

**MATH SKILLS**● **Momentum****Sample Problem**

Thoroughbred horses are among the fastest horses in the world and are used in famous racing events such as the Kentucky Derby. The mass of a thoroughbred is about  $5.00 \times 10^2$  kg. If a horse with this mass is galloping with a momentum of  $8.22 \times 10^3$  kg • m/s, what is its speed?

- List the given and unknown values.

$$\text{Given:} \quad \text{mass, } m = 5.00 \times 10^2 \text{ kg}$$

$$\text{momentum, } p = 8.22 \times 10^3 \text{ kg} \bullet \text{ m/s}$$

$$\text{Unknown:} \quad \text{speed, } v = ? \text{ m/s}$$

- Rearrange the momentum equation to solve for speed.

$$\text{momentum} = \text{mass} \times \text{speed} \quad p = mv$$

$$p \frac{1}{m} = mv \frac{1}{m}$$

$$v = \frac{p}{m}$$

- Substitute momentum and mass values into the equation, and solve.

$$v = \frac{8.22 \times 10^3 \text{ kg} \bullet \text{ m} / \text{ s}}{5.00 \times 10^2 \text{ kg}}$$

$$v = 16.4 \text{ m/s}$$

**Your Turn to Think**

- A pitcher in a professional baseball game throws a fastball, giving the baseball a momentum of  $5.83 \text{ kg} \bullet \text{ m/s}$ . Given that the baseball has a mass of  $0.145 \text{ kg}$ , what is its speed?
- The maximum speed measured for a golf ball is  $273 \text{ km/h}$ . If a golf ball with a mass of  $47 \text{ g}$  had a momentum of  $5.83 \text{ kg} \bullet \text{ m/s}$ , the same as that of the baseball in the previous problem, what would its speed be? How does this speed compare to a golf ball's maximum measured speed?
- The World Solar Challenge in 1987 was the first car race in which all the vehicles were solar powered. The winner was the *GM Sunraycer*, which had a mass of  $177.4 \text{ kg}$ , not counting the driver's mass. Assume that the driver had a mass of  $61.5 \text{ kg}$ , so that the total momentum of the car and driver was  $4.416 \times 10^3 \text{ kg} \bullet \text{ m/s}$ . What was the car's speed in  $\text{m/s}$  and  $\text{km/h}$ ?

**MATH SKILLS**● **Momentum** *continued***Sample Problem**

Although larger than the Atlantic walrus, the Pacific walrus can swim with a speed of about 9.7 m/s. If the momentum of a swimming walrus is  $1.07 \times 10^4$  kg • m/s, what is its mass?

1. List the given and unknown values.

*Given:* speed,  $v = 9.7$  m/s

momentum,  $p = 1.07 \times 10^4$  kg • m/s

*Unknown:* mass,  $m = ?$  kg

2. Rearrange the momentum equation to solve for mass.

$$\text{momentum} = \text{mass} \times \text{speed}$$

$$p = mv$$

$$p \frac{1}{v} = mv \frac{1}{v}$$

$$m = \frac{p}{v}$$

3. Substitute momentum and speed values into the equation, and solve.

$$m = \frac{1.07 \times 10^4 \text{ kg} \cdot \text{m} / \text{s}}{9.7 \text{ m} / \text{s}}$$

$$m = 1.1 \times 10^3 \text{ kg}$$

**Your Turn to Think**

4. The lightest pilot-driven airplane ever built was the *Baby Bird*. Suppose the *Baby Bird* moves along the ground without a pilot at a speed of 88.0 km/h. Under these circumstances, the momentum of the empty plane would be only 2790 kg • m/s. What is the mass of the plane?
5. The most massive automobile to have been manufactured on a regular basis was the Russian-made Zil-41047. If one of these cars were to move at just 8.9 m/s, its momentum would be  $2.67 \times 10^4$  kg • m/s. Use this information to calculate the mass of a Zil-41047.
6. The brightest, hottest, and most massive stars are the brilliant blue stars designated as spectral class O. As is the case of all stars, class O stars move with speeds that are measured in km/s.
  - a. If a class O star moves with a speed of 255 km/s and has a momentum of  $8.62 \times 10^{36}$  kg • m/s, what is the star's mass?

**MATH SKILLS**● **Momentum** *continued*

- b. A class O star typically has a mass of at least 10 solar masses (that is, 10 times the mass of the sun, which is  $1.99 \times 10^{30}$  kg). Express the mass calculated in part (a) in terms of solar masses.

**Sample Problem**

The Shinkansen, Japan's high-speed "bullet train," consists of several different versions of trains that have been in service since 1963. The 100-series trains consists of 16 steel cars that have a combined mass of  $9.25 \times 10^5$  kg. The top speed of a regular 100-series train is 220 km/h. What would be the momentum of one of these trains?

