has four prongs and supplies appliances with an effective voltage of 240 V.
A 240 V plug can also supply an appliance with an effective voltage of 120 V for parts of the appliance that do not require 240 V.

5. There must be an adapter that is connected between the laptop and the wall outlet that converts the alternating current into direct current.

6. A fuse is a device that is placed in series in a circuit. The fuse melts and opens the circuit if the current exceeds some maximum value at which the fuse is rated. A fuse must be replaced to close the circuit again.
A circuit breaker functions in a similar way as a fuse, except it does not melt. A circuit breaker is made with a bimetallic strip that bends to open the circuit if there is too much current in the wire. A circuit breaker can also be reset to close the circuit again.
A GFCI is similar to a circuit breaker. A GFCI is more sensitive to very small changes in current and opens the circuit much more quickly than a circuit breaker.
An AFCI is similar to a GFCI. It acts quickly to shut off a circuit when an arc along the circuit is detected.

7. The difference between the voltage used in household circuits in North America and Europe is primarily due to historical choice. Once a voltage was adopted for use in an area, the distribution systems and electric machines and appliances were designed for that specific voltage, so it would be very impractical to change the voltage used. There are very few differences when using the different power systems so one system is not better than another.

Section 13.4: Electricity Generation

Mini Investigation: What Factors Affect Electricity Generation?, page 602

A. Answers may vary. Sample answers:
Moving the magnet more quickly into the coil increased the amount of current produced.
B. Reversing the pole of the magnet inserted in the coil did not affect the amount of current produced.
C. Using two magnets greatly increased the amount of current produced.
D. Increasing the number of windings in the coil increased the amount of current produced.
Decreasing the number of windings in the coil decreased the amount of current produced.

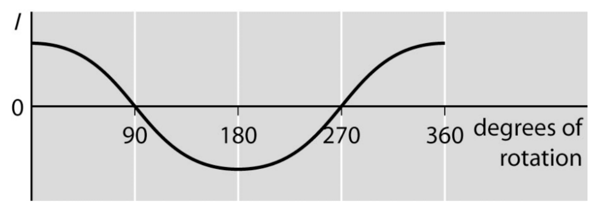
Research This: Wind Turbines, page 604

For large-scale land-based turbines:
A. Answers may vary. Sample answer:
The turbine spins at a rate of about 30 to 60 rotations per minute. The electricity is controlled through a gearbox, which is connected between the shaft from the turbine and the shaft driving the generator. The gearbox controls the rate of rotation of the shaft driving the generator, which determines how much electricity is generated.
B. Answers may vary. Sample answer:
The wind turbine must be regularly inspected and maintained to ensure proper operation of the controller, the computer that starts, stops, and rotates the turbine appropriately. The controller also controls the generator, the rotor (which consists of the blades of the turbine and the hub where they connect), and other electronic and mechanical parts of the turbine.
C. Answers may vary. Students' pamphlets should include information on the development of their chosen wind turbine technology and a summary of how the technology works.

Section 13.4 Questions, page 604

1. Diagrams should look like Figure 1 from page 599 of the Student Book with the arrow at the axis of rotation indicating a counterclockwise rotation instead of clockwise.
(a) The current will be at its maximum at the angles of 0° and 180° relative to the starting point, because the plane of the loop will be parallel to the external magnetic field at these angles.
(b) The current will be zero at the angles of 90° and 270° relative to the starting point, because the plane of the loop will be perpendicular to the external magnetic field at these angles.
(c)

(d) Reversing the polarity of the external magnets would reverse the initial direction of the current. The graph from part (c) would look like the following:



2. The rotation rate of the loop in the generator in Figure 1 is the same as the frequency of the alternating current that it generates. Each time the loop rotates through half of a complete rotation, the current changes direction.
3. The frequency of alternating current in North America is 60 Hz, so a generator armature in North America must rotate 60 times per second.
4. As the shaded side of the armature moves away from the north pole of the external magnet, Lenz's law determines the left side of the armature to be a south magnetic pole. Using the right-hand rule for a coil, the direction of the conventional current is down across the front of the coil. Looking at the diagram and following the conventional current around the coil, it can be seen that the conventional current exits the coil through the inner split ring and travels through the external circuit in the counterclockwise direction.

Section 13.5: Transformers

Mini Investigation: Observing Transformers at Work, page 606

A. Answers may vary. Sample answer:
The transformer did not work with DC because the multimeter connected to the primary coil showed a voltage but the multimeter connected to the secondary coil did not show any voltage.

B. Answers may vary. Sample answer:
The AC voltage on the primary coil was less than the AC voltage on the secondary coil.

C. Answers may vary. Sample answer:
The voltage was increased, so the transformer is a step-up transformer.

Tutorial 1 Practice, page 608

1. Given: $V_p = 240$ V; $N_p = 550$; $N_s = 110$
Required: V_s
Analysis: $\dfrac{V_p}{V_s} = \dfrac{N_p}{N_s}$

$$V_s = \frac{V_p N_s}{N_p}$$

Solution:

$$V_s = \frac{V_p N_s}{N_p} = \frac{(240\text{ V})(110)}{550}$$

$$V_s = 48\text{ V}$$

Statement: The voltage in the secondary coil is 48 V.

2. Given: $V_p = 31.0$ V; $N_p = 211$; $N_s = 844$
Required: V_s
Analysis: $\dfrac{V_p}{V_s} = \dfrac{N_p}{N_s}$

$$V_s = \frac{V_p N_s}{N_p}$$

Solution:

$$V_s = \frac{V_p N_s}{N_p} = \frac{(31.0\text{ V})(844)}{211}$$

$$V_s = 124\text{ V}$$

Statement: The voltage in the secondary coil is 124 V.

Tutorial 2 Practice, page 608

1. Given: $V_p = 240$ V; $V_s = 12$ V; $I_p = 0.15$ A
Required: I_s
Analysis: $\dfrac{I_s}{I_p} = \dfrac{V_p}{V_s}$

$$I_s = \frac{V_p I_p}{V_s}$$

Solution:

$$I_s = \frac{V_p I_p}{V_s} = \frac{(240\ \cancel{\text{V}})(0.15\text{ A})}{12\ \cancel{\text{V}}}$$

$$I_s = 3.0\text{ A}$$

Statement: The current in the secondary coil is 3.0 A.

2. Given: $V_p = 620$ V; $V_s = 12\ 000$ V; $I_s = 1.3$ A
Required: I_p
Analysis: $\dfrac{I_s}{I_p} = \dfrac{V_p}{V_s}$

$$I_p = \frac{V_s I_s}{V_p}$$

Solution:

$$I_p = \frac{V_s I_s}{V_p} = \frac{(12\ 000\ \cancel{\text{V}})(1.3\text{ A})}{620\ \cancel{\text{V}}}$$

$$I_p = 25\text{ A}$$

Statement: The current in the primary coil is 25 A.

