

Chapter 2: Describing Motion: Kinematics in One Dimension

2-1 Reference Frames and Displacement

2-2 Average Velocity

2-3 Instantaneous Velocity

2-4 Acceleration

2-5 Motion at Constant Acceleration

2-7 Freely Falling Body

Introduction

Mechanics: is the branch of physics that studies the motion of objects and the forces acting on them.

It is divided into three main branches:

ثابت

1. **Statics** – Study of objects at rest.

ساکن

Example: A book resting on a table.

حرکت

2. **Kinematics** – Study of the motion of objects without considering the forces causes the motion.

حرکت

Topics: Distance, displacement, speed, velocity, acceleration

3. **Dynamics** – Study of motion along with forces that produce it.

Topics: Newton's laws of motion, friction, work, energy, power, momentum.

2-1 Reference Frames and Displacement

الأزاحة

It is a coordinate system from which the position and motion of an object are observed and measured.

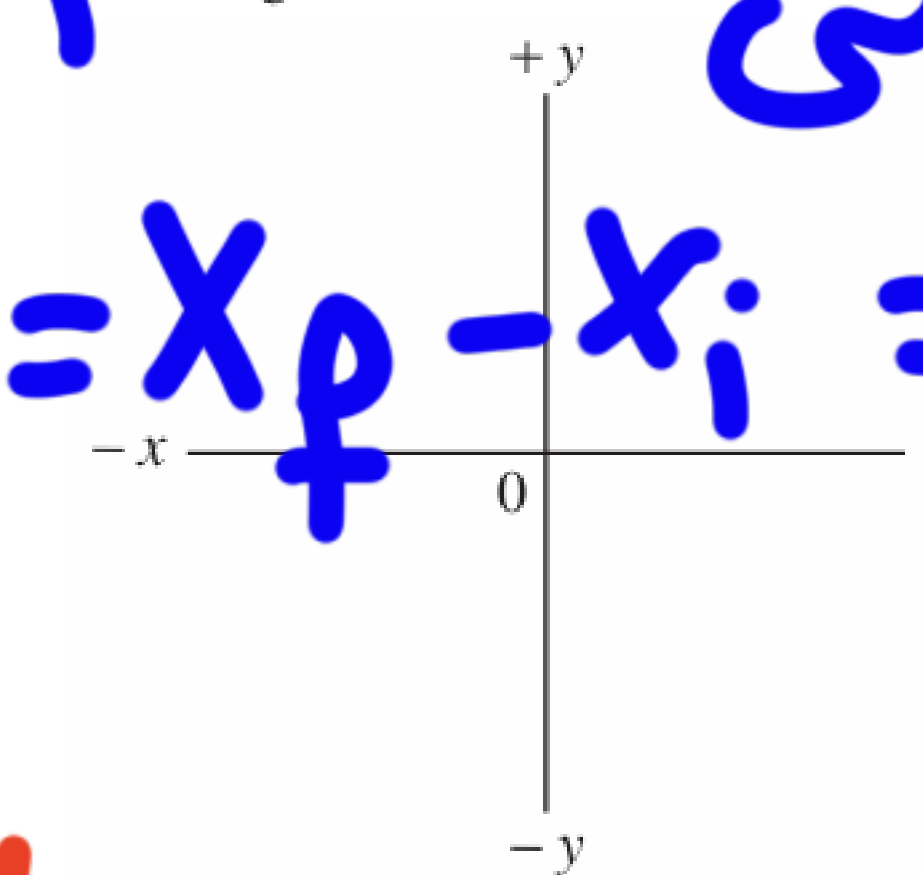
Example:

- The train is moving at **80 km/h relative to the ground**.
- A person walks past you toward the front of the train at **5 km/h**.
- So, the **person's speed with respect to the train** is 5 km/h.
- Since the person and train are moving in the **same direction**, their speeds are added.
- **The person's speed with respect to the ground** is $80+5 = 85$ km/h.
- When describing the motion of an object, we should mention its direction.
- For one-dimensional motion x axis as the line along which the motion takes place. The position of an object is given by x coordinate.
- If the motion is vertical, we use y axis.

FIGURE 2-2 A person walks toward the front of a train at 5 km/h. The train is moving 80 km/h with respect to the ground, so the walking person's speed, relative to the ground, is 85 km/h.



