5.5 Power

It takes time to change one form of energy into another. The rate at which energy is transformed depends on certain factors. For example, your muscles transform the chemical energy in food into kinetic energy (motion) and thermal energy much faster if you run up a set of stairs than if you walk slowly up the same set of stairs. Your body feels warmer and more tired the faster you climb the stairs.

You may also analyze this situation in terms of the work your body does in climbing to the top of the stairs. Whether you run or walk up a set of stairs, your body applies the same force against gravity and travels the same vertical distance. Your body does the same amount of work in each case. However, your body does the work faster when you run and slower when you walk. In other words, the rate at which work is done depends on how fast you move.

power (P) the rate of transforming energy or doing work

Physicists use the word **power (P)** to describe the rate at which energy is transformed, or the rate at which work is done. Your body produces more power when you run up a set of stairs than when you climb up slowly. We may describe power mathematically as follows:

$$P = \frac{\Delta E}{\Delta t} \quad \text{or} \quad P = \frac{W_{net}}{\Delta t}$$

Energy, work, and time are scalar quantities, so power is also a scalar quantity (it has no direction associated with it). Since energy and work are measured in joules and time is measured in seconds, power is measured in joules per second (J/s). In the SI system, the unit for power is called the watt (W) in honour of James Watt, a Scottish engineer who invented the first practical steam engine. One watt is equal to 1 J/s.

Earlier in this chapter, you learned that work involves the transfer, or transformation, of energy. For example, if a golf club does 100 J of work on a golf ball in 0.1 s, then the club transfers 100 J of energy to the golf ball in 0.1 s. The golf ball's energy changes by 100 J in 0.1 s. Thus, the work done by the club on the golf ball is equal to the change in energy, or $W_{net} = \Delta E$. We may calculate the golf club's power using the equation $P = \frac{W_{net}}{\Delta t}$ or the equation $P = \frac{\Delta E}{\Delta t}$. Both equations yield the same result because $W_{net} = \Delta E$. In Tutorial 1, you will solve problems involving power.

LEARNING TIP

Power and the Work–Energy Principle

Although we developed the work–energy principle ($W_{net} = \Delta E$) in terms of changes in an object's kinetic energy, the principle also applies when an object's potential energy changes.

Investigation 5.5.1

Student Power (p. 258)

In this investigation, you will explore your own personal power and work done using different types of fitness equipment. You will design your own procedure using fitness equipment of your choice.

Tutorial 1 Calculating Power

In this Tutorial, we will use the equation $P = \frac{\Delta E}{\Delta t}$ to solve both of the following Sample Problems, although we may use the equation $P = \frac{W_{net}}{\Delta t}$ as well since $W_{net} = \Delta E$.

Sample Problem 1

How much power does a swimmer produce if she transforms 2.4 kJ of chemical energy (in food) into kinetic energy and thermal energy in 12.5 s?

Solution

Since this question gives the values for the energy transformation and the time interval, we may use the equation $P = \frac{\Delta E}{\Delta t}$ to calculate the power.

Given: $\Delta E = 2.4$ kJ or 2.4×10^3 J; $\Delta t = 12.5$ s

Required: P

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

Solution:
$$\begin{aligned} P &= \frac{\Delta E}{\Delta t} \\ &= \frac{2.4 \times 10^3 \text{ J}}{12.5 \text{ s}} \\ &= 190 \text{ J/s} \\ P &= 190 \text{ W} \end{aligned}$$

Statement: The swimmer's power is 190 W.

Sample Problem 2

A 64 kg student climbs from the ground floor to the second floor of his school in 5.5 s. The second floor is 3.7 m above the ground floor. What is the student's power?

Solution

The first two phrases in this problem describe a situation in which a student travels from a lower floor to a higher floor of his school. This means that the student's gravitational potential energy increases from a value of zero at the ground floor (the reference level) to a value given by the equation $E_g = mgh$ at the second floor. Thus, the value of E_g is equal to the change in the student's energy, ΔE, which may be substituted into the equation $P = \frac{\Delta E}{\Delta t}$ to calculate the student's power.