Section 13.5 Questions, page 609

1. Transformers need an alternating current to operate continuously because they operate according to the law of electromagnetic induction, which states that a changing magnetic field is required to induce a current. The alternating current in the primary coil causes a changing magnetic field to be induced in the core, which then induces an alternating current in the secondary circuit.

2. A step-up transformer has more windings on its secondary circuit than on its primary circuit. A step-down transformer has more windings on its primary circuit than on its secondary circuit.

3. If the voltage and current increase in a step-up transformer, there would be more power coming out of the secondary coil than power going into the primary coil. Since power is equivalent to energy in equal amounts of time this would violate the law of conservation of energy.

4. The voltage would increase since it is directly proportional to the number of windings on the secondary coil. The current would decrease since it is inversely proportional to the number of windings on the secondary coil.

5. A device that has the same number of windings on both the primary coil and the secondary coil would not be capable of raising or lowering AC voltage, so it should not be classified as a transformer.

6. Transformers are not 100 % efficient because some of the energy is transformed into unusable thermal energy in the coils, as well as sound energy.

7. The number of windings on the primary coil of the transformer is 1.5 times greater than on the secondary coil, so $\frac{N_p}{N_s} = 1.5.$ Using the equations related to transformers, solve for V_s and I_s:

$$\frac{V_p}{V_s} = \frac{N_p}{N_s}$$

$$\frac{V_p}{V_s} = 1.5$$

$$1.5 \times V_s = V_p$$

$$V_s = \frac{V_p}{1.5}$$

$$= \frac{12.0\text{ V}}{1.5}$$

$$V_s = 8.0\text{ V}$$

$$\frac{I_s}{I_p} = \frac{N_p}{N_s}$$

$$\frac{I_s}{I_p} = 1.5$$

$$I_s = 1.5 \times I_p$$

$$= 1.5 \times (3.0\text{ A})$$

$$I_s = 4.5\text{ A}$$

So V_s = 8.0 V and I_s = 4.5 A.

8.

Transformer	V_p	V_s	N_p	N_s	I_p	I_s	Step-up or step-down?
1	12 V	120 V	100	**1000**	1.2 A	**0.12 A**	**step-up**
2	**660 V**	110 V	600	100	150 mA	**900 mA**	**step-down**
3	30 V	**5 V**	120	**20**	0.28 A	1.68 A	**step-down**

9. Substitute the given values for V_p and V_s in the relevant equation related to transformers to find the ratio of the windings:

$$\frac{V_p}{V_s} = \frac{N_p}{N_s}$$

$$\frac{N_p}{N_s} = \frac{V_p}{V_s}$$

V_p = 120 V; V_s = 15.0 V

$$\frac{N_p}{N_s} = \frac{V_p}{V_s}$$

$$= \frac{120\ \cancel{\text{V}}}{15.0\ \cancel{\text{V}}}$$

$$\frac{N_p}{N_s} = 8$$

So the ratio of the primary windings to secondary windings in the transformer is 8 : 1.

Section 13.6: Power Plants and the Electrical Grid

Section 13.6 Questions, page 612

1. AC power generation was chosen over DC power generation because AC power can work with transformers, which can step up the voltage of AC power and transmit it with little power loss. DC power does not work with transformers.

2. (a) Use the power equation in the form $P = I^2R$:

$$\begin{aligned} P &= I^2R \\ &= (2\,\text{kA})^2(10\,\Omega) \\ &= (2000\,\text{A})^2(10\,\Omega) \\ &= 4\times10^7\ \text{W} \\ P &= 40\,\text{MW} \end{aligned}$$

So 40 MW of power is transformed to unusable thermal energy. The percentage of power lost can now be found:

$$\frac{40\ \cancel{\text{MW}}}{200\ \cancel{\text{MW}}}\times100 = 20\ \%$$

So 20 % of the power was lost.

(b) Use the power equation in the form $P = I^2R$:

$$\begin{aligned} P &= I^2R \\ &= (200\ \text{A})^2(10\ \Omega) \\ &= 4\times10^5\ \text{W} \\ P &= 0.4\ \text{MW} \end{aligned}$$

So 0.4 MW of power is transformed to unusable thermal energy. The percentage of power lost can now be found:

$$\frac{0.4\ \cancel{\text{MW}}}{200\ \cancel{\text{MW}}}\times100 = 0.2\ \%$$

So 0.2 % of the power was lost.

(c) Use the power equation in the form $P = I^2R$:

$$\begin{aligned} P &= I^2R \\ &= (3000\ \text{A})^2(0.50\ \Omega) \\ &= 4.5\times10^6\ \text{W} \\ P &= 4.5\ \text{MW} \end{aligned}$$

So 4.5 MW of power is transformed to unusable thermal energy. The percentage of power lost can now be found:

$$\frac{4.5\ \cancel{\text{MW}}}{10\ \cancel{\text{MW}}}\times100 = 45\ \%$$

So 45 % of the power was lost.

3. Electrical energy cannot be easily stored so generating electrical energy on demand ensures that most of the electrical energy produced is used quickly, which reduces waste.

4. Commercial generators have multiple armatures and coils, use electromagnets, and must be maintained at a desired frequency. The electrical generators described in Section 13.4 did not have these features.

5. The connection point in the middle of the coil is used to create the three-wire system for household circuits that was described in Section 13.3. In the three-wire system, the wire connected to the middle of the transformer is the white wire and the wires connected on the ends are the red and black wires.

6. No, it would not be possible for the generator to power itself. A generator is not 100 % efficient because energy is always converted into unusable thermal energy through the motion of the generator and the resistance in the wires, so a generator powered by itself would have continuously less input energy and would eventually stop.

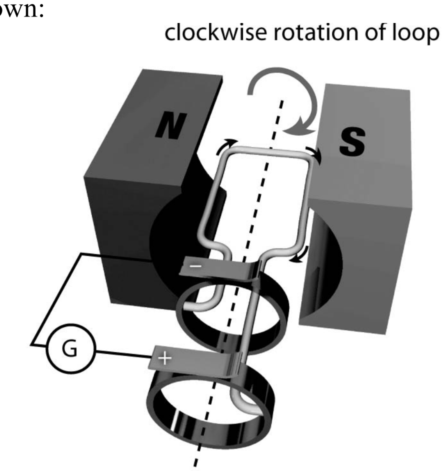
Chapter 13 Review, pages 616–623

Knowledge

1. (d)
2. (c)
3. (a)
4. (c)
5. (c)
6. (a)
7. (c)
8. (d)
9. (c)
10. False. Increasing the number of loops in a coil *increases* the amount of current induced by a changing magnetic field.
11. True
12. True
13. False. *Arc Fault Circuit Interrupters* are devices that prevent sparking or arcing that could cause a fire.
14. False. Most homes in North America use *alternating* current.
15. True
16. True
17. False. Transformers can only operate using *alternating* current.