FIGURE 2-3 Standard set of xy coordinate axes, sometimes called "rectangular coordinates."



$x_i = 0$ $x_f = 5 \text{ m}$

$\Delta x = x_f - x_i = 5 - 0 = 5 \text{ m}$

التغير في المكان = الأزاحة

أبديائي نهائي

2-1 Reference Frames and Displacement

- *Distance: Total length the object travels. It is a scalar. It cannot be zero or negative.*
- *Displacement: Change in position of the object. It could be zero or negative.*
- *It is a vector – has magnitude and direction.*

A person walking 70 m to the east and then turning around and walking back (west) a distance of 30 m.

Total distance traveled is 100 m.

Displacement is 40 m.

- The motion of an object over a particular time interval is represented as follows:

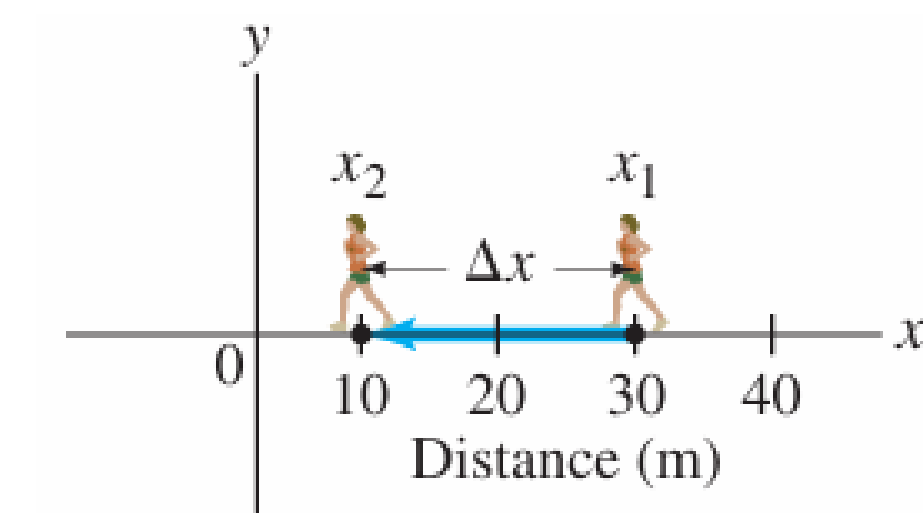
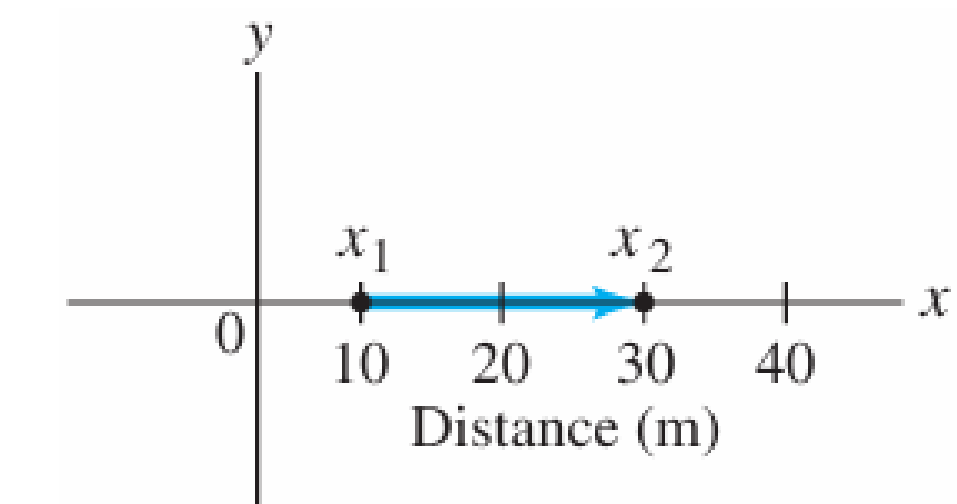
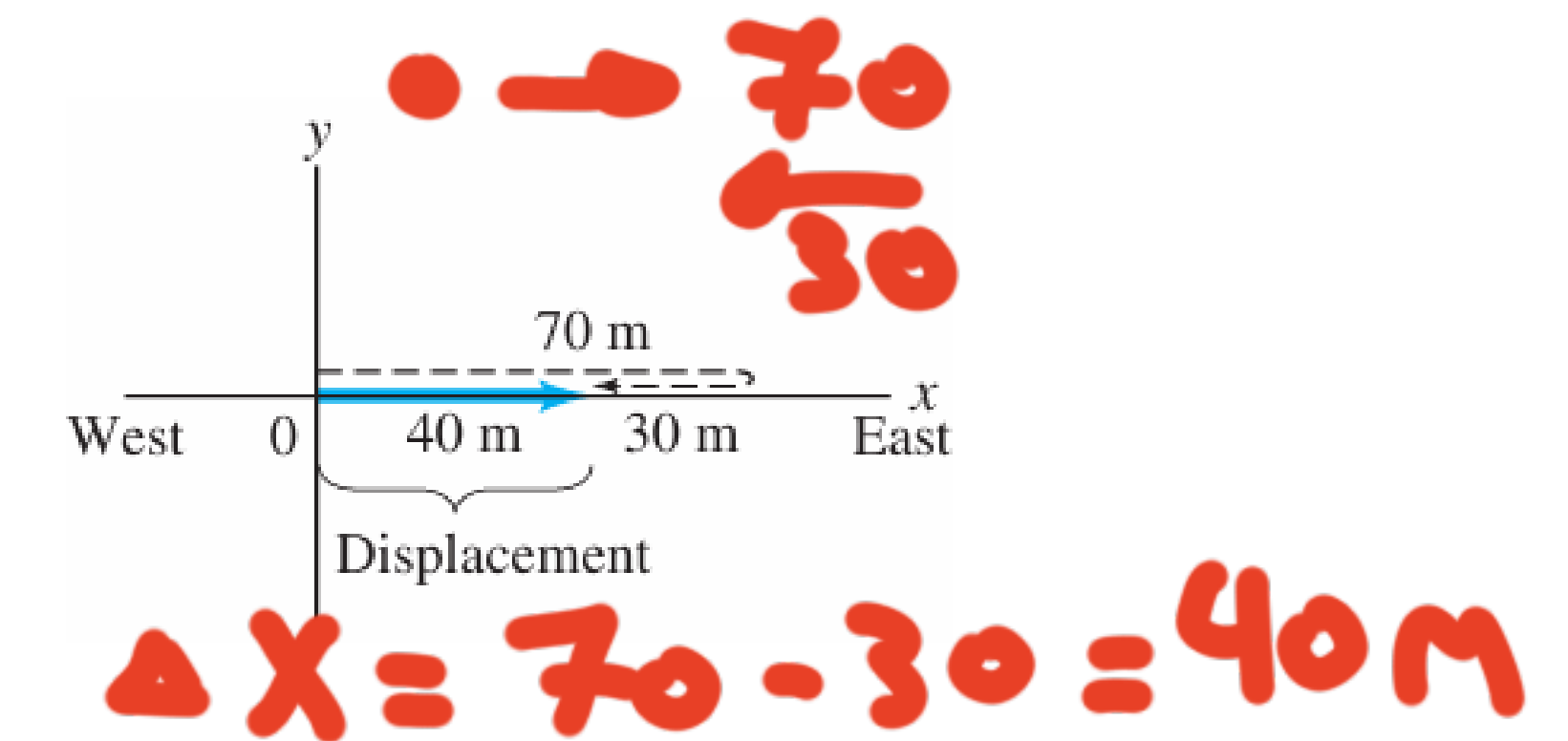
The object is on x axis, at time t_1 the position is x_1 and

at time t_2 the position is x_2

Displacement $\Delta x = x_2 - x_1$. (Δ (delta) means change in

Example 1: $x_1 = 10.0$ m and $x_2 = 30.0$ m $\Delta x = 30 - 10 = 20$ m

Example 2: $x_1 = 30.0$ m and $x_2 = 10.0$ m $\Delta x = 10 - 30 = -20$ m



متوسط السرعة

2-2 Average Velocity

Speed: How far an object travels in a given time interval. It is a scalar. Unit: m/s

