I Mechanics


THERE'S A LOT OF PHYSICS IN PLAYING TUG O' WAR. FOR EXAMPLE, ISN'T THE RIGHT END OF THE ROPE BEING PULLED AS HARD AS I PULL THIS LEFT END? ISN'T IT STILL BEING PULLED IF IT'S TIED TO A TREE INSTEAD OF IN MY FRIEND'S HANDS? DON'T I WIN IF I PUSH HARDER ON THE GROUND RATHER THAN PULL HARDER ON THE ROPE? AND DOESN'T IT TAKE ENERGY TO EXERT THIS FORCE AND IMPART MOTION? THESE SAMPLE IDEAS ARE FROM THE FOUNDATION OF PHYSICS--MECHANICS-- WHAT THE NEXT 15 CHAPTERS ARE ABOUT. READ, THINK, AND ENJOY!

2 Motion

Motion is all around us. We see it in the everyday activity of people, of cars on the highway, in trees that sway in the wind, and with patience, we see it in the nightime stars. There is motion at the microscopic level that we cannot see directly: jostling atoms make heat or even sound; flowing electrons make electricity; and vibrating electrons produce light. Motion is everywhere.

Motion is easy to recognize but harder to describe. Even the Greek scientists of 2000 years ago, who had a very good understanding of many of the ideas of physics we study today, had great difficulty in describing motion. They failed because they did not understand the idea of *rate*. A **rate** is a quantity divided by *time*. It tells how fast something happens, or how much something changes in a certain amount of time. In this chapter you will learn how motion is described by the rates known as *speed*, *velocity*, and *acceleration*. It would be very nice if this chapter helps you to master these concepts, but it will be enough for you to become familiar with them, and to be able to distinguish among them. The next few chapters will sharpen your understanding of these concepts.

2.1 Motion Is Relative

Everything moves. Even things that appear to be at rest move. They move with respect to, or **relative** to, the sun and stars. A book that is at rest, relative to the table it lies on, is moving at about 30 kilometers per second relative to the sun. And it moves even faster relative to the center of our galaxy. When we discuss the motion of something, we describe its motion relative to something else. When we say that a space shuttle moves at 8 kilometers per second, we mean relative to the earth below. When we say a racing car in the Indy 500 reaches a speed of 300 kilometers per hour, of course we mean relative to the track. Unless stated otherwise, when we discuss the speeds of things in our environment, we mean with respect to the surface of the earth. Motion is relative.

2.2 Speed

A moving object travels a certain distance in a given time. A car, for example, travels so many kilometers in an hour. **Speed** is a measure of how fast something is moving. It is the rate at which distance is covered. Remember, the word *rate* is a clue that something is being *divided by time*. Speed is always measured in terms of a unit of distance divided by a unit of time. Speed is defined as the distance covered per unit of time. The word *per* means "divided by."

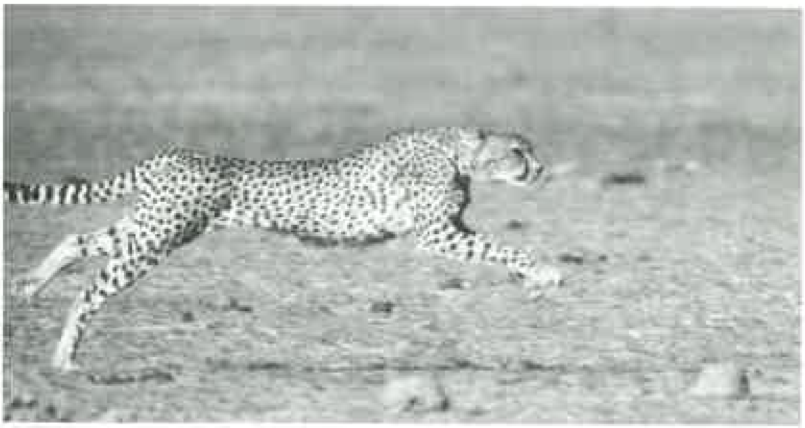

Fig. 2-1 A cheetah is the fastest land animal over distances less than 500 meters and can achieve peak speeds of 100 km/h.

Any combination of distance and time units is legitimate for speed—miles per hour (mi/h); kilometers per hour (km/h); centimeters per day (the speed of a sick snail?); lightyears per century—whatever is useful and convenient. The slash symbol (/) is read as "per." Throughout this book we'll primarily use meters per second (m/s). Table 2-1 shows some comparative speeds in different units.