1. List the given and unknown values.

*Given:*            *mass,  $m = 9.25 \times 10^5$  kg*

*speed,  $v = 220$  km/h*

*Unknown:*        *momentum,  $p = ?$*

2. Perform any necessary conversions.

To find the speed in m/s, the value for speed must be multiplied by the number of meters in a kilometer and divided by the number of seconds in an hour.

$$v = 220 \frac{\text{km}}{\text{h}} \times \frac{1000 \text{ m}}{1 \text{ km}} \times \frac{1 \cancel{\text{h}}}{60 \text{ min}} \times \frac{1 \text{ min}}{60 \text{ s}}$$

$$v = 61 \text{ m/s}$$

3. Write out the equation for momentum.

$$\text{momentum} = \text{mass} \times \text{speed} \qquad p = mv$$

4. Substitute mass and speed values into the momentum equation, and solve.

$$p = (9.25 \times 10^5 \text{ kg}) \times (61 \text{ m/s})$$

$$p = 5.6 \times 10^7 \text{ kg} \cdot \text{m/s}$$

**Your Turn to Think**

7. The 300-series Shinkansen trains consist of 16 aluminum cars with a combined mass of  $7.10 \times 10^5$  kg. The reduction in mass from the 100-series enables the 300-series trains to reach a top speed of 270 km/h. What is the momentum of one of these trains at its top speed? Is the momentum of a 300-series train greater or less than the momentum of a 100-series train traveling at its top speed?
8. The largest animal ever to have lived on Earth is the blue whale. Consider a blue whale with a mass of  $1.46 \times 10^5$  kg and a top swimming speed of 24 km/h. What is the momentum of this whale at this speed?

**MATH SKILLS**● **Momentum** *continued*

9. The current holder of the men's world record for running 200 m is Michael Johnson, who in 1996 ran 200.0 m in 19.32 s. Johnson's mass at the time of his record-breaking run was about 77 kg. What was his momentum at his average speed?

**Mixed Review**

10. The highest land speed for a rail-guided vehicle was set in 1982 by a rocket sled at Holloman Air Force Base, in southern New Mexico. The sled was unmanned, but if it had a payload with a mass of 25 kg, the payload's momentum would have been about  $6.8 \times 10^4 \text{ kg} \cdot \text{m/s}$ . What was the speed, in m/s and km/h, of the payload and sled?
11. The largest species of hummingbird is the *Patagonia gigas*, or the giant hummingbird of the Andes. This bird has a length of 21 cm and can fly with a speed of up to 50.0 km/h. Suppose one of these hummingbirds flies at this top speed. If its momentum is  $2.78 \times 10^{-1} \text{ kg} \cdot \text{m/s}$ , what is the hummingbird's mass?
12. Although it cannot sustain its top speed for more than 8.65 s, the cheetah can run a distance of 274 m during that time. If a cheetah with a mass of 50.0 kg is moving at top speed, what is its momentum?
13. The fastest speed recorded for a race car in the Indianapolis 500 was set in 1996 during a pre-race qualifying round. The minimum mass for a race car in the United States is 705 kg, so the minimum momentum of the record-setting car would have been  $7.49 \times 10^4 \text{ kg} \cdot \text{m/s}$ . What was the car's speed in both m/s and km/h?
14. A hovercraft, also known as an air-cushion vehicle, glides on a cushion of air, allowing it to travel with equal ease on land or water. The first commercial hovercraft to cross the English Channel, the V. A-3, had an average speed of 96 km/h. Its momentum at this speed was  $4.8 \times 10^4 \text{ kg} \cdot \text{m/s}$ . What was the mass of the V. A-3?
15. The danger that space debris poses to spacecraft can be understood in terms of momentum. At 160 km above Earth's surface, any object will have a speed of about  $7.82 \times 10^3 \text{ m/s}$ . Consider a meteoroid (a small orbiting rock) that is about half a meter in diameter and has a mass of 423 kg. What is its momentum? How does this compare to the momentum of one car of a 100-series Shinkansen train, from the sample problem on the previous page, traveling at top speed?
16. The fastest helicopter, the Westland Lynx, has a mass of  $3.343 \times 10^3 \text{ kg}$  and a maximum momentum of  $3.723 \times 10^5 \text{ kg} \cdot \text{m/s}$ . What is its top speed?
17. A student with a mass of 55 kg rides a bicycle at a speed of 5.0 m/s. The momentum of the bicycle and rider equals  $320 \text{ kg} \cdot \text{m/s}$ .
- What is the combined mass of the student and bicycle?
  - How fast would the bicycle alone have to move in order to have the same momentum as that of the student and bicycle together?

## MATH SKILLS

### ● Momentum *continued*

18. The largest passenger ship still in service is the SS *Norway*, which was built in 1962 and refurbished in 1980. The SS *Norway* has a mass of  $6.9 \times 10^7$  kg and a top cruising speed of 33 km/h. What is the momentum of the SS *Norway* once it has reached its top cruising speed?