$$\text{Average Speed} = \frac{\text{Distance traveled}}{\text{time elapsed}}$$

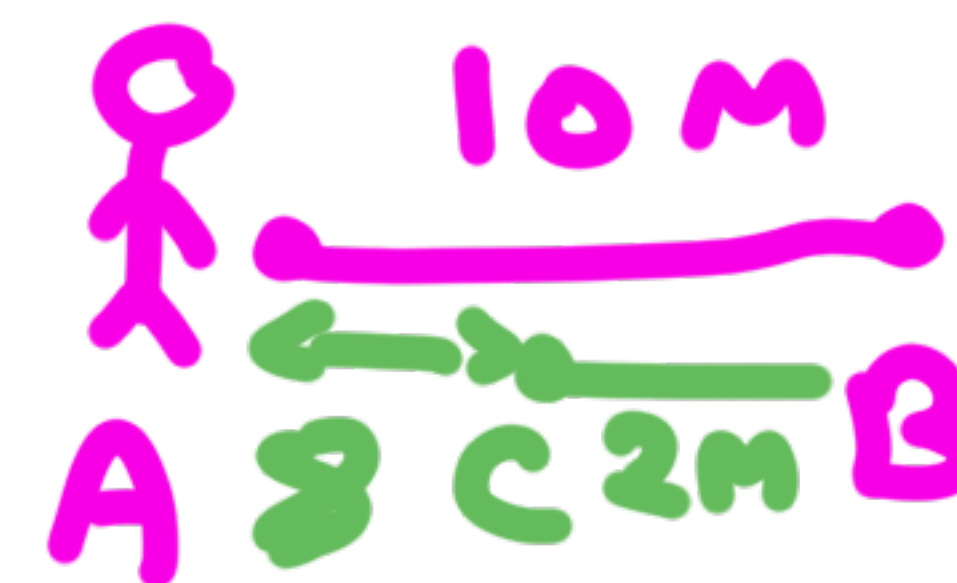
المسافة الكلية التي يقطعها الجسم

Velocity: How fast an object is moving and also the direction in which it is moving. It is a vector. Unit: m/s

أهتز مسافة في اتجاه الجسم

$$\text{Average Velocity } \bar{v} = \frac{\text{displacement}}{\text{time elapsed}} = \frac{\text{final position} - \text{initial position}}{\text{time elapsed}} = \frac{x_2 - x_1}{t_2 - t_1} = \frac{\Delta x}{\Delta t}$$

- Average speed and average velocity have the same magnitude when the motion is all in one direction.
- Average speed is not necessarily equal to the magnitude of the average velocity.
- In one dimensional motion the average velocity is positive for an object moving to the right along the x axis and negative when the object moves to the left.



