Physics 30 Lesson 18B Electric Power and Energy

I. Electric power

From Lesson 4 (Energy, Work and Power) we know that power is work / time:

$$P = \frac{W}{t} \qquad \text{units: } \frac{J}{s} = W \text{ (watts)}$$

and since $W = \Delta E$

$$P = \frac{\Delta E}{t}$$

from Lesson 10 (Electric potential) we know that $\Delta E = q\,V$ therefore power can be determined by

$$P = \frac{qV}{t}$$

from Lesson 12 (Electric current) we know that $I = \frac{q}{t}$

$$P = \frac{qV}{t} = VI$$

Electric power is determined by using the formula:

$$\boxed{P = V\,I}$$ units: W (watts)

Example 1

An electric toaster uses 15.0 A from a 120 V line. What is the power consumed by the toaster when it operates?

$P = V\,I = 120\text{ V}\,(15.0\text{ A}) =$ **1800 W = 1.80 kW**

The power equation can also be combined with Ohm's Law to derive two other power equations:

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

$P = V\,I = V\frac{V}{R} = \frac{V^2}{R}$ $\qquad \boxed{P = \frac{V^2}{R}}$

$V = I\,R$

$P = V\,I = (I\,R)\,I = I^2\,R$ $\qquad \boxed{P = I^2\,R}$

Example 2

What is the resistance of a circuit that includes a toaster that consumes 1.0 kW of power on a 120 V line?

$P = \frac{V^2}{R}$ $\qquad R = \frac{V^2}{P} = \frac{(120\ V)^2}{1000\ W} =$ **14.4 Ω**

Example 3

What power is consumed when a 500 Ω resistor draws a current of 10.0 A?

$P = I^2 R = (10.0\ A)^2\ (500\ \Omega) =$ **50.0 kW**

II. Electric energy

From Lesson 10 we know that

$$\Delta E = q\ V$$

However, for electric circuits we usually do not refer to the amount of charge passing through it, rather we talk about the amount of current given. We know that q = I t therefore

$E = q\ V = (I\ t)V$ $\qquad$ $\boxed{E = V\ I\ t}$

Example 4

What energy is stored in a 9.0 V battery that can deliver a current of 5.0 mA for 20 minutes?

$E = V\ I\ t = 9.0\ V\ (5.0 \times 10^{-3}\ A)\ (20 \times 60\ s) =$ **54 J**

An alternative unit of energy to the Joule is formed if we have the power in kilowatts (kW) and the time in hours (h).

$E = P\ t =$ $\boxed{\text{kWh (kilowatthour)}}$

$(1\ kWh = 3.6 \times 10^6\ J)$

Note: A kilowatt-hour is a unit of energy, not power.

Example 5

What energy in Joules and kWh is consumed by a 500 W toaster that operates for 20 minutes?

E = P t = 500 W (20 x 60 s) = **600 kJ**

E = P t = 0.500 kW (20/60 h) = **0.167 kWh**

III. Cost of electrical energy

When electric power companies charge for electrical power they charge a certain amount for each kWh of energy. If a rate is given either as a cost/Joule or cost/kWh, then you must use the appropriate units in the calculation.

Example 6

A toaster with a resistance of 10.0 Ω is connected to a 120 V line. If the toaster operates for 30 minutes per day, what is the cost of operating the toaster for one year in an area where the electrical energy costs $ 0.060 / MJ?

$$P = \frac{V^2}{R} = \frac{(120\ V)^2}{10.0\ \Omega} = 1440\ W$$

E = P t = 1440 W (30 min/day x 60 s/min x 365 days) = 946.1 MJ (year)

cost = rate x energy = $ 0.060 / MJ x 946.1 MJ = **$ 57** (per year)

Example 7

An appliance draws 15 A from a 120 V line. If the appliance operates 5.0 h/day, six days a week, for 50 weeks per year, what is the cost of operating the appliance for one year if electrical energy costs $ 0.050 / kWh?

P = V I = 120 V (15 A) = 1800 W = 1.8 kW

E = P t = 1.8 kW (5.0 h/day)(6 days/week)(50 weeks) = 2700 kWh

cost = rate x energy = $ 0.050 / kWh x 2700 kWh = **$ 135.00**

IV. Practice problems

1. What is the power output of a SONY walkman which runs on two 1.5 V batteries connected in series and draws 1.50 mA of current? (4.5 mW)

2. A certain appliance has a resistance of 15.0 Ω and runs on a 120 V line. How much energy is required to run this appliance for 2.0 h? (1.92 kWh)

3. If the cost of electric power is $ 0.060 / kWh, calculate the cost of running a spotlight which draws 3.33 A at 120 V for 2.0 h a day for 30 days. ($1.44)

V. Hand-in assignment

1. What power company supplies power to the Calgary area? How much do they currently charge per kWh of electrical energy?