Given: $m = 64$ kg; $g = 9.8$ N/kg; $h = 3.7$ m; $\Delta t = 5.5$ s

Required: P

Analysis: $E_g = mgh$; $P = \frac{\Delta E}{\Delta t}$

Solution: $E_g = mgh$

$$= (64\ \cancel{\text{kg}})\left(9.8\ \frac{\text{N}}{\cancel{\text{kg}}}\right)(3.7\ \text{m})$$

$$E_g = 2.321 \times 10^3\ \text{J (two extra digits carried)}$$

$$\Delta E = 2.321 \times 10^3\ \text{J}$$

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

$$= \frac{2.321 \times 10^3\ \text{J}}{5.5\ \text{s}}$$

$$= 4.2 \times 10^2\ \text{J/s}$$

$$P = 4.2 \times 10^2\ \text{W}$$

Statement: The student's power is 4.2×10^2 W.

Practice

1. How long would it take a motor with 0.50 kW of power to do 1200 J of work? T/I [ans: 2.4 s]
2. A mountain climber with a mass of 55 kg starts from a height of 850 m above sea level at 9 in the morning and reaches a height of 2400 m by noon. What is the climber's average power? T/I [ans: 77 W]
3. A 60.0 kg person accelerates from rest to 12 m/s in 6.0 s. What is the person's power? T/I [ans: 720 W]

Mini **Investigation**

Human Power

Skills: Performing, Observing, Analyzing

SKILLS HANDBOOK **A6.2**

In this activity, you will compare the power of a student walking slowly and walking quickly up a flight of stairs.

Equipment and Materials: bathroom scale; metric tape measure or metre stick; staircase; stopwatch

1. Use a scale to measure your partner's mass. Calculate your partner's weight in newtons.
2. Use a tape measure or metre stick to measure the height of a staircase. You may do this by measuring the height of one step and multiplying this by the total number of steps.
3. Use a stopwatch to measure the time it takes your partner to walk up the stairs slowly at constant speed. Repeat this three times and average the results.

Exercise caution when walking up the stairs. Never run.

4. Measure the time it takes your partner to walk up the stairs more quickly at constant speed. Repeat this three times and average the results.

A. Calculate the average power produced by walking up the stairs slowly. T/I

B. Calculate the average power produced by walking up the stairs more quickly. T/I

C. Was your partner's power greater when walking up the stairs quickly or slowly? Explain your observations. T/I

D. Compare your partner's power in walking up the stairs slowly and walking up the stairs quickly to the power of a 100 W light bulb. Which process produces the most power: walking up the stairs slowly, walking up the stairs more quickly, or using the light bulb? Explain why you think this is the case. T/I

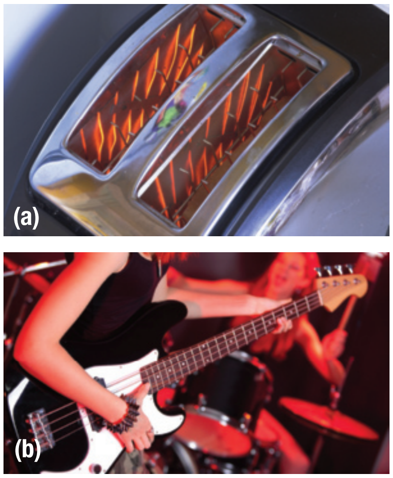

Figure 1 (a) A toaster and (b) an electric guitar transform electrical energy.

Electrical Power

Electrical devices transform electrical energy into other forms of energy. For example, the hot, glowing elements of a toaster transform electrical energy into thermal energy and radiant energy, and an electric guitar transforms electrical energy into sound energy and thermal energy (**Figure 1**).

Like other energy-transforming devices, electrical devices may transform energy quickly or slowly. When they transform energy more quickly, they are more powerful, and when they transform energy more slowly, they are less powerful. The maximum power of an electrical device or appliance is sometimes referred to as the device's power rating. The power rating of an electrical device may be calculated using the equation $P = \frac{\Delta E}{\Delta t}$. Rearranging this equation yields the equation $\Delta E = P\Delta t$, which may be used to calculate the amount of energy transformed by a device. In the following Tutorial, you will calculate the power of an electrical device.