$$\text{Distance} = 10 + 2 = 12\text{m}$$

$$\text{Displacement} = \Delta x \\ = 10 - 2 = 8\text{m}$$

الكميات

Quantity

الازاحة

Displacement

قياسي

Scalar

→ magnitude only
المسافة Distance

Ex: Mass, Time, Speed

متجهي

Vector

→ magnitude
→ Direction

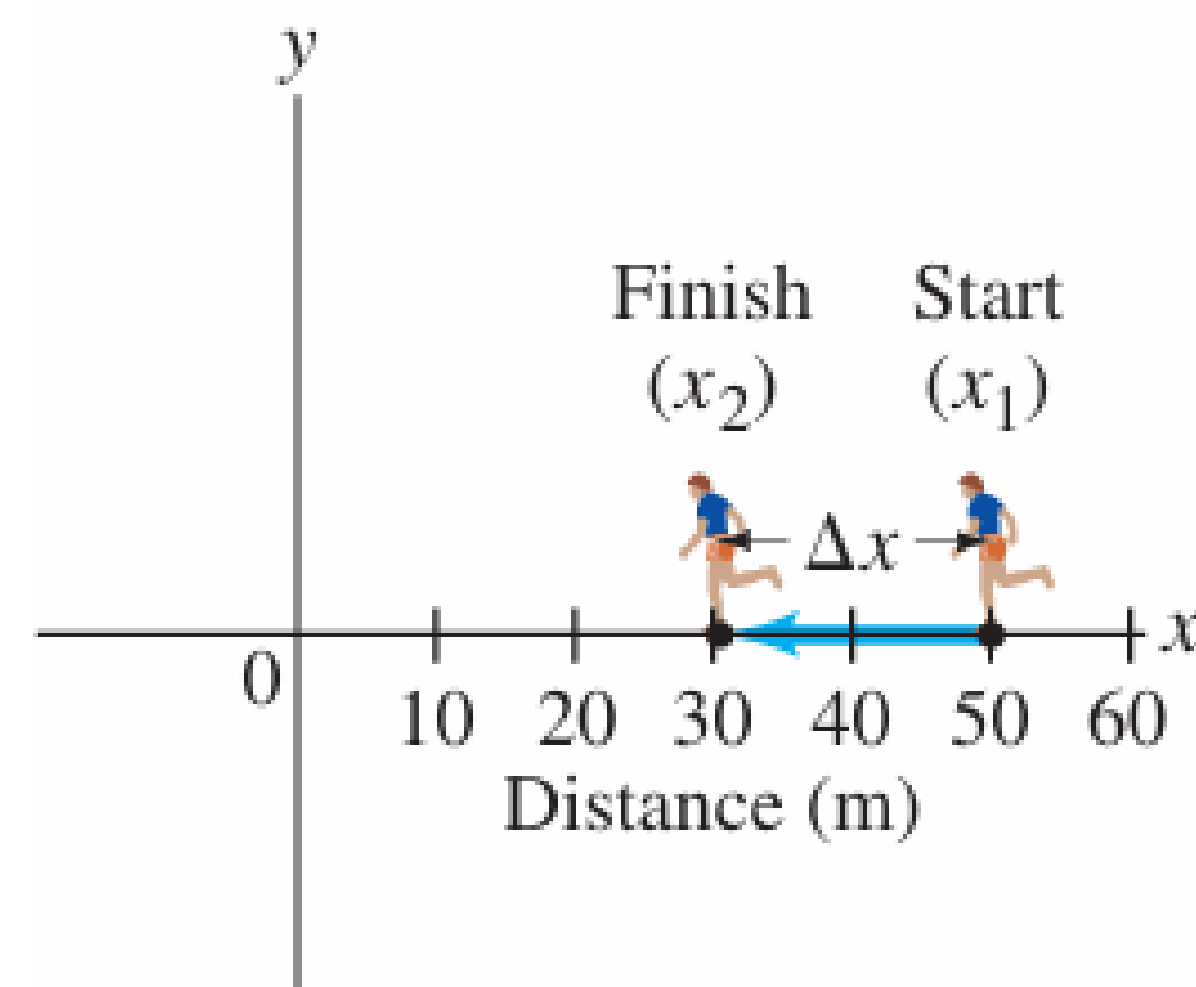
Ex: Force, Velocity



Example Problem 2-1

FIGURE 2-7 Example 2-1.

A person runs from $x_1 = 50.0$ m to $x_2 = 30.5$ m. The displacement is -19.5 m.



EXAMPLE 2-1 Runner's average velocity. The position of a runner is plotted as moving along the x axis of a coordinate system. During a 3.00 -s time interval, the runner's position changes from $x_1 = 50.0$ m to $x_2 = 30.5$ m, as shown in Fig. 2-7. What is the runner's average velocity?

APPROACH We want to find the average velocity, which is the displacement divided by the elapsed time.

SOLUTION The displacement is

$$\begin{aligned}\Delta x &= x_2 - x_1 \\ &= 30.5 \text{ m} - 50.0 \text{ m} = -19.5 \text{ m}.\end{aligned}$$

The elapsed time, or time interval, is given as $\Delta t = 3.00$ s. The average velocity (Eq. 2-2) is

$$\bar{v} = \frac{\Delta x}{\Delta t} = \frac{-19.5 \text{ m}}{3.00 \text{ s}} = -6.50 \text{ m/s}.$$

The displacement and average velocity are negative, which tells us that the runner is moving to the left along the x axis, as indicated by the arrow in Fig. 2-7.

The runner's average velocity is 6.50 m/s to the left.

to the left

$$\bar{v} = \frac{\Delta x}{\Delta t} = \frac{x_f - x_i}{\Delta t} = \frac{30.5 - 50}{3} = -6.5 \frac{\text{m}}{\text{s}}$$

Example Problem 2-2 & 2-3

كم البعد

EXAMPLE 2-2 Distance a cyclist travels. How far can a cyclist travel in 2.5 h along a straight road if her average velocity is 18 km/h?