2. Calculate the electrical energy dissipated in 1.5 min when there is a current of 4.0A through a potential difference of 60 V. (2.2×10^4 J)

3. Calculate the power dissipated by each of the following loads.
   a) a clothes dryer drawing 12.5 A from a 240 V source (3.00×10^3 W)
   b) a kettle that draws 12.0 A and has a resistance of 8.3 Ω (1.2×10^3 W)
   c) a 240 Ω heating pad plugged into a 120 V source (60.0 W)

4.
   a) What maximum power can be used on a 240 V circuit with a 15 A fuse? (3.60 kW)
   b) How much more current can safely be drawn from a 120 V outlet fused at 20 A if an 800 W toaster and an 1180 W kettle are already operating in the circuit? (3.5 A)

5. A 1.0 kW toaster, designed to operate a 120 V, is mistakenly connected to a source of 240 V.
   a) What current is the toaster designed to draw? (8.3 A)
   b) What current will draw when connected to 240 V? (17 A)
   c) What power will it use on 240 V, and what will be the likely result? (4.1 kW)

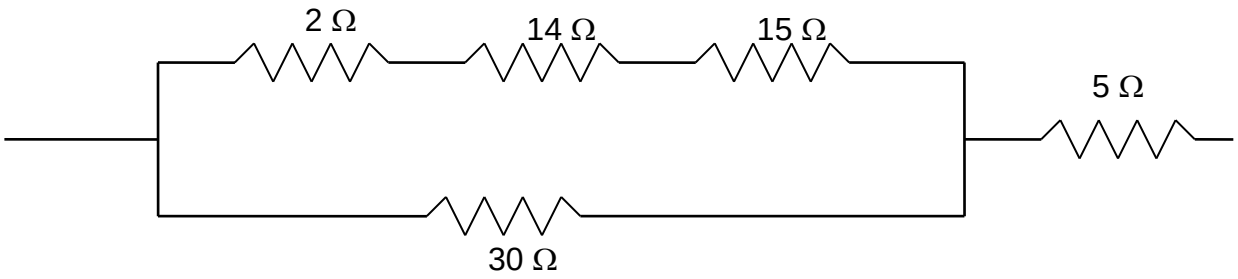
6. A refrigerator compressor draws 2.5 A from a 120 V source and operates for an average of 15 min out of each hour. Calculate the annual cost of operating the refrigerator if the average cost of electrical energy is \$0.042/kW·h. (\$27.59)

7. An electric heater has a resistance of 16 Ω when operating on a 120 V line. If the cost of electrical energy is \$ 0.030/MJ, how much does it cost to operate for 30 minutes? (\$0.049)

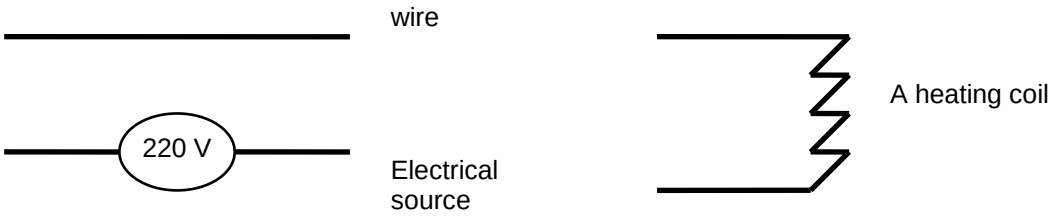
8. An electric lawn mower has a resistance of 160 Ω and draws 15 A. What is the cost of operating the lawn mower for 30 minutes if electrical energy costs \$ 0.12/kWh? (\$2.16)

9. In a town, electrical energy costs \$ 0.040 / kWh. A modern kerosene lamp produces about the same amount of light as one 100 watt light bulb but uses 32.8 mL of fuel per hour. If kerosene costs \$ 0.22 / L, how much money is saved if a 100 W bulb is used over a 2000 hour period of time? (\$6.43)

10. If the circuit below is connected to a power source of 120 V for 36 days, what is the cost of operating the circuit if the cost of electrical energy is $ 0.13 / MJ? ($287.60)



11. Hot water in a domestic residence is produced by heating water in a tank. The heating source in many hot water tanks is provided by 220 V electrical coils that are placed in the tank. Each of the coils has a resistance of 15 Ω.



a. Using the symbols above, draw the circuit diagram that would use two coils to heat the water in the <u>shortest</u> possible time.

b. What current is provided by the 220 V source to the heating coils?

c. What is the power consumed by each heating coil?

d. If you wanted to measure the current and potential difference across one of the coils, draw in the appropriate meters and how you would hook them in.

e. The amount of energy needed to heat water is given by the formula $E = m\,c\,\Delta T$, where m is the mass of water, c is the specific heat capacity of water (4.19 kJ/(^{o}C kg)), and ΔT is the change in temperature.

How long in minutes would it take for the two heating coils to raise the temperature in the tank containing 160 kg of water by 1.0 ^{o}C?