12.7 Power in Electric Circuits

To predict the amount of energy used by an electrical device, such as a radio, stove, lights, or television, we first need to know the amount of time the device will be used. For some devices such as freezers, refrigerators, and clocks, we can predict the amount of time the device is in operation, and the amount of energy used can be calculated using the formula for energy from section 12.4:

$$\Delta E = VI\Delta t$$

(For most devices in the home, $V = 120$ V. For other devices, like stoves and dryers, $V = 240$ V.)

Why would you want to know how much energy an appliance would use in a year? Because energy costs money—electrical energy is not free. To calculate the cost for devices that are not used for predictable amounts of time, it is often more useful to know the rate at which the device uses energy, or the **power** (P). Power is the rate at which energy is used or supplied, and it does not depend on how long the device is on (**Figure 1**). Therefore, as covered in Chapter 4,

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

If we substitute $\Delta E = VI\Delta t$, we get

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

power: (P) the rate at which energy is used or supplied

Figure 1
With many devices using a lot of electrical energy at the same time, the power rating is very high.

The equation $P = VI$ is an expression for the electric power dissipated by a current, I, through a potential difference, V.

Note that potential difference is measured in volts (joules per coulomb) and current is measured in amperes (coulombs per second), and the unit of electric power is the product of the units of potential difference and current, namely,

$$\text{(volt)(ampere)} = \text{(joule/coulomb)(coulomb/second)}$$
$$= \text{joule/second}$$
$$= \text{watt}$$

Therefore, electric power is measured in watts—the same unit that was used to measure mechanical power in Chapter 4. If the load has a resistance, R, then two different expressions can be derived by applying Ohm's law.

From Ohm's Law, $I = \dfrac{V}{R}$ and $V = IR$, we can write

$P = VI$ also $P = VI$

$\quad = (IR)I \qquad\qquad = V\left(\dfrac{V}{R}\right)$

$P = I^2R \qquad\qquad P = \dfrac{V^2}{R}$

To summarize, for a load with a current, I, potential difference, V, and resistance, R, the power is given by

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

and, when SI units are used for I, V, and R, power is measured in watts.

Sample Problem 1

What is the current drawn by a 1.0×10^2-W light bulb operating at a potential difference of 120 V?

Solution

$P = 1.0 \times 10^2$ W
$V = 1.2 \times 10^2$ V
$I = ?$

$$P = VI$$
$$I = \frac{P}{V}$$
$$= \frac{1.0 \times 10^2 \text{ W}}{1.2 \times 10^2 \text{ V}}$$
$$I = 0.83 \text{ A}$$

The current drawn is 0.83 A.

Sample Problem 2

What is the resistance of a 6.0×10^2-W kettle that draws a current of 5.0 A?

Solution

$P = 6.0 \times 10^2$ W
$I = 5.0$ A
$R = ?$

$$P = I^2R$$
$$R = \frac{P}{I^2}$$
$$= \frac{6.0 \times 10^2 \text{ W}}{(5.0 \text{ A})^2}$$
$$R = 24 \ \Omega$$

The resistance is 24 Ω.

Sample Problem 3

What power is dissipated by an electric frying pan that has a resistance of 12 Ω and operates at a potential difference of 120 V?

Solution

$R = 1.2 \times 10^1 \, \Omega$

$V = 1.2 \times 10^2 \, V$

$P = ?$

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

$$= \frac{(1.2 \times 10^2 \, V)^2}{1.2 \times 10^1 \, \Omega}$$

$$P = 1.2 \times 10^3 \, W$$

The power dissipated is 1.2×10^3 W, or 1.2 kW.

Note that the appliances discussed in the problems above, or in any other examples or questions, typically operate on AC and not DC. The values of V and I in all these problems are actually RMS values (the square root of the mean of the square of the instantaneous current or voltage). This concept will be covered in more advanced courses.

Practice

Understanding Concepts

1. A large refrigerator operates at a voltage of 120 V, drawing a current of 4.6 A. What is the power rating of the refrigerator?