Tutorial 2 Calculating the Power of an Electrical Device

In this Tutorial, we will determine the power of an electrical device.

Sample Problem 1

What is the power of an electric elevator motor if it uses 2.9×10^5 J of electrical energy to lift an elevator car 12 m in 16 s?

Solution

In this problem, the elevator motor transforms 2.9×10^5 J of electrical energy into the elevator car's gravitational potential energy when it is 12 m above the ground. Therefore, $\Delta E = 2.9 \times 10^5$ J and $\Delta t = 16$ s.

Given: $\Delta E = 2.9 \times 10^5$ J; $\Delta t = 16$ s

Required: P

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

Solution:
$$\begin{aligned} P &= \frac{\Delta E}{\Delta t} \\ &= \frac{2.9 \times 10^5 \text{ J}}{16 \text{ s}} \\ &= 1.8 \times 10^4 \text{ J/s} \\ &= 1.8 \times 10^4 \text{ W} \\ P &= 18 \text{ kW} \end{aligned}$$

Statement: The elevator motor's power is 18 kW.

Practice

1. The Pickering Nuclear power plant has a power rating of 3100 MW. How much energy can the generating station produce in one day? (Answer in MJ.) T/I [ans: 2.7×10^8 MJ]

Table 1 Power Ratings of Appliances

Appliance	Power rating (W)
laptop computer	20–75
vacuum cleaner	200–700
microwave oven	600–1500
dishwasher	1200–1500
refrigerator	100–500
stove	6000–10 000

The electric elevator motor in Tutorial 2 transformed 290 kJ of electrical energy into gravitational potential energy in 16 s—a power of 18 kW. This is a common result for the power ratings of electrical devices: the ratings tend to be in the hundreds or thousands of watts. **Table 1** lists the power ratings of some typical household appliances.

Energy Ratings and the Cost of Electricity

Companies that provide electrical energy to consumers use electricity meters to measure the total amount of electrical energy used (**Figure 2** on the next page). This amount depends on the number of electrical devices being used, the power rating of each device, and the total amount of time each device is used. It is common for electricity meters to measure the electrical energy used in units of kilowatt hours (kWh).

The use of the kilowatt hour for measuring a change in energy (energy used) becomes apparent when we analyze the equation $\Delta E = P\Delta t$. When power, P, is measured in kilowatts, kW, and the time interval, Δt, is measured in hours, h, the product $P\Delta t$ produces the unit kilowatt hours, kWh. The energy used (transformed) by an electrical appliance, ΔE, is sometimes called the energy consumption rating, or energy rating, of the appliance. Thus, the energy rating is commonly measured in kilowatt hours. In the following Tutorial, we will determine the energy rating of a common household appliance and the cost of operating the appliance.

Figure 2 Electricity meters measure the amount of electrical energy used.

Tutorial 3 Determining the Energy Rating of a Device

In this Tutorial, we will use the equation $P = \dfrac{\Delta E}{\Delta t}$ to calculate the energy rating and the cost of operating an electrical device with a particular power rating for a given amount of time.

Sample Problem 1

What is the cost of operating a 25 W light bulb 4.0 h a day for 6.0 days if the price of electrical energy is 5¢/kWh?

Solution

We will solve this problem in two parts. In part (a), we will calculate the amount of energy the light bulb will use (transform) in 6 days of operation (4 h per day). Then, in part (b), we will use the amount of electrical energy transformed to calculate the cost of the electrical energy. Note that the amount of electrical energy transformed must be calculated in kilowatt hours, not joules, since the electricity provider charges per kilowatt hour, not per joule. Therefore, we convert the units first.

Given: $P = 25$ W or 0.025 kW; $\Delta t = 6.0\ \cancel{d}\left(\dfrac{4.0\ \text{h}}{\cancel{d}}\right) = 24$ h; price of electrical energy = 5¢/kWh

Required: ΔE, energy used (transformed); cost

Analysis: $P = \dfrac{\Delta E}{\Delta t}$

Solution:

(a) $P = \dfrac{\Delta E}{\Delta t}$

$$\Delta E = P\Delta t$$
$$= (0.025\ \text{kW})(24\ \text{h})$$
$$\Delta E = 0.60\ \text{kWh}$$

(b) $\text{cost} = (0.60\ \cancel{\text{kWh}})\left(\dfrac{5¢}{\cancel{\text{kWh}}}\right)$

$$\text{cost} = 3¢$$

Statement: It costs 3¢ to operate a 25 W light bulb for 24 h.