Understanding

18. Coil A will induce more current than coil B because it has more windings. A greater number of windings in a coil means more electric current can be induced for a given change in the magnetic field.
19. For coil B to generate twice the amount of electricity as coil A in a changing magnetic field, it should have twice the number of windings as coil A.
$2(100) – 85 = 115$
So, coil B should have 115 windings added.
20. (a) By Lenz's law, the induced magnetic field of the coil must oppose the motion of the magnet being dropped. For this to happen, the top of the coil must repel the south pole of the magnet being dropped, so the top of the coil must be a south magnetic pole. If the top of the coil is a south magnetic pole the magnetic field will point downwards.
(b) Using the right-hand rule for a coil, if the direction of the magnetic field is downwards then the current will move through the coil to the left across the front of the coil.
21. (a) By Lenz's law, the induced magnetic field of the coil must oppose the motion of the magnet being dropped. For this to happen, the top of the coil must repel the north pole of the magnet being dropped, so the top of the coil must be a north magnetic pole. If the top of the coil is a north magnetic pole the magnetic field will point upwards.
(b) Using the right-hand rule for a coil, if the direction of the magnetic field is upwards then the current will move through the coil to the right across the front of the coil.
22. A ground fault circuit interrupter (GFCI) is most likely to be used to prevent electrical accidents, such as a circuit pathway being accidentally set up involving the outdoor outlet and the water in the hot tub.
23. An arc fault circuit interrupter (AFCI) should be installed in the house to help prevent fires or electrical damage due to arcing in the deteriorating wiring.
24. The rotation of the loop in a clockwise direction in the magnetic field causes a conventional current in the loop in the direction shown:



The plane of the loop is parallel to the external magnetic field so the induced current is at a maximum.
25. For the conventional current to be in the direction shown, the loop must be spinning clockwise. Since the plane of the loop is not parallel or perpendicular to the external magnetic field, its current is not at a maximum or at zero.

26. The transformer in Figure 5 has more secondary windings than primary windings so it increases the voltage in the secondary coil. Since it increases the voltage, it is a step-up transformer.

27. (a) For the transformer to be a step-up transformer, the secondary circuit should have more coils than the primary circuit. So the secondary circuit should have more than 50 coils.

(b) For the transformer to be a step-down transformer, the secondary circuit should have fewer coils than the primary circuit. So the secondary circuit should have less than 50 coils.

28. (a) For the transformer to be a step-up transformer, the primary circuit should have fewer coils than the secondary circuit. So the primary circuit should have less than 100 coils.

(b) For the transformer to be a step-down transformer, the primary circuit should have more coils than the secondary circuit. So the primary circuit should have more than 100 coils.

29. (a) Given: $V_p = 200$ V; $I_p = 5$ A; $I_s = 10$ A

Required: V_s

Analysis: $\frac{I_s}{I_p} = \frac{V_p}{V_s}$

$$V_s = \frac{V_p I_p}{I_s}$$

Solution:

$$V_s = \frac{V_p I_p}{I_s} = \frac{(200\text{ V})(5\cancel{\text{A}})}{10\cancel{\text{A}}}$$

$$V_s = 100\text{ V}$$

Statement: The voltage of the secondary circuit is 100 V.

(b) Substitute the value given for V_p and the value found for V_s in part (a) into the relevant equation related to transformers to find the ratio of the number of windings:

$$\frac{V_p}{V_s} = \frac{N_p}{N_s}$$

$$\frac{N_p}{N_s} = \frac{V_p}{V_s}$$

$V_p = 200$ V; $V_s = 100$ V

$$\frac{N_p}{N_s} = \frac{V_p}{V_s} = \frac{200\cancel{\text{V}}}{100\cancel{\text{V}}}$$

$$\frac{N_p}{N_s} = 2$$

So the ratio of the primary windings to secondary windings in the transformer is 2 : 1.

30. (a) Given: $V_p = 3.0 \times 10^2$ V; $N_p = 200$; $N_s = 300$

Required: V_s

Analysis: $\frac{V_p}{V_s} = \frac{N_p}{N_s}$

$$V_s = \frac{V_p N_s}{N_p}$$

Solution:

$$V_s = \frac{V_p N_s}{N_p} = \frac{(3.0 \times 10^2\text{ V})(300)}{200}$$

$$V_s = 450\text{ V}$$

Statement: The voltage in the secondary circuit is 450 V.

(b) Substitute the value given for V_p and the value found for V_s in part (a) into the relevant equation related to transformers to find the ratio of the currents:

$$\frac{I_s}{I_p} = \frac{V_p}{V_s}$$

$$\frac{I_p}{I_s} = \frac{V_s}{V_p}$$

$V_p = 3.0 \times 10^2$ V; $V_s = 450$ V

$$\frac{I_p}{I_s} = \frac{V_s}{V_p} = \frac{450\cancel{\text{V}}}{300\cancel{\text{V}}}$$

$$\frac{I_p}{I_s} = 1.5$$

So the ratio of the current in the primary circuit to the current in the secondary circuit is 3 : 2 or 1.5 : 1.

31. (a) Given: V_p = 60 V; N_p = 120; N_s = 160; I_s = 5.0 A

Required: V_s

Analysis: $\frac{V_p}{V_s} = \frac{N_p}{N_s}$

$$V_s = \frac{V_p N_s}{N_p}$$

Solution:

$$V_s = \frac{V_p N_s}{N_p} = \frac{(60\text{ V})(160)}{120}$$

$$V_s = 80\text{ V}$$

Statement: The voltage of the secondary circuit is 80 V.

(b) Given: V_p = 60 V; N_p = 120; N_s = 160; I_s = 5.0 A

Required: I_p

Analysis: $\frac{I_s}{I_p} = \frac{V_p}{V_s}$

$$I_p = \frac{V_s I_s}{V_p}$$

Solution: Use the value for found for V_s in part (a) to solve for I_p:

$$I_p = \frac{V_s I_s}{V_p} = \frac{(80\text{ V})(5.0\text{ A})}{60\text{ V}} = 6.7\text{ A}$$

$$I_p = 7\text{ A}$$

Statement: The current of the primary circuit is 7 A.