2. Write an equation for each of the following:
   (a) voltage in terms of power and electric current
   (b) electric current in terms of power and voltage
   (c) electric resistance in terms of power and electric current
   (d) electric resistance in terms of power and voltage

3. Using a voltage of 1.2×10^2 V, what current do the following draw?
   (a) a 2.0×10^2-W light bulb   (b) a 1200-W heater

4. Calculate the resistance of a 360-W hair dryer designed for a 120-V power supply.

5. The current through a device of resistance 22 Ω is 2.0 A. Find the power rating of the device.

Answers

1. 5.5×10^2 W

3. (a) 1.7 A
   (b) 1.0×10^1 A

4. $4.0 \times 10^1 \, \Omega$

5. 88 W

The Cost of Electricity

To calculate the energy used in operating an electrical device, all we need to know is the power of the device and the amount of time it is used. However, the basic unit of energy, the joule, is a very small unit, and, for this reason, the electrical energy consumed is measured by means of a larger unit derived from the joule.

Energy used can be written as

$$\Delta E = P \Delta t$$

Figure 2
Readings from electrical meters are used to calculate the amount of energy used.

Then, if power is measured in kilowatts (kW) and time is measured in hours (h), electrical energy can be measured in **kilowatt hours** (kW·h), which is the energy dissipated in 1 h by a load with a power of 1 kW.

It is often useful to calculate the relationship between the joule and the kilowatt hour, using the equation

$$\Delta E = P\Delta t$$
$$= (1.0 \text{ kW}) (1.0 \text{ h})$$
$$= 1.0 \text{ kW·h}$$
$$= (1.0 \times 10^3 \text{ J/s}) (3.6 \times 10^3 \text{ s})$$
$$\Delta E = 3.6 \times 10^6 \text{ J}$$

Therefore, $1.0 \text{ kW·h} = 3.6 \times 10^6 \text{ J} = 3.6 \text{ MJ}$.

If several appliances are operating simultaneously, you can calculate the total power usage by adding the amount of power dissipated by each of the appliances. The utility company installs a meter on each house to measure and keep track of the total energy usage (**Figure 2**). The total cost of electricity is obtained by multiplying the number of kilowatt hours of energy used by the rate (price per kilowatt hour). Generally, rates vary by region and by type of user (residential or commercial).

Sample Problem 4

Calculate the cost of operating a 4.0×10^2-W spotlight for 2.0 h a day for 30 d at a rate of 9.0¢/kW·h.

Solution

$P = 4.0 \times 10^2 \text{ W} = 0.40 \text{ kW}$
$\Delta t = (2.0 \text{ h/d})(30 \text{ d}) = 60 \text{ h}$
cost = ?

$$\Delta E = P\Delta t$$
$$= (0.40 \text{ kW}) (60 \text{ h})$$
$$\Delta E = 24 \text{ kW·h}$$

$$\text{cost} = (24 \text{ kW·h}) (9.0¢/\text{kW·h})$$
$$\text{cost} = 216¢, \text{ or } \$2.16$$

Sample Problem 5

Find the cost of operating an oven for 3.0 h if it draws 25 A from a 240-V supply at a rate of 8.5¢/kW·h.

Solution

$\Delta t = 3.0 \text{ h}$
$I = 25 \text{ A}$
$V = 240 \text{ V}$

$$P = IV$$
$$= (25 \text{ A})(240 \text{ V})$$
$$P = 6.0 \times 10^3 \text{ W, or } 6.0 \text{ kW}$$

$\Delta E = P\Delta t$

$\quad = (6.0 \text{ kW})(3.0 \text{ h})$

$\Delta E = 18 \text{ kW·h}$

cost $= (18 \text{ kW·h})(8.5¢/\text{kW·h})$

cost $= 153¢$, or $1.53

The Energuide label (**Figure 3**) for major electrical household appliances shows the annual energy rating in kilowatt hours, based on average use. The label is required by law on all appliances sold in Canada. Some common values of power ratings are shown in **Table 1**.

Table 1 Power Rating of Electrical Appliances

Appliance	Power rating	Current (with 120 V supply)
iron	1200 W	10 A
stove	6 to 10 kW	*
refrigerator	200 W	1.7 A
toaster	1000 W	8.3 A
microwave oven	600 W	5.0 A
vacuum cleaner	500 W	4.2 A

* Stoves operate at 240 V and draw currents in the range of 25 A to 40 A.