Table 2-1 Approximate Speeds in Different Units
20 km/h = 12 mi/h = 6 m/s
40 km/h = 25 mi/h = 11 m/s
60 km/h = 37 mi/h = 17 m/s
80 km/h = 50 mi/h = 22 m/s
100 km/h = 62 mi/h = 28 m/s
120 km/h = 75 mi/h = 33 m/s

Fig. 2-2 The speedometer for a North American car gives readings of instantaneous speed in both mi/h and km/h. Odometers for the US market give readings in mi; those for the Canadian market give readings in km.

Instantaneous speed

A car does not always move at the same speed. A car may travel down a street at 50 km/h, slow to 0 km/h at a red light, and speed up to only 30 km/h because of traffic. You can tell the speed of the car at any instant by looking at the car's speedometer. The speed at any instant is called the **instantaneous speed**. A car traveling at 50 km/h may go at that speed for only one minute. If it continued at that speed for a full hour, it would cover 50 km in that hour. If it continued at that speed for only half an hour, it would cover only half that distance: 25 km. If it continued for only one minute, it would cover less than 1 km.

Average speed

In planning a trip by car, the driver often wants to know how long it will take to cover a certain distance. The car will certainly not travel at the same speed all during the trip. All the driver cares about is the **average speed** for the trip as a whole. The average speed is defined as follows:

$$\text{average speed} = \frac{\text{total distance covered}}{\text{time interval}}$$

Average speed can be calculated rather easily. For example, if we drive a distance of 60 kilometers in a time of 1 hour, we say our average speed is 60 kilometers per hour (60 km/h). Or if we travel 240 kilometers in 4 hours, we find:

$$\text{average speed} = \frac{\text{total distance covered}}{\text{time interval}} = \frac{240\text{ km}}{4\text{ h}} = 60\text{ km/h}$$

Note that when a distance in kilometers (km) is divided by a time in hours (h), the answer is in kilometers per hour (km/h).

Since average speed is the whole distance covered divided by the total time of travel, it does not indicate the different speeds and variations that may have taken place during shorter time intervals. In practice, we experience a variety of speeds on most trips, so the average speed is often quite different from the speed at any instant, the instantaneous speed. Whether we talk about average speed or instantaneous speed, we are talking about the rates at which distance is traveled.

► **Questions**

1. a. With the speedometer on the dashboard of every car is an odometer, which records the distance traveled. If the initial reading is set at zero at the beginning of a trip and the reading is 35 km one-half hour later, what has been your average speed?
   b. Would it be possible to attain this average speed and never exceed a reading of 70 km/h on the speedometer?
2. If a cheetah can maintain a constant speed of 25 m/s, it will cover 25 meters every second. At this rate, how far will it travel in 10 seconds? In 1 minute?

2.3 Velocity

In everyday language, we can use the words *speed* and *velocity* interchangeably. In physics, we make a distinction between the two. Very simply, the difference is that **velocity** is speed in a given direction. When we say a car travels at 60 km/h, we are specifying its speed. But if we say a car moves at 60 km/h to the north, we are specifying its velocity. Speed is a description of how fast;

► **Answers**

(Are you reading this before you have formulated a reasoned answer in your mind? If so, do you also exercise your body by watching others do push-ups? Exercise your thinking! When you encounter the many questions as above throughout this book, *think* before you read the footnoted answers. You'll not only learn more, you'll enjoy learning more.)

1. a.

$$\text{Average speed} = \frac{\text{total distance covered}}{\text{time interval}} = \frac{35\text{ km}}{0.5\text{ h}} = 70\text{ km/h}$$

   b. No, not if the trip started from rest and ended at rest, for any intervals with an instantaneous speed less than 70 km/h would have to be compensated with instantaneous speeds greater than 70 km/h to yield an average of 70 km/h. In practice, average speeds are usually appreciably less than peak instantaneous speeds.