32. (a) Given: N_p = 60; I_p = 8.0 A; I_s = 12 A; V_s = 20 V

Required: V_p

Analysis: $\frac{I_s}{I_p} = \frac{V_p}{V_s}$

$$V_p = \frac{I_s V_s}{I_p}$$

Solution:

$$V_p = \frac{I_s V_s}{I_p} = \frac{(12\,\cancel{\text{A}})(20\text{ V})}{8.0\,\cancel{\text{A}}}$$

$$V_s = 30\text{ V}$$

Statement: The voltage of the secondary circuit is 30 V.

(b) Given: N_p = 60; I_p = 8.0 A; I_s = 12 A; V_s = 20 V

Required: N_s

Analysis: $\frac{I_s}{I_p} = \frac{N_p}{N_s}$

$$N_s = \frac{I_p N_p}{I_s}$$

Solution:

$$N_s = \frac{I_p N_p}{I_s} = \frac{(8.0\,\cancel{\text{A}})(60)}{12\,\cancel{\text{A}}}$$

$$N_s = 40$$

Statement: The secondary circuit has 40 coils.

33. (a) Given: I_p = 5.0 A; V_p = 60.0 V; N_s = 120; V_s = 25 V

Required: N_p

Analysis: $\frac{V_p}{V_s} = \frac{N_p}{N_s}$

$$N_p = \frac{V_p N_s}{V_s}$$

Solution:

$$N_p = \frac{V_p N_s}{V_s} = \frac{(60.0\,\cancel{\text{V}})(120)}{25\,\cancel{\text{V}}} = 288$$

$$N_p = 290$$

Statement: The primary circuit has 290 coils.

(b) Given: I_p = 5.0 A; V_p = 60.0 V; N_s = 120; V_s = 25 V

Required: I_s

Analysis: $\frac{I_s}{I_p} = \frac{V_p}{V_s}$

$$I_s = \frac{V_p I_p}{V_s}$$

Solution:

$$I_s = \frac{V_p I_p}{V_s} = \frac{(60.0\,\cancel{\text{V}})(5.0\text{ A})}{25\,\cancel{\text{V}}}$$

$$I_s = 12\text{ A}$$

Statement: The current in the secondary circuit is 12 A.

34. Solve for I in the power equation $P = VI$ and then substitute the values given for P and V to find I, which is the amount of current produced:

$$P = VI$$

$$I = \frac{P}{V}$$

P = 1500 MW; V = 20.0 kV

$$\begin{aligned} I &= \frac{P}{V} \\ &= \frac{1500\,\text{MW}}{20.0\,\text{kV}} \\ &= \frac{1.5\times10^{9}\ \text{W}}{2.0\times10^{4}\ \text{V}} \\ I &= 7.5\times10^{4}\,\text{A} \end{aligned}$$

So the amount of current produced is 7.5×10^4 A.

35. Solve for V in the power equation $P = VI$ and then substitute the values given for P and I to find V, which is the electric potential difference:

$$P = VI$$

$$V = \frac{P}{I}$$

$P = 8.0 \times 10^2$ MW; I = 15 kA

$$\begin{aligned} V &= \frac{P}{I} \\ &= \frac{8.0\times10^{2}\ \text{MW}}{15\ \text{kA}} \\ &= \frac{8.0\times10^{8}\ \text{W}}{1.5\times10^{4}\ \text{A}} \\ &= 5.3\times10^{4}\,\text{V} \\ V &= 53\ \text{kV} \end{aligned}$$

So the electric potential difference is 53 kV.

36. Substitute the values given for V and I in the power equation $P = VI$ to find P, which is the amount of power produced:

$$P = VI$$

V = 150 kV; I = 40.0 A

$$\begin{aligned} P &= VI \\ &= (150\ \text{kV})(40.0\,\text{A}) \\ &= (1.5\times10^{5}\ \text{V})(40.0\,\text{A}) \\ &= 6.0\times10^{6}\ \text{W} \\ P &= 6.0\ \text{MW} \end{aligned}$$

So the amount of power produced is 6.0 MW.

37. (a) Use the power equation in the form $P = I^2R$:

$$\begin{aligned} P &= I^{2}R \\ &= (40.0\ \text{kA})^{2}(0.30\ \Omega) \\ &= (4.00\times10^{4}\ \text{A})^{2}(0.30\ \Omega) \\ &= 4.8\times10^{8}\ \text{W} \\ P &= 480\ \text{MW} \end{aligned}$$

So the total power loss due to transmission through the wire is 480 MW.

(b) Use the power equation in the form $P = I^2R$ and the new value for I:

$$\begin{aligned} P &= I^{2}R \\ &= (2.0\ \text{kA})^{2}(0.30\ \Omega) \\ &= (2.0\times10^{3}\ \text{A})^{2}(0.30\ \Omega) \\ &= 1.2\times10^{6}\ \text{W} \\ P &= 1.2\ \text{MW} \end{aligned}$$

So the total power loss due to transmission through the wire is now 1.2 MW.

38. Use the power equation in the form $P = I^2R$:

$$\begin{aligned} P &= I^{2}R \\ &= (20.0\ \text{kA})^{2}(0.20\ \Omega) \\ &= (2.00\times10^{4}\ \text{A})^{2}(0.20\ \Omega) \\ &= 8\times10^{7}\ \text{W} \\ P &= 80\ \text{MW} \end{aligned}$$

So 80 MW of power is transformed to unusable thermal energy. The percentage of power lost can now be found:

$$\frac{80\ \cancel{\text{MW}}}{5.0\times10^{2}\ \cancel{\text{MW}}}\times100 = 16\ \%$$

So 16 % of the power was lost in the transmission line.

39. First determine the amount of power lost in transmission in watts:

0.50 % of 2300 MW = 1.15×10^7 W (one extra digits carried)

So the amount of power lost in transmission, P, is 1.15×10^7 W.

Now solve for R, the total resistance in the transmission wire, in the power equation in the form $P = I^2R$:

$$\begin{aligned} P &= I^{2}R \\ R &= \frac{P}{I^{2}} \\ &= \frac{1.15\times10^{7}\ \text{W}}{(4.0\ \text{kA})^{2}} \\ &= \frac{1.15\times10^{7}\ \text{W}}{(4.0\times10^{3}\,\text{A})^{2}} \\ R &= 0.72\ \Omega \end{aligned}$$

So the total resistance in the transmission wire is 0.72 Ω.