Note: These power ratings refer to the electrical power used by the appliances, and not their power output, which, due to their relative efficiencies, may be considerably lower.

Figure 3
To keep the cost of energy low, buy the appliance with the lowest energy consumption rating capable of fulfilling your requirements.

Practice

Understanding Concepts

6. If it costs 8.9¢/kW·h for electrical energy, how much would it cost to leave a 60.0-W light bulb on for
   (a) one hour?　　(b) one day?　　(c) one year?

7. A small television is connected to a 120-V power supply and draws a current of 1.2 A. How much would it cost to use the television for an average of 2.0 h a day for 30 days if the rate for electrical energy is 8.5¢/kW·h?

8. A student decides to help lower the electric bill by listening to the 120-W stereo for an average of 45 minutes a day instead of the usual hour. If the rate is 9.2¢/kW·h, how much money will be saved on the electric bill in a year?

Answers

6. (a) 0.53¢
   (b) 13¢
   (c) $46.78

7. 73¢

8. $1.01

SUMMARY　Power in Electric Circuits

- The rate at which a device uses energy is known as power, represented by the equation $P = VI$.
- Electrical energy is measured in kilowatt hours (kW·h).
- The total cost of electricity can be calculated by multiplying the number of kilowatt hours of energy used by the rate (price per kilowatt hour).

Understanding Concepts

1. Find the cost of operating an electric toaster for 3.0 h if it draws 5.0 A from a 120-V outlet. Electric energy costs 8.8¢/kW·h.

2. The blower motor on an oil furnace, rated at 250 W, comes on, for an average of 5.0 min at a time, a total of 48 times a day. What is the monthly (30 d) cost of operating the motor if electricity costs 9.4¢/kW·h?

3. The following appliances were operated for a 30-day month, in a 120-V circuit: a coffee percolator of resistance 15 Ω for 0.50 h/d, a 250-W electric drill for 2.0 h/d, and a toaster that draws 5.0 A for 15 min/d. Calculate the electric bill for these devices for the month at an average cost of 9.0¢/kW·h.

4. What is the potential difference across a 1250-W baseboard heater that draws 5.2 A?

5. If a 7.0×10^2-W toaster and an 1100-W kettle are plugged into the same 120-V outlet in parallel, what total current will they draw?

6. What is the maximum power that can be used in a circuit with a potential difference of 120 V and a maximum current of 20.0 A?

7. A portable heater is plugged into a 120-V outlet and draws a current of 8.0 A for 10.0 min. Calculate each of the following:
   (a) the quantity of electric charge that flows through the heater
   (b) the energy consumed by the heater
   (c) the power dissipated by the heater

8. A student starts working and decides to contribute to the family electric bill by paying for the energy he uses. He makes a table (**Table 2**) of the electric devices he uses, the power rating of the device, and the time of use for a month. If the cost of electric energy is 9.2¢/kW·h, how much does he owe his parents at the end of the month?

9. Given two resistors R_1 = 12 Ω and R_2 = 4.0 Ω connected in series to an 18.0-V battery, find (a) the total power and (b) the power dissipated by each resistor. Compare your answers for both parts.

10. Repeat question 9 with the two resistors connected in parallel.

Applying Inquiry Skills

11. As an electrical engineer for Westinghouse, you are asked to design an immersion heater that can be placed into a glass of water to boil it for coffee.
    (a) Using a 12-V battery, bare high resistance wire, and a hollow glass tube, draw a diagram of a prototype immersion heater.
    (b) Calculate the energy used and the power rating of the heater if 250 g of water is heated from 15°C to 85°C in 240 s. (Assume 100% efficiency.)
    (c) Suggest one or two improvements you could make to your heater that would make it heat the water faster.

Making Connections

12. What are the advantages of connecting appliances in parallel in a household circuit?

13. Electric power companies charge a rate that decreases when the amount of energy consumed by a household exceeds a certain minimum quantity. Comment on the wisdom of this method.

14. In many households, the total power dissipated is higher in the middle of the summer and the middle of the winter. Explain why.

Table 2

Electrical device	Power rating (kW)	Time used per month (h)
television	0.08	90
computer	0.2	45
VCR	0.04	8
stereo	0.03	80
washer	0.5	4
dryer	5.0	4
microwave	0.75	1