2. In 10 s the cheetah will cover 250 m, and in 1 minute (or 60 s) it will cover 1500 m, more than fifteen football fields! If we know the average speed and the time of travel, then the distance covered is

$$\text{distance} = \text{average speed} \times \text{time interval}$$
$$\text{distance} = (25\text{ m/s}) \times (10\text{ s}) = 250\text{ m}$$
$$\text{distance} = (25\text{ m/s}) \times (60\text{ s}) = 1500\text{ m}$$

A little thought will show that this relationship is simply a rearrangement of

$$\text{average speed} = \frac{\text{distance}}{\text{time interval}}$$

velocity is how fast and in what direction.* We will see in the next section that there are good reasons for the distinction between speed and velocity.

▶ **Question**

The speedometer of a car moving northward reads 60 km/h. It passes another car that travels southward at 60 km/h. Do both cars have the same speed? Do they have the same velocity?

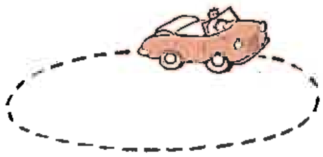

Fig. 2-3 The car on the circular track may have a constant speed, but not a constant velocity because its direction of motion is changing every instant.

Constant Velocity

From the definition of velocity it follows that to have a constant velocity requires both constant speed *and* constant direction. Constant speed means that the motion remains at the same speed—the object does not move faster or more slowly. Constant direction means that the motion is in a straight line—the object's path does not curve at all. Motion at constant velocity is motion in a straight line at constant speed.

Changing Velocity

If *either* the speed *or* the direction (or both) is changing, then the velocity is considered to be changing. Constant speed and constant velocity are not the same. A body may move at constant speed along a curved path, for example, but it does not move with constant velocity because its direction is changing every instant.

In a car, there are three controls that are used to change the velocity. One is the gas pedal; it is used to increase the speed. The second is the brake; it is used to decrease the speed. The third is the steering wheel; it is used to change the direction.

2.4 Acceleration

We can change the state of motion of an object by changing its speed, by changing its direction of motion, or by changing both. Any of these changes is a change in velocity. Sometimes we are

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▶ **Answer**

Both cars have the same speed, but they have opposite velocities because they are moving in opposite directions.

* Directional quantities are called *vectors*; velocity is a vector. Nondirectional quantities are called *scalars*; speed is a scalar. Vector and scalar quantities will be covered in Chapter 6.

interested in how fast the velocity is changing. A driver on a two-lane road who wants to pass another car would like to be able to speed up and pass in the shortest possible time. The rate at which the velocity is changing is called the *acceleration*. Because acceleration is a rate, it is a measure of how fast the velocity is changing per unit of time:

$$\text{acceleration} = \frac{\text{change of velocity}}{\text{time interval}}$$

We are all familiar with acceleration in an automobile. The driver depresses the gas pedal, appropriately called the accelerator. The passengers then experience acceleration, or "pickup" as it is sometimes called, as they tend to lurch toward the rear of the car. The key idea that defines acceleration is *change*. Whenever we change our state of motion, we are accelerating. A car that can accelerate well has the ability to change its velocity rapidly. A car that can go from zero to 60 km/h in 5 seconds has a greater acceleration than another that can go from zero to 80 km/h in 10 seconds. So having a good acceleration is being "quick to change" and not necessarily fast.

In physics, the term *acceleration* applies to decreases as well as increases in speed. The brakes of a car can produce large retarding accelerations; that is, they can produce a large decrease per second in the speed. This is often called *deceleration*, or *negative acceleration*. We experience deceleration when the driver of a bus or car slams on the brakes and we tend to lurch forward.

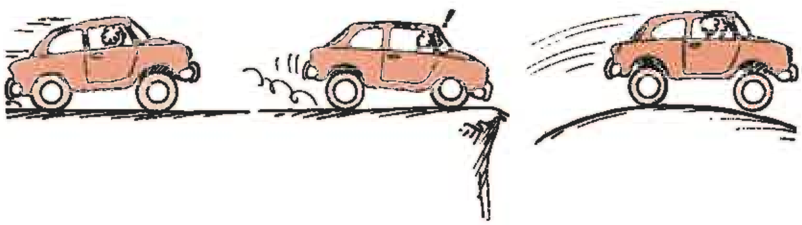

Fig. 2-4 A car is accelerating whenever there is a *change* in its state of motion.

Acceleration applies to changes in *direction* as well as changes in speed. If you ride around a curve at a constant speed of 50 km/h, you feel the effects of acceleration as you tend to lurch toward the outside of the curve. You may round the curve at constant speed, but your velocity is not constant because your direction is changing every instant. Your state of motion is changing; you are accelerating. Now you can see why it is important to distinguish between speed and velocity, and why acceleration is defined as the rate of change of *velocity*, rather than *speed*. Acceleration, like velocity, is directional. If we change either speed or direction, or both, we change velocity and we accelerate.