40. First find the amount of power lost due to transmission in watts, using the power equation in the form $P = I^2R$:

$$\begin{aligned}P &= I^2R \\ &= (6.0\text{ kA})^2(0.50\ \Omega) \\ &= (6.0\times10^3\text{ A})^2(0.50\ \Omega) \\ &= 1.8\times10^7\text{ W} \\ P &= 18\text{ MW}\end{aligned}$$

So the power lost due to transmission is 18 MW.

This power loss represents 0.70 % of the total power, so the total power that the nuclear plant generates can now be found.

Let P be the total power generated.

$P \times 0.70\ \% = 18$ MW

$P = 18\text{ MW} \div 0.70\ \%$

$P = 2600$ MW

So the nuclear power plant generates 2600 MW of power.

41. (a) Using the right-hand rule for a coil, the bottom of the coil is a north magnetic pole. If the bottom of the coil is a north magnetic pole, the magnetic field will point downwards.

(b) By Lenz's law, the induced magnetic field of the large coil must oppose the magnetic field of the small coil. For this to happen, the top of the large coil must repel the north pole of the smaller coil that is placed inside it, so the top of the large coil must be a north magnetic pole. If the top of the large coil is a north magnetic pole, the magnetic field will point upwards.

(c) Using the right-hand rule for a coil, if the direction of the magnetic field is upwards then the current will move through the large coil to the right across the front of the coil.

42. (a) The small coil cannot have the same polarity as the large coil, so the current must be moving in the opposite direction through the small coil, which to the left across the front of the coil.

(b) Using the right-hand rule for a coil, the top of the large coil is a north magnetic pole. If the top of the coil is a north magnetic pole, the induced magnetic field will point upwards.

(c) Using the right-hand rule for a coil and the direction of the current found in part (a), the bottom of the small coil is a north magnetic pole. If the bottom of the coil is a north magnetic pole, the induced magnetic field will point downwards.

43. A current will not be induced in the wire, because the magnetic field is not changing. The law of electromagnetic induction states that a changing magnetic field is required to cause an induced current in a conductor.

44. A current is induced in the wire and it is to the right. The magnetic field in the region of the conductor is changing when the magnet is moved above the conductor. So, by the law of electromagnetic induction, a current is induced in the wire. By Lenz's law, the induced current must induce a magnetic field that opposes the motion of the magnet. Using the right-hand rule for a straight conductor, the current must flow to the right for this to happen.

45. First determine the total number of windings in the length of coil type A that the student has:

$$\frac{25\text{ windings}}{1\ \cancel{\text{cm}}}\times 14\ \cancel{\text{cm}} = 350\text{ windings}$$

The length, L, of coil type B must have the same total number of windings as the length of coil type A to produce the same amount of current in a changing magnetic field. So the length, L, of coil type B must have 350 windings and L can now be found:

$$\frac{10\text{ windings}}{1\text{ cm}}\times L = 350\text{ windings}$$

$$L = 350\ \cancel{\text{windings}}\times\frac{1\text{ cm}}{10\ \cancel{\text{windings}}}$$

$$L = 35\text{ cm}$$

So the length of coil type B needed is 35 cm.

46. To reduce the amount current by a factor of two, the coil should have half as many loops as it originally had. This is because the amount of induced current is directly proportional to the number of loops in the coil.

47. (a) By the law of electromagnetic induction, a changing magnetic field is required in the region of a conductor to induce a current in the conductor. When the magnet is moving into the copper loop the magnetic field in the region of the loop is changing, so there is an induced current. When the magnet stops moving after it is inside the loop the magnetic field is no longer changing, so the induced current stops.

48. (a) As the shaded side of the armature moves away from the north pole of the external magnet, Lenz's law determines the left side of the armature to be a south magnetic pole. Using the right-hand rule for a coil, the direction of the conventional current is down across the front of the coil.

(b) As the shaded side of the armature moves toward the north pole of the external magnet, Lenz's law determines the left side of the armature to be a north magnetic pole. Using the right-hand rule for a coil, the direction of the conventional current is up across the front of the coil.

49. Using the right-hand rule for a coil, the magnetic polar orientation of the shaded region is a north pole. The induced magnetic field must be repelling the external magnetic field; for this to happen, the coil must be spinning clockwise.

50. (a) Given: $V_p = 200$ V; $N_p = 120$; $V_s = 50$ V

Required: N_s

Analysis: $\frac{V_p}{V_s} = \frac{N_p}{N_s}$

$$N_s = \frac{V_s N_p}{V_p}$$

Solution:

$$N_s = \frac{V_s N_p}{V_p}$$

$$= \frac{(50 \cancel{V})(120)}{200 \cancel{V}}$$

$$N_s = 30$$

Statement: The secondary circuit has 30 coils.

(b) First use Ohm's law in the form $I = \frac{V}{R}$ and the values given for V_p and R_p to find I_p, the current in the primary circuit:

$$I_p = \frac{V_p}{R_p}$$

$$= \frac{200 \text{ V}}{10 \text{ }\Omega}$$

$$I_p = 20 \text{ A}$$

So the current in the primary circuit, I_p, is 20 A.

Now use the relevant equation related to transformers to find the current in the secondary circuit, I_s:

$$\frac{I_s}{I_p} = \frac{N_p}{N_s}$$

$$I_s = \frac{I_p N_p}{N_s}$$

$$= \frac{(20 \text{ A})(120)}{30}$$

$$I_s = 80 \text{ A}$$

So the current in the secondary circuit, I_s, is 80 A.

51. (a) Given: $I_p = 30.0$ A; $N_p = 50$; $N_s = 150$

Required: I_s

Analysis: $\frac{I_s}{I_p} = \frac{N_p}{N_s}$

$$I_s = \frac{I_p N_p}{N_s}$$

Solution:

$$I_s = \frac{I_p N_p}{N_s}$$

$$= \frac{(30.0 \text{ A})(50)}{150}$$

$$I_s = 10.0 \text{ A}$$

Statement: The current in the secondary circuit is 10.0 A.

(b) Use Ohm's law in the form $V = IR$ and the value found for I_s in part (a) and the value given for R_s to find V_s, the potential difference in the secondary circuit:

$$V_s = I_s R_s$$

$$= (10.0 \text{ A})(4.2 \text{ }\Omega)$$

$$V_s = 42 \text{ V}$$

So the potential difference in the secondary circuit, V_s, is 42 V.

Now use the relevant equation related to transformers to find the potential difference in the primary circuit, V_p:

$$\frac{V_p}{V_s} = \frac{N_p}{N_s}$$

$$V_p = \frac{V_s N_p}{N_s}$$

$$= \frac{(42 \text{ V})(50)}{150}$$

$$V_p = 14 \text{ V}$$

So the potential difference in the primary circuit, V_p, is 14 V.

