Preview of Period 14: Generating and Transmitting Electricity

14.1 Generating Electricity

How do generators convert kinetic energy into electricity?

14.2 Resistance and Joule Heating

Why are low resistance wires desirable?

What causes wires to overheat?

14.3 Transmitting Electricity

How can we efficiently and safely transmit electricity from generating plants to consumers?

14.4 Transformers

How do transformers change the voltage and current in a circuit?
Act. 14.1: Generating Electricity

- Generating plants convert kinetic energy into electrical energy by rotating coils of conducting wire near magnets.

- When magnets and iron rods wrapped in wire spin relative to one another, an electric current is produced in the wire.

- To rotate the coils of wire, generating plants use kinetic energy from steam or from water falling over a dam's spillway to turn turbines.

- Generating plants burn fossil fuels or use nuclear energy to heat water for steam to turn turbines.
Act. 14.2: Resistance and Joule Heating

Joule heating occurs when a resistor is heated as current flows through it.

\[ P_{joule} = I^2 R \]

- \( P_{joule} \) = power (in watts)
- \( I \) = current (in amps)
- \( R \) = resistance (in ohms)

Since the current \( I \) is squared \((I \times I = I^2)\), even a small amount of current can produce substantial joule heating.

\( P_{joule} = I^2 R \) is a combination of two familiar equations: \( P = I V \) and \( V = I R \)

Substitute \( V = I R \) for the \( V \) in \( P = I V \)

\[ P = I V = I I R = I^2 R = P_{joule} \]

How much power would be wasted by joule heating if \( 1.82 \times 10^6 \) amps of current flowed through long distance transmission lines with a resistance of 4 ohms?

\[ P_{joule} = I^2 R = (1.82 \times 10^6 \text{amps})^2 \times 4 \Omega = 3.31 \times 10^{12} \text{amps}^2 \times 4 \Omega = 1 \times 10^{13} \text{watts} \]
Act.14.2.a: Resistance and Joule Heating

1. Use a multimeter to measure the toaster’s resistance when it is NOT operating. Attach the multimeter leads to the prongs of the toaster plug.
   
   Caution: Push down the toaster switch, but do NOT plug the toaster into an outlet.

2. Use a wattmeter to measure the toaster’s voltage and current when it is operating.
   
   Plug the toaster into the outlet attached to the wattmeter cord.
Measuring Resistance with a Multimeter

1. Turn the dial to the ohm symbol (Ω).
2. Check that the wire leads are attached to the outlets on the lower right of the meter.
3. Push the toaster switch down.
4. Attach the ends of the leads to each prong of the toaster plug.
Voltage and Current with a Wattmeter

1. Plug the wattmeter into the power strip and turn it on.
2. Plug the toaster into the outlet in the wattmeter cord. Push the switch down.
3. To measure current, press 10 amps
4. To measure voltage, press 200 volts
5. Turn the meter OFF when you finish!
Act 14.2: Joule Heating

What happens to the toaster's resistance while it is operating?

♦ Most of the power goes to the toaster's resistor.

♦ Some energy is wasted heating the connecting wires because they have some resistance.

♦ The result is a voltage drop along the wire: $V = I R$ and

♦ Joule heating in the wire: $P_{joule} = I^2 R$
Both of these effects depend on the current, $I$, and the resistance, $R$, but not on the voltage.

**Act. 14.3 Transmitting Electricity**

- Large amounts of electricity cannot be easily stored. Therefore, electricity must be generated as it is needed and transmitted to consumers. What is the most efficient way to transmit electricity?

  How can we reduce joule heating in transmission wires? Should we use:

  - Higher voltage or lower voltage?
  - Very large currents or smaller currents?
  - High resistance wires or low resistance wires?

Which circuit will have brighter bulbs?

**Circuit #1**

**Circuit #2**
Example of Power Transmission

Suppose we must transmit 1,670,000 amps of current with a voltage drop of no more than 18 volts across the transmission wires. How small must the resistance of the wires be?

Solve $V = IR$, for the resistance, $R$:

$$\frac{V}{I} = R = \frac{18 \text{ volts}}{1.67 \times 10^6 \text{ amps}} = 11 \times 10^{-6} \text{ ohms} = 1.1 \times 10^{-5} \text{ ohm}$$

How much power does this small resistance waste as joule heating?

$$P_{\text{joule}} = I^2R = (1.67 \times 10^6 \text{ amps})^2 \times 1.1 \times 10^{-5} \text{ ohms} = 2.8 \times 10^{12} \text{ amps}^2 \times 1.1 \times 10^{-5} = 31 \times 10^6 \text{ watts}$$

What percent of the total power is wasted?

$$\frac{31 \times 10^6 \text{ watts}}{200 \times 10^6 \text{ watts}} = 0.15 = 15\%$$
Act 14.3: Transformers

Transformers trade high voltage for low current or low voltage for high current.

A step-up transformer increases the voltage and decreases the current flowing in a circuit.

A step-down transformer decreases the voltage and increases the current.

Transformers work only with alternating (AC) current. They do not work with the direct (DC) current provided by batteries or capacitors.
Voltage, Current, and Transformers

♦ Transformers trade high voltage for low current or low voltage for high current,

♦ The total power remains constant (except for small heating losses)

\[ Power_{in} = Power_{out} \]

Since \( P = I \cdot V \),

\[ I_{in} \cdot V_{in} = I_{out} \cdot V_{out} \]

Is this a step up or step down transformer?
How much power goes into and comes out of it?
Period 14 Summary

14.1: Electricity is generated when coils of wire wrapped around an iron core spin near magnets.

Gravitational potential energy from falling water or thermal energy from steam turns the blades of turbines.

Turbines spin the wire coils near magnets.

14.2: The joule heating equation, \( P = I^2 R \), shows that much power is wasted in heating the wires when large currents are transmitted.

- Significantly lowering of resistance of transmission wires is not practical.
- Sending high voltage current to homes is not safe.
- Therefore, electricity is distributed over long distances at high voltage and supplied to homes at low voltage.
Period 14 Summary, Continued

14.3:  Transformers trade current and voltage, while keeping the power nearly constant.

\[ Power_{in} = Power_{out} \]

So \[ I_{in} \ V_{in} = I_{out} \ V_{out} \]

Step-up transformers reduce the current and increase the voltage for efficient long distance transmission of electricity.

Step-down transformers reduce the voltage and increase the current for safer home use of electricity.
Period 14 Review Questions

R.1 How does a power plant generate electricity?

R.2 Why don’t generating plants use falling water or steam pressure to spin the coils or wire directly without the use of turbines?

R.3 Explain the advantages and disadvantages of transmitting electricity at high voltages.

R.4 Why are appliances, which require large amounts of power for proper operation, such as electric ranges and clothes dryers, designed to operate from 220 volt lines rather than 120 volt lines?

R.5 The Law of Conservation of Energy states that energy cannot be created or destroyed. Doesn’t a transformer, which increases a current from 10 amps to 20 amps, violate this law? Explain why or why not.