In most of this book we will be concerned only with motion along a straight line. When straight-line motion is being considered, it is common to use speed and velocity interchangeably. When the direction is not changing, acceleration may be expressed as the rate at which *speed* changes.

$$\text{acceleration (along a straight line)} = \frac{\text{change in speed}}{\text{time interval}}$$

Speed and velocity are measured in units of distance per time. The units of acceleration are a bit more complicated. Since acceleration is the change in velocity or speed per time interval, its units are those of speed per time. If we speed up without change in direction from zero to 10 km/h in 1 second, our change in speed is 10 km/h in a time interval of 1 s. Our acceleration (along a straight line) is

$$\text{acceleration} = \frac{\text{change in speed}}{\text{time interval}} = \frac{10\text{ km/h}}{1\text{ s}} = 10\text{ km/h·s}$$

The acceleration is 10 km/h·s (read as 10 kilometers per hour second). Note that a unit for time enters twice: once for the unit of speed and again for the interval of time in which the speed is changing. If you understand this, you can answer the following questions. If you don't, maybe the answers to the questions will be of help.

▶ **Questions**

1. Suppose a car moving in a straight line steadily increases its speed each second, first from 35 to 40 km/h, then from 40 to 45 km/h, then from 45 to 50 km/h. What is its acceleration?
2. In 5 seconds a car moving in a straight line increases its speed from 50 km/h to 65 km/h while a truck goes from rest to 15 km/h in a straight line. Which undergoes the greater acceleration? What is the acceleration of each vehicle?

▶ **Answers**

1. We see that the speed increases by 5 km/h during each 1-s interval. The acceleration is therefore 5 km/h·s during each interval.
2. The car and truck both increase their speeds by 15 km/hr during the same time interval, so their accelerations are the same. If you realized this without first calculating the accelerations, you're thinking conceptually. The acceleration of each vehicle is:

$$\text{acceleration} = \frac{\text{change in speed}}{\text{time interval}} = \frac{15\text{ km/h}}{5\text{ s}} = 3\text{ km/h·s}$$

Although the speeds involved are quite different, the rates of change of speed are the same. Hence the accelerations are equal.

2.5 Free Fall: How Fast

Drop a stone and it falls. Does it accelerate while falling? We know it starts from a rest position, and gains speed as it falls. We know this because it would be safe to catch if it fell a meter or two, but not from the top of a tall building. Thus, the stone must gain more speed during the time it drops from a building than during the shorter time it takes to drop a meter. This gain in speed indicates that the stone does accelerate as it falls.

Gravity causes the stone to fall downward once it is dropped. In real life, air resistance affects the acceleration of a falling object. Let's imagine that there is no air resistance, and gravity is the only thing that affects a falling object. Such an object would then be in **free fall**. Table 2-2 shows the instantaneous speed at the end of each second of fall of a freely-falling object dropped from rest. The **elapsed time** is the time that has elapsed, or passed, since the beginning of the fall.

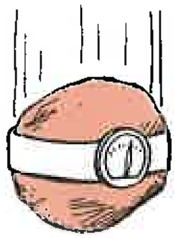

Fig. 2-5 If a falling rock were somehow equipped with a speedometer, in each succeeding second of fall its reading would increase by 10 m/s. Table 2-2 shows the speeds we would read at various seconds of fall.

Table 2-2 Free-Fall Speeds of Object Dropped from Rest

Elapsed Time (seconds)	Instantaneous Speed (meters/second)
0	0
1	10
2	20
3	30
4	40
5	50
•	•
•	•
•	•
t	$10t$

Note in Table 2-2 the way the speed changes. During each second of fall the instantaneous speed of the object increases by an additional 10 meters per second. This speed gain per second is the acceleration:

$$\text{acceleration} = \frac{\text{change in speed}}{\text{time interval}} = \frac{10 \text{ m/s}}{1 \text{ s}} = 10 \text{ m/s}^2$$

Note that when the change in speed is in m/s and the time interval is in s, the acceleration is in m/s^2 (read "meters per second squared"). The unit of time, the second, enters twice—once for the unit of speed, and again for the time interval during which the speed changes.