APPROACH We want to find the distance traveled, so we solve Eq. 2-2 for Δx .

SOLUTION In Eq. 2-2, $\bar{v} = \Delta x / \Delta t$, we multiply both sides by Δt and obtain

$$\Delta x = \bar{v} \Delta t = (18 \text{ km/h})(2.5 \text{ h}) = 45 \text{ km}.$$

$$t = 2.5 \text{ h}$$

$$\bar{v} = 18 \frac{\text{km}}{\text{h}}$$

$$\bar{v} = \frac{\Delta x}{\Delta t}$$

$$\Delta x = \bar{v} \Delta t$$

$$= 18 \times 2.5$$

$$= 45 \text{ km}$$

EXAMPLE 2-3 Car changes speed. A car travels at a constant 50 km/h for 100 km. It then speeds up to 100 km/h and is driven another 100 km. What is the car's average speed for the 200-km trip?

APPROACH At 50 km/h, the car takes 2.0 h to travel 100 km. At 100 km/h it takes only 1.0 h to travel 100 km. We use the definition of average velocity, Eq. 2-2.

SOLUTION Average velocity (Eq. 2-2) is

$$\bar{v} = \frac{\Delta x}{\Delta t} = \frac{100 \text{ km} + 100 \text{ km}}{2.0 \text{ h} + 1.0 \text{ h}} = 67 \text{ km/h}.$$

NOTE Averaging the two speeds, $(50 \text{ km/h} + 100 \text{ km/h})/2 = 75 \text{ km/h}$, gives a wrong answer. Can you see why? You must use the definition of $\bar{v}$, Eq. 2-2.

$$v = \frac{x}{t} \Rightarrow t = \frac{x}{v} \Rightarrow t_1 = \frac{x_1}{v_1} = \frac{100}{50} = 2 \text{ h}$$

$$v_1 = 50 \frac{\text{km}}{\text{h}}$$

$$x_1 = 100 \text{ km}$$

$$v_2 = 100 \text{ km/h}$$

$$x_2 = 100 \text{ km}$$

$$\bar{v} = \frac{\text{Distance}}{\text{time}}$$

$$t_2 = \frac{x_2}{v_2} = \frac{100}{100} = 1 \text{ h}$$

$$\begin{aligned} \therefore \bar{v} &= \frac{x_1 + x_2}{t_1 + t_2} = \frac{100 + 100}{2 + 1} \\ &= 66.66 \text{ km/h} \end{aligned}$$