52. (a) Given: $N_p = 70$; $R_p = 25$ Ω; $N_s = 280$; $V_s = 7.00 \times 10^2$ V

Required: V_p

Analysis: $\frac{V_p}{V_s} = \frac{N_p}{N_s}$

$$V_p = \frac{V_s N_p}{N_s}$$

Solution:

$$V_p = \frac{V_s N_p}{N_s}$$

$$= \frac{(7.00\times 10^2\ \text{V})(70)}{280}$$

$$V_p = 175\ \text{V}$$

Statement: The potential difference in the primary circuit is 175 V.

(b) First use Ohm's law in the form $I = \frac{V}{R}$ and the value found for V_p in part (a) and the value given for R_p to find I_p, the current in the primary circuit:

$$I_p = \frac{V_p}{R_p}$$

$$= \frac{175\ \text{V}}{25\ \Omega}$$

$$I_p = 7.0\ \text{A}$$

So the current in the primary circuit, I_p, is 7.0 A.

Now use the relevant equation related to transformers to find the current in the secondary circuit, I_s:

$$\frac{I_s}{I_p} = \frac{N_p}{N_s}$$

$$I_s = \frac{I_p N_p}{N_s}$$

$$= \frac{(7.0\ \text{A})(70)}{280}$$

$$I_s = 1.75\ \text{A} \quad \text{(one extra digit carried)}$$

So the current in the secondary circuit, I_s, is 1.75 A.

Now use Ohm's law in the form $R = \frac{V}{I}$ and the value found for I_s and the value given for V_s to find R_s, the resistance in the secondary circuit:

$$R_s = \frac{V_s}{I_s}$$

$$= \frac{7.00\times 10^2\ \text{V}}{1.75\ \text{A}}$$

$$R_s = 4.0\times 10^2\ \Omega$$

So the resistance in the secondary circuit is $4.0 \times 10^2\ \Omega$.

53. Note: After the first printing, the given potential difference of the secondary circuit was revised to 1.00×10^2 V. The solution below reflects this change.

(a) Given: $V_p = 2.0$ kV; $R_p = 5.00 \times 10^2\ \Omega$; $V_s = 1.00 \times 10^2$ V; $N_s = 50$

Required: N_p

Analysis: $\frac{V_p}{V_s} = \frac{N_p}{N_s}$

$$N_p = \frac{V_p N_s}{V_s}$$

Solution:

$$N_p = \frac{V_p N_s}{V_s}$$

$$= \frac{(2.0\ \text{kV})(50)}{1.00\times 10^2\ \text{V}}$$

$$= \frac{(2.0\times 10^3\ \cancel{\text{V}})(50)}{1.00\times 10^2\ \cancel{\text{V}}}$$

$$N_p = 1000$$

Statement: The primary circuit has 1000 coils.

(b) First use Ohm's law in the form $I = \frac{V}{R}$ and the values given for V_p and R_p to find I_p, the current in the primary circuit:

$$I_p = \frac{V_p}{R_p}$$

$$= \frac{2.0\ \text{kV}}{5.00\times 10^2\ \Omega}$$

$$= \frac{2.0\times 10^3\ \text{V}}{5.00\times 10^2\ \Omega}$$

$$I_p = 4.0\ \text{A}$$

So the current in the primary circuit, I_p, is 4.0 A.

Now use the relevant equation related to transformers to find the current in the secondary circuit, I_s:

$$\frac{I_s}{I_p} = \frac{V_p}{V_s}$$

$$I_s = \frac{I_p V_p}{V_s}$$

$$= \frac{(4.0\ \text{A})(2.0\ \text{kV})}{1.00\times 10^2\ \text{V}}$$

$$= \frac{(4.0\ \text{A})(2.0\times 10^3\ \cancel{\text{V}})}{1.00\times 10^2\ \cancel{\text{V}}}$$

$$I_s = 8.0\times 10^1\ \text{A}$$

So the current in the secondary circuit, I_s, is 8.0×10^1 A.

Now use Ohm's law in the form $R = \frac{V}{I}$ and the value found for I_s and the value given for V_s to find R_s, the resistance in the secondary circuit:

$$R_s = \frac{V_s}{I_s}$$
$$= \frac{1.00 \times 10^2 \text{ V}}{8.0 \times 10^1 \text{A}}$$
$$R_s = 1.3\ \Omega$$

So the resistance in the secondary circuit is 1.3 Ω.

54. First find the current that the power is transmitted with using the power equation in the form $P = VI$ and the values given for P and V:

$$P = VI$$
$$I = \frac{P}{V}$$
$$= \frac{1500 \text{ MW}}{3.00 \times 10^2 \text{ kV}}$$
$$= \frac{1.5 \times 10^9 \text{ W}}{3.00 \times 10^5 \text{ V}}$$
$$I = 5.0 \times 10^3 \text{ A}$$

So the power is transmitted with a current of 5.0×10^3 A.

Now use the power equation in the form $P = I^2R$ to find the amount of power lost due to transmission:

$$P = I^2 R$$
$$= (5.0 \times 10^3 \text{ A})^2 (0.150\ \Omega)$$
$$P = 3.75 \text{ MW} \quad \text{(one extra digit carried)}$$

So 3.75 MW of power is lost. The percentage of power lost can now be found:

$$\frac{3.75 \cancel{\text{MW}}}{1500 \cancel{\text{MW}}} \times 100 = 0.25\ \%$$

So 0.25 % of the power was lost.

55. First determine the amount of power lost in transmission in watts:

0.90 % of 12 MW = 1.08×10^5 W (one extra digit carried)

So the amount of power lost in transmission, P, is 1.08×10^5 W.

Now determine the current that the power is transmitted with using the power equation in the form $P = VI$ and the values given for P and V:

$$P = VI$$
$$I = \frac{P}{V}$$
$$= \frac{12 \text{ MW}}{1.00 \times 10^2 \text{ kV}}$$
$$= \frac{12 \times 10^6 \text{ W}}{1.00 \times 10^5 \text{ V}}$$
$$I = 120 \text{ A}$$

So the power is transmitted with a current of 120 A.

Now solve for R in the power equation in the form $P = I^2R$ and then substitute the value found for P and I to find R, which is the total resistance in the transmission wire:

$$P = I^2 R$$
$$R = \frac{P}{I^2}$$
$$= \frac{1.08 \times 10^5 \text{ W}}{(120 \text{ A})^2}$$
$$R = 7.5\ \Omega$$

So the total resistance in the transmission wire is 7.5 Ω.