The acceleration of an object falling under conditions where air resistance is negligible is about 10 meters per second squared (10 m/s^2). For free fall, it is customary to use the letter g to represent the acceleration (because in free fall, the acceleration is due to gravity). Although g varies slightly in different parts of the world, its average value is nearly 10 m/s^2. More accurately, it is 9.8 m/s^2, but it is easier to see the ideas involved when it is rounded off to 10 m/s^2. Where accuracy is important, the value of 9.8 m/s^2 should be used for the acceleration during free fall.

Note in Table 2-2 that the instantaneous speed of an object falling from rest is equal to the acceleration multiplied by the amount of time it falls.

$$\text{instantaneous speed} = \text{acceleration} \times \text{elapsed time}$$

The instantaneous speed v of an object falling from rest after an elapsed time t can be expressed in shorthand notation:*

$$v = gt$$

The letter v symbolizes both speed and velocity. Take a moment to check this equation with Table 2-2. You will see that whenever the acceleration g = 10 m/s^2 is multiplied by the elapsed time in seconds, you have the instantaneous speed in meters per second.

> ▶ **Question**
>
> What would the speedometer reading on the falling rock shown in Figure 2-5 be 4.5 seconds after it drops from rest? How about 8 s after it is dropped? 100 s?

So far, we have been looking at objects moving straight downward under gravity. Now, when an object is thrown upward, it continues to move upward for a while. Then it comes back down. At the highest point, when it is changing its direction of motion from upward to downward, its instantaneous speed is zero. Then it starts downward just as if it had been dropped from rest at that height.

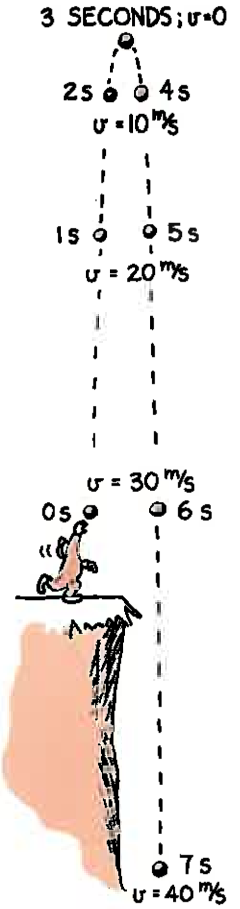

Fig. 2-6 The rate at which the speed changes each second is the same whether the ball is going upward or downward.

▶ **Answer**

The speedometer readings would be 45 m/s, 80 m/s, and 1000 m/s, respectively. You can reason this from Table 2-2 or use the equation $v = gt$, where g is replaced by 10 m/s^2.

* This relationship follows from the definition of acceleration when the acceleration is g and the initial speed is zero. If the object is initially moving downward at speed v_o, the speed v after any elapsed time t is $v = v_o + gt$. This book will not be concerned with such added complications. You can learn a lot from even the most simple cases!

What about the upward part of the path? During the upward motion, the object slows from its initial upward velocity to zero velocity. We know it is accelerating because its velocity is changing—its speed is decreasing. The acceleration during the upward motion is the same as during the downward motion: g = 10 m/s². The instantaneous *speed* at each point in the path is the same whether the object is moving upward or downward (see Figure 2-6). The *velocities* are different, of course, because they are in different directions. During each second, the speed or the velocity changes by 10 m/s. The acceleration is 10 m/s² the whole time, whether the object is moving upward or downward.

2.6 Free Fall: How Far

How *fast* a falling object moves is entirely different from how *far* it moves. To understand this, return to Table 2-2. At the end of the first second, the object is moving downward with an instantaneous speed of 10 m/s. Does this mean it falls a distance of 10 m during the first second? No. If it fell 10 m the first second, it would have to have had an *average* speed of 10 m/s. But we know the speed started at zero and increased to 10 m/s only at the end of a full second. How do we find average speed for an object moving in a straight line with constant acceleration, as it is doing here? We find it the same way we find the average of any two numbers: add them and divide by 2. So if we add the initial speed, zero in this case, and the final speed of 10 m/s, and then divide by 2, we get 5 m/s. During the first second, the object has an average speed of 5 m/s. It falls a distance of 5 m. To check your understanding of this, carefully consider the following check question before going further.