Practice

1. Twenty incandescent light bulbs are turned on for 12 h a day for an entire year to light up a store. Each bulb has a power rating of 100.0 W. The average cost of electricity is 6.0¢/kWh. T/I
   (a) Determine the total amount of energy used by all the bulbs in the year. [ans: 8800 kWh]
   (b) Calculate the cost of lighting the store for the year. [ans: $530]
   (c) How much money could be saved by using CFLs instead of the incandescent bulbs if each CFL has a power rating of 23 W? [ans: $400]

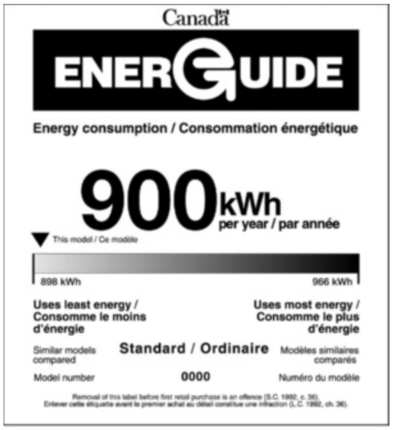

Figure 3 EnerGuide label on a typical household refrigerator

The Canadian government requires all manufacturers of electrical appliances to place an EnerGuide label on all electrical appliances sold in Canada (**Figure 3**). The EnerGuide label shows the annual energy rating for an appliance in kilowatt hours. The consumer may use this value and the price of electrical energy to determine the average annual cost of operating the appliance. Consumers are encouraged to purchase appliances that have the lowest energy consumption rating possible. This will allow them to consume less electrical energy and save money.

5.5 Summary

- Power is the rate of transforming energy or the rate of doing work. The equations for power are $P = \frac{W_{net}}{\Delta t}$ or $P = \frac{\Delta E}{\Delta t}$.
- Power is a scalar quantity measured in watts (1 W = 1 J/s).
- Electrical devices transform electrical energy into other forms of energy, and the power rating of these devices can be determined using the equations for power.
- The electrical energy used by an electrical device can be found using the equation $\Delta E = P\Delta t$.

5.5 Questions

1. A 54 kg person climbs a set of stairs at a constant speed from the first floor to the fourth floor in 32 s. The change in height from one floor to the next is 3.4 m. T/I
   (a) Calculate the gravitational potential energy at the top of the climb relative to the first floor.
   (b) Calculate the power of the person for the climb.
   (c) If a lighter person climbed the stairs in the same time, would this person's power be higher or lower? Explain.
2. A 65 kg student climbs 5.0 m up a rope in gym class at a constant speed of 1.4 m/s. T/I
   (a) Determine the time it takes the student to climb up the rope, and then determine the student's power.
   (b) Determine the student's power without finding the time it takes the student to climb up the rope. Explain your reasoning.
3. A student uses a pulley to lift a mass into the air. K/U C
   (a) Assume the mass is lifted at a constant speed. Describe one way you could determine the power of the student when she is lifting the mass.
   (b) Assume the mass started from rest at ground level and accelerated upward with a constant acceleration. What types of energy will the object have while it is being pulled up by the student? How would you determine the student's power in this case?
4. A family of five is planning to install solar panels on the roof of their home to help reduce the cost of electricity and save energy to help the environment. The family plans to install 10 panels, each with a power rating of 600 W. On average, a solar panel can produce electricity for 4.5 h daily. T/I
   (a) How much solar energy will the solar panels transform into electrical energy each day?
   (b) Assume the average cost of electricity is 5.5¢/kWh. How much money will the family save in a year on their electrical energy bill?
   (c) Each person in the family uses electrical energy at an average rate of 2 kWh per day. Will they still need to buy electricity from an electrical energy supplier? Explain your reasoning.
5. Show that 1 kWh = 3.6 MJ. C