56. First find an equation relating the power generated by the dam, the current that the power is transmitted with, and the total resistance. This equation is:

$$0.70\ \% \text{ of } P = I^2 R$$
$$0.0070 P = I^2 R$$

Now rearrange for I in the power equation $P = VI$ and substitute the expression for I into the previous equation:

$$P = VI$$
$$I = \frac{P}{V}$$
$$(0.0070)P = I^2 R$$
$$(0.0070)P = \left(\frac{P}{V}\right)^2 R$$

Now solve for P in this equation and substitute the values given for V and R to determine P, which is the total power generated by the dam:

$$(0.0070)P = \left(\frac{P}{V}\right)^2 R$$

$$\frac{P^2}{V^2}R = 0.0070P$$

$$\frac{P^{\not 2}}{V^2 \not P}R = \left(\frac{0.0070\not P}{\not P}\right)$$

$$\frac{P}{V^2}R = 0.0070$$

$$P = \frac{0.0070V^2}{R}$$

V = 220 kV; R = 0.40 Ω

$$\begin{aligned} P &= \frac{0.0070V^2}{R} \\ &= \frac{0.0070(220\text{ kV})^2}{0.40\ \Omega} \\ &= \frac{0.0070(2.2\times 10^5\text{ V})^2}{0.40\ \Omega} \\ P &= 850\text{ MW} \end{aligned}$$

So the dam produces 850 MW of power.

57. First solve for V in the power equation $P = VI$ and then substitute the values given for P and I to find V, which is the voltage of the primary circuit:

$$\begin{aligned} P &= VI \\ V &= \frac{P}{I} \\ &= \frac{1800\text{ MW}}{30.0\text{ kA}} \\ &= \frac{1.8\times 10^9\text{ W}}{3.00\times 10^4\text{ A}} \\ V &= 6.0\times 10^1\text{ kV} \end{aligned}$$

So the voltage in the primary circuit is 6.0×10^1 kV.

Now use the relevant equation related to transformers to find the number of windings in the primary circuit, N_p:

$$\begin{aligned} \frac{V_p}{V_s} &= \frac{N_p}{N_s} \\ V_p N_s &= V_s N_p \\ N_s &= \frac{V_s N_p}{V_p} \\ &= \frac{(240\not{\text{kV}})(100)}{6.0\times 10^1\not{\text{kV}}} \\ N_s &= 400 \end{aligned}$$

So 400 windings are used in the secondary circuit.

58. Given: V_p = 40.0 kV; N_p = 100; N_s = 500

Required: V_s

Analysis: $\dfrac{V_p}{V_s} = \dfrac{N_p}{N_s}$

$$V_s = \frac{V_p N_s}{N_p}$$

Solution:

$$\begin{aligned} V_s &= \frac{V_p N_s}{N_p} \\ &= \frac{(40.0\text{ kV})(500)}{100} \\ &= \frac{(4.00\times 10^4\text{ V})(500)}{100} \\ &= 2.00\times 10^5\text{ V} \\ V_s &= 2.00\times 10^2\text{ kV} \end{aligned}$$

Statement: The power is transmitted with a potential difference of 2.00×10^2 kV.

Now solve for I in the power equation $P = VI$ and then substitute the value found for V and the value given for P and V to find I, which is the current with which the power is transmitted:

$$\begin{aligned} P &= VI \\ I &= \frac{P}{V} \end{aligned}$$

P = 2500 MW; $V = 2.00 \times 10^2$ kV

$$\begin{aligned} I &= \frac{P}{V} \\ &= \frac{2500\text{ MW}}{2.00\times 10^2\text{ kV}} \\ &= \frac{2.5\times 10^9\text{ W}}{2.00\times 10^5\text{ V}} \\ &= 1.3\times 10^4\text{ A} \\ I &= 13\text{ kA} \end{aligned}$$

So the current with which the power is transmitted is 13 kA.

59. First find the potential difference of the primary circuit, V_p, using the relevant equation related to transformers:

$$\frac{V_p}{N_p} = \frac{V_s}{N_s}$$

$$V_p = \frac{V_s N_p}{N_s}$$

$$= \frac{(240 \text{ kV})(100)}{800}$$

$$V_p = 3.0 \times 10^4 \text{ V}$$

So the potential difference of the primary circuit is 3.0×10^4 V.

Now use the power equation in the form $P = VI$ with the value found for V and the value given for I to find P, the power that the nuclear plant produces:

$$P = VI$$

$$= (3.0 \times 10^4 \text{ V})(24 \text{kA})$$

$$= (3.0 \times 10^4 \text{ V})(24 \times 10^3 \text{A})$$

$$= 7.2 \times 10^8 \text{ MW}$$

$$P = 720 \text{ MW}$$

So the power plant produces 720 MW of power.

60. First find the power that is lost in watts after the current is sent through the transformer:

1200 MW × 0.20 % = 2.4 MW

Now solve for I in the power equation $P = I^2R$ and substitute the value found for P and the value given for R to find I, which is the current after the transformer change:

$$P = I^2 R$$

$$I^2 = \frac{P}{R}$$

$$I = \sqrt{\frac{P}{R}}$$

$$= \sqrt{\frac{2.4 \text{ MW}}{\frac{2}{3} \ \Omega}}$$

$$= \sqrt{\frac{2.4 \times 10^6 \text{ W}}{\frac{2}{3} \ \Omega}}$$

$$I = 1.9 \text{ kA}$$

So the current after the transformer change, which can be called I_s, is 1.9 kA.

Now use the relevant equation related to transformers to find the current before the transformer change, I_p:

$$\frac{I_s}{I_p} = \frac{N_p}{N_s}$$

$$I_p = \frac{I_s N_s}{N_p}$$

$$= \frac{(6.0 \text{ kA})(600)}{120}$$

$$I_p = 30 \text{ kA}$$

So the current before the transformer change, I_p, is 30 kA.

The potential different before the transformer change, V_p, can now be found by solving for V in the power equation $P = VI$ and substituting the value found for I and the value given for P:

$$P = VI$$

$$V = \frac{P}{I}$$

$$= \frac{1200 \text{ MW}}{30 \text{ kA}}$$

$$= \frac{1.2 \times 10^9 \text{ W}}{3.0 \times 10^4 \text{ A}}$$

$$V = 40 \text{ kV}$$

So the voltage before the transformer change, V_p, is 40 kV.