▶ **Question**

During the span of the second time interval in Table 2-2, the object begins at 10 m/s and ends at 20 m/s. What is the *average speed* of the object during this 1-second interval? What is its *acceleration?*

▶ **Answer**

The average speed will be

$$\frac{\text{beginning speed} + \text{final speed}}{2} = \frac{(10\ \text{m/s}) + (20\ \text{m/s})}{2} = \frac{30\ \text{m/s}}{2} = 15\ \text{m/s}$$

The acceleration will be

$$\frac{\text{change in speed}}{\text{time interval}} = \frac{(20\ \text{m/s}) - (10\ \text{m/s})}{1\ \text{s}} = \frac{10\ \text{m/s}}{1\ \text{s}} = 10\ \text{m/s}^2.$$

Table 2-3 shows the total distance moved by a freely falling object dropped from rest. At the end of one second it has fallen 5 m. At the end of 2 s it has dropped a total distance of 20 m. At the end of 3 s it has dropped 45 m altogether. These distances form a mathematical pattern: at the end of time t, the object has fallen a distance d of $\frac{1}{2}gt^2$.* Try using $g = 10\ \text{m/s}^2$ to calculate the distance fallen for some of the times shown in Table 2-3.

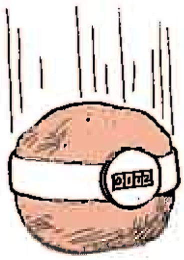

Fig. 2-7 Pretend that a falling rock is somehow equipped with an *odometer*. The readings of distance fallen increase with time and are shown in Table 2-3.

Table 2-3 Free-Fall Distances of Object Dropped from Rest

Elapsed Time (seconds)	Distance Fallen (meters)
0	0
1	5
2	20
3	45
4	80
5	125
•	•
•	•
•	•
t	$\frac{1}{2}gt^2$

▶ **Question**

An apple drops from a tree and hits the ground in one second. What is its speed upon striking the ground? What is its average speed during the one second? How high above ground was it when it first dropped?

▶ **Answer**

Using $10\ \text{m/s}^2$ for g we find

$$\text{speed } v = gt = (10\ \text{m/s}^2) \times (1\ \text{s}) = 10\ \text{m/s}$$

$$\text{average speed } \bar{v} = \frac{\text{beginning } v + \text{final } v}{2} = \frac{(0\ \text{m/s}) + (10\ \text{m/s})}{2} = 5\ \text{m/s}$$

(The bar over the symbol v denotes *average* speed $\bar{v}$.)

$$\text{distance } d = \text{average speed} \times \text{time interval} = (5\ \text{m/s}) \times (1\ \text{s}) = 5\ \text{m}$$

or equivalently,

$$\text{distance } d = \tfrac{1}{2}gt^2 = (\tfrac{1}{2}) \times (10\ \text{m/s}^2) \times (1\ \text{s})^2 = 5\ \text{m}$$

Notice that the distance can be found by either of these equivalent relationships.

* $$\begin{aligned}\text{distance} &= \text{average speed} \times \text{time interval}\\ &= \frac{\text{beginning speed} + \text{final speed}}{2} \times \text{time}\\ &= \frac{0 + gt}{2} \times t\\ &= \tfrac{1}{2}gt^2\end{aligned}$$

2.7 Air Resistance and Falling Objects

Drop a feather and a coin and you'll notice that the coin reaches the floor way ahead of the feather. Air resistance is responsible for these different accelerations. This fact can be shown quite nicely with a closed glass tube connected to a vacuum pump. The feather and coin are placed inside. When air is inside the tube and it is inverted, the coin falls much more rapidly than the feather. The feather flutters through the air. But if the air is removed with a vacuum pump and the tube is quickly inverted, the feather and coin fall side by side at acceleration g (Figure 2-8). Air resistance noticeably alters the motion of falling pieces of paper or feathers. But air resistance less noticeably affects the motion of more compact objects like stones and baseballs. Most objects falling in air can be considered to be falling freely. (Air resistance will be covered in more detail in Chapter 4.)

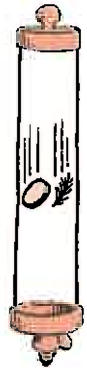

Fig. 2-8 A feather and a coin accelerate equally when there is no air around them.

2.8 How Fast, How Far, How Quick How Fast Changes

Much of the confusion that arrives in analyzing the motion of falling objects comes about from mixing up "how fast" with "how far." When we wish to specify how fast something freely falls from rest after a certain elapsed time, we are talking about speed or velocity. The appropriate equation is $v = gt$. When we wish to specify how far that object has fallen, we are talking about distance. The appropriate equation is $d = \frac{1}{2}gt^2$. Velocity or speed (how fast) and distance (how far) are entirely different from each other.

The most confusing concept, and one of the most difficult encountered in this book, is "how quickly does speed or velocity change": acceleration. What makes acceleration so complex is that it is *a rate of a rate*. It is often confused with velocity, which is itself a rate (the rate at which distance is covered). Acceleration is not velocity, nor is it even a change in velocity; acceleration is the rate at which velocity itself changes.

Please be patient with yourself if you find that you require a few hours to achieve a clear understanding of motion. It took people nearly 2000 years, from the time of Aristotle to Galileo, to achieve as much!

2 Chapter Review

Concept Summary

Motion is described relative to something.

Speed is a measure of how fast something is moving.

- Speed is the rate at which distance is covered; it is measured in units of distance divided by time.
- Instantaneous speed is the speed at any instant.
- Average speed is the total distance covered divided by the time interval.

Velocity is speed together with the direction of travel.

- The velocity is constant only when the speed and the direction are both constant.

Acceleration is the rate at which the velocity is changing.

- In physics, an object is considered to be accelerating when its speed is increasing, when its speed is decreasing, and/or when the direction is changing.
- Acceleration is measured in units of speed divided by time.

An object in free fall is falling under the influence of gravity alone, where air resistance does not affect its motion.

- An object in free fall has a constant acceleration of about 10 m/s^2.

Important Terms

acceleration (2.4)
average speed (2.2)
elapsed time (2.5)
free fall (2.5)
instantaneous speed (2.2)
rate (2.1)
relative (2.1)
speed (2.2)
velocity (2.3)

Note: Each chapter in this book concludes with a set of Review Questions and Think and Explain exercises. The Review Questions are designed to help you fix ideas and catch the essentials of the chapter material. You'll notice that answers to the questions can be found within the chapter. Think and Explain exercises stress thinking rather than mere recall of information and call for an *understanding* of the definitions, principles, and relationships of the chapter material. In many cases the intention of particular Think and Explain exercises is to help you apply the ideas of physics to familiar situations.

The Activities, which are at the end of most chapters, are pre-lab activities that can be done in or out of class, or simple home projects to do on your own. Their purpose is to encourage you to discover the joy of *doing* physics.

Review Questions

1. What is meant by saying that motion is relative? For everyday motion, what is motion usually relative to? (2.1)

2. Speed is the rate at which what happens? (2.2)

3. You walk across the room at 1 kilometer per second. Express this speed in abbreviated units, or symbols. (2.2)

4. What is the difference between instantaneous speed and average speed? (2.2)

5. Does the speedometer of a car read instantaneous speed or average speed? (2.2)

6. What is the difference between speed and velocity? (2.3)

7. If the speedometer in a car reads a constant speed of 40 km/h, can you say that the car

has a constant velocity? Why or why not? (2.3)

8. What two controls on a car enable a change in *speed*? Name another control that enables a change in *velocity*. (2.3)

9. What quantity describes how quickly you change how fast you're traveling, or how quickly you change your direction? (2.4)

10. Acceleration is the rate at which what happens? (2.4)

11. What is the acceleration of a car that travels in a straight line at a constant speed of 100 km/h? (2.4)

12. What is the acceleration of a car that, while moving in a straight line, increases its speed from zero to 100 km/h in 10 seconds? (2.4)

13. By how much does the speed of a vehicle moving in a straight line change each second when it is accelerating at 2 km/h·s? At 4 km/h·s? At 10 km/h·s? (2.4)

14. Under what conditions can acceleration be defined as the rate at which the *speed* is changing? (2.4)

15. Why does the unit of time enter twice in the unit of acceleration? (2.4)

16. How much gain in speed each second does a freely falling object acquire? (2.5)

17. For a freely-falling object dropped from rest, what is its instantaneous speed at the end of the fifth second of fall? The sixth second? (2.5)

18. For a freely-falling object dropped from rest, what is its *acceleration* at the end of the fifth second of fall? The sixth second? At the end of any elapsed time t? (2.5)