Now use the relevant equation related to transformers to find the voltage after the transformer change, V_s:

$$\frac{V_p}{V_s} = \frac{N_p}{N_s}$$

$$V_s = \frac{V_p N_s}{N_p}$$

$$= \frac{(40 \text{ kV})(600)}{120}$$

$$V_s = 2.0 \times 10^2 \text{ kV}$$

So the voltage after the transformer change, V_s, is 2.0×10^2 kV.

61. (a) Let V_1 and N_1 be the output voltage and number of windings, respectively, of the first segment of the secondary coil and V_2 and N_2 be the output voltage and number of windings, respectively, of the second segment of the secondary coil. Then $\frac{V_p}{V_1} = \frac{N_p}{N_1}$ and $\frac{V_p}{V_2} = \frac{N_p}{N_2}$.

(b) Since energy is conserved, the energy going into the primary coil, ΔE_p, must equal the total energy coming out of the two segments of the secondary coils, ΔE_1 and ΔE_2. Using this and the fact that $\Delta E = P\Delta t$, the required equations can be derived:

$$\Delta E_p = \Delta E_1 + \Delta E_2$$
$$P_p \cancel{t} = P_1 \cancel{t} + P_2 \cancel{t}$$
$$P_p = P_1 + P_2$$

So the equation for the input power compared to the output power is $P_p = P_1 + P_2$. Substituting $P = VI$ into this equation, an equation relating the input current and voltage to the output currents and voltages can be found:

$$P_p = P_1 + P_2$$
$$V_p I_p = V_1 I_1 + V_2 I_2$$

So the equation relation the voltages and currents is $V_p I_p = V_1 I_1 + V_2 I_2$.

(c) From part (a) and the values given for V_p, N_p, and N_1, we find:

$$\frac{V_p}{V_1} = \frac{N_p}{N_1}$$
$$V_1 = \frac{V_p N_1}{N_p}$$
$$= \frac{120\text{ V}(5)}{100}$$
$$V_1 = 6.0\text{ V}$$

So $V_1 = 6.0$ V.

From part (a) and the values given for V_p, N_p, and N_2, we find:

$$\frac{V_p}{V_2} = \frac{N_p}{N_2}$$
$$V_2 = \frac{V_p N_2}{N_p}$$
$$= \frac{120\text{ V}(20)}{100}$$
$$V_2 = 24\text{ V}$$

So $V_2 = 24$ V.

(d) This type of transformer is useful because it can act as a step-up transformer for one secondary circuit and a step-down transformer for another secondary circuit.

62. Coil B would have more current. Consider a coil C, made with the same material as coil A and the same length as coil B, that is also placed in the magnetic field. When the magnetic field drops to zero the magnitude of the current in coil B would be twice that of the magnitude of current in coil C, because coil B has half the resistance of coil C. When the magnetic field drops to zero the magnitude of the current in coil A would be less than twice that of the magnitude of the current in coil C, because coil A has twice the number of loops but also a proportionally higher resistance because of the extra loops. This shows that coil B would have more current than coil A.

Evaluation

63. The law of electromagnetic induction states that a change in the magnetic field in the region of a conductor induces a voltage in the conductor, causing an induced electric current in the conductor. By Ohm's law, the current in a conductor is inversely proportional to the resistance of the conductor, so to induce the most current in a conductor it should be made of material with a low resistance.

64. When you see a blue spark when you a pull out a plug out of an outlet too fast, the alternating current is arcing. Alternating current means that the voltage in a circuit is constantly varying. This means the potential difference around the plug remains constant because it is no longer connected to the circuit, but the potential difference around the outlet continues to vary. The two regions quickly experience a large potential difference and a spark occurs that allows the excess charge on the plug to discharge. It is important to turn off a device before unplugging it because sparks can damage the plug or outlet and wear away the insulation on the plug or outlet. This can cause wires to become exposed or a dangerous short circuit.

65. Superconductors require very low temperatures to function, which requires expensive technology, so they are not economical to use to transmit power. If superconductor technology was available at the time of Edison and Tesla, Edison may have won the energy battle because superconductors transmit DC power, which was the type of power that Edison used. If superconductors could be used economically in our electrical grid, electrical energy could be transmitted very efficiently and so less power would have to be generated.

Reflect on Your Learning

66. Answers may vary. Students could include an explanation about how electromagnetic induction gave them a better understanding of how electricity is generated and distributed, including a description of how electromagnetic induction is used in AC generators and transformers.

67. Answers may vary. Students could describe how an investigation into the current induced in a coil by the movement of a magnet improved their understanding of alternating currents, since a change in the direction of the movement of the magnet corresponded to change in the direction of the current.

68. Answers may vary. Students should discuss how learning about motors and generators either helped or confused their understanding of how both devices operate.

69. Answers may vary. Students should choose a safety device from Section 13.3 and explain why they found it interesting. Students should also describe the benefits of having the safety devices installed in the home.

Research

70. Answers may vary. Students should provide information and sources as to the overall strength of Earth's magnetic field and compare that to a field strength found in a commercial electric power plant. Using these numbers students should then approximate about how many times larger a generator would need to be in order to use the field of Earth. It should be noted that it would not be possible to build an electric generator that uses Earth's magnetic field, because Earth's magnetic field strength is approximately 100 000 times weaker than the magnets used in modern generators. To create an electric generator that uses Earth's magnetic field, it would have to be extremely large and would have to be somehow moved relative to the rotation of Earth in order to experience a changing magnetic field.

71. Answers may vary. Sample answer:
RMS voltage means "root mean square voltage" and for a typical alternating current is equal to the peak voltage divided by $\sqrt{2}$. It is used because the value of the RMS voltage for an alternating current in a circuit is equivalent to the voltage needed for a direct current in the same circuit to deliver the same average amount of power. The V_{RMS} value for alternating current in North America is 120 V. The 'average' voltage cannot be used because the average voltage for an alternating current is always zero. Since the V_{RMS} value for alternating current in North America is 120 V, the peak voltage for household outlets is 120 V × $\sqrt{2}$ = 170 V.

72. Answers may vary. Sample answer:
In Europe, a voltage of 230 V at a frequency of 50 Hz is the power standard that is most used. The differences exist because of historical choices and the fact that it is difficult to change power standards once they are adopted because all electrical equipment must be designed for a specific power standard. There are very few effects of using a different power standard, so no standard should be considered much better than any another.

73. Answers may vary. Students should find that some electrical safety devices in a power plant operate according to the same principles as typical circuit breakers and fuses, but may have lower tolerances for the loads. Other safety features include insulating high voltage wires with special materials, covering these high voltage wires with grounded conductors, and installing automatic monitoring and alarm systems.

74. Students' answers should include cited references for all the information requested. Answers should summarize how the generators in commercial power plants work and how they differ from those discussed in the textbook.