19. For an object thrown straight upward, what is its *instantaneous speed* at the top of its path? Its *acceleration*? (Why are your answers different?) (2.5)

20. How far will a freely-falling object fall from a position of rest in five seconds? Six seconds? (2.6)

21. How far will an object move in one second if its average speed during that second is 5 m/s? (2.6)

22. How far will a freely-falling object have fallen from a position of rest when its instantaneous speed is 10 m/s? (2.6)

23. Does air resistance increase or decrease the acceleration of a falling object? (2.7)

24. What is the appropriate equation for how *fast* something freely falls from a position of rest? For how *far* that object falls? (2.8)

25. Why is it said that acceleration is a *rate of a rate*? (2.8)

Activities

1. By any method you choose, determine your average speed of walking.

2. Try this with your friends. Hold a dollar bill so that the midpoint hangs between a friend's fingers (Figure A). Challenge your friend to catch it by snapping his or her fingers shut when you release it. The bill won't be caught! Explanation: It takes at least $\frac{1}{7}$ second for the necessary impulses to travel from the eye to the brain to the fingers. But in only $\frac{1}{8}$ second, the bill falls 8 cm (from $d = \frac{1}{2}gt^2$), which is half the length of the bill.

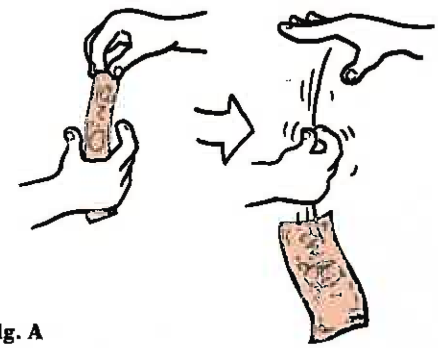

Fig. A

3. You can compare your reaction time with that of a friend by catching a ruler that is dropped between your fingers. Let your friend hold the ruler as shown in Figure B. Snap your fingers shut as soon as you see the ruler released. The number of centimeters that pass through your fingers depends on your reaction time. You can find your reaction time in seconds by solving $d = \frac{1}{2}gt^2$ for time: $t = \sqrt{2d/g} = 0.045\sqrt{d}$, where d is in centimeters.

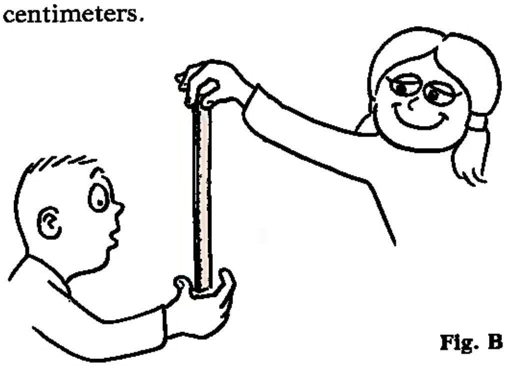

Fig. B

Think and Explain

1. Why is it that an object can accelerate while traveling at constant speed, but not at constant velocity?

2. Light travels in a straight line at a constant speed of 300 000 km/s. What is its acceleration?

3. Which has the greater acceleration when moving in a straight line—a car that increases its speed from 50 to 60 km/h, or a bicycle that goes from zero to 10 km/h in the same time? Defend your answer.

4. a. If a freely-falling rock were equipped with a speedometer, by how much would its speed readings increase with each second of fall?
   b. Suppose the freely-falling rock were dropped near the surface of a planet where $g = 20\ \text{m/s}^2$. By how much would its speed readings change each second?

5. If a freely-falling rock were equipped with an odometer, would the readings for distance fallen each second be the same, increase with time, or decrease with time?

6. a. When a ball is thrown straight upward in the absence of air resistance, by how much does the speed decrease each second?
   b. After it reaches the top and begins its return downward, by how much does its speed increase each second?
   c. How much time is required in going up compared to coming down?

7. Table 2-2 shows that the instantaneous speed of an object dropped from rest is 10 m/s after 1 s of fall. Table 2-3 shows that the object has fallen only 5 m during this time. Your friend says this is incorrect, because distance traveled equals speed times time, so the object should fall 10 m. What do you say?

8. a. What is the instantaneous speed of a freely-falling object 10 s after it is released from a rest position?
   b. What is its average speed during this time?
   c. How far will it travel in this time?