السرعة اللحظية

2-3 Instantaneous Velocity

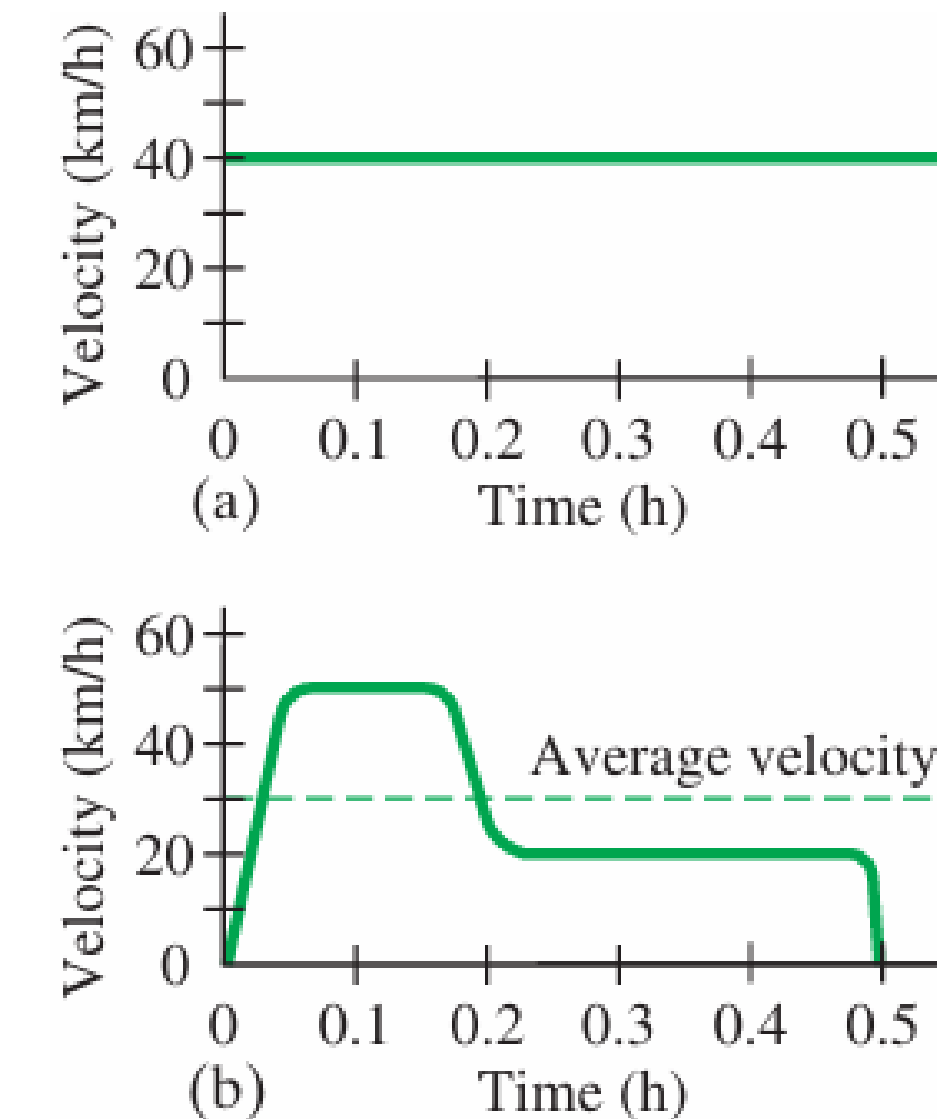
$$v = \frac{dx}{dt}$$

- Velocity at any instant of time is known as instantaneous velocity (v).

$$v = \lim_{\Delta t \rightarrow 0} \frac{\Delta x}{\Delta t}$$

- If the object moves uniform (constant) (Fig. a), velocity during a particular time interval, then its instantaneous speed is always equals the magnitude of the instantaneous velocity. Because distance traveled and the magnitude of the displacement become the same when they become infinitesimally small.
- In Fig. b, a car start from rest speed up to 50 km/h, remain at that velocity for a time then slow down to 20 km/h in a traffic jam, and finally stop at its destination after traveling a total of 15 km in 30 min.
- Average velocity $\bar{v} = \frac{\Delta x}{\Delta t} = \frac{15}{0.50} = 30$ km/h
- A car's speedometer shows its instantaneous speed.

FIGURE 2-9 Velocity of a car as a function of time: (a) at constant velocity; (b) with velocity varying in time.



العجلة، التسارع

2-4 Acceleration

$$= \frac{v}{t} \left(\frac{m}{s^2} \right)$$

- **Acceleration:** Change in velocity over change in time. It is a vector. Unit: m/s²

- **Average acceleration** $\vec{a} = \frac{\text{change in velocity}}{\text{time elapsed}} = \frac{v_2 - v_1}{t_2 - t_1} = \frac{\Delta v}{\Delta t}$

العجلة اللحظية

- **Instantaneous acceleration** is the average acceleration over an infinitesimally short time interval

$$a = \lim_{\Delta t \rightarrow 0} \frac{\Delta v}{\Delta t}$$

$$a = \frac{dv}{dt}$$

- **Deceleration:** When an object is slowing down it is known as decelerating.

$$v = \frac{x}{t} \rightarrow \bar{v} = \frac{\Delta x}{\Delta t}$$

$$a = \frac{v}{t} \rightarrow \bar{a} = \frac{\Delta v}{\Delta t}$$

$$\bar{a} = \frac{v_f - v_i}{\Delta t}$$

Example Problem 2-4

$$\begin{aligned}
 v_i &= 0 \\
 v_f &= 75 \frac{\text{km}}{\text{h}} \\
 t &= 5 \text{ sec} \\
 \bar{a} &= \frac{\Delta v}{\Delta t} = \frac{v_f - v_i}{\Delta t} \\
 &= \frac{75 - 0}{5} = 15 \frac{\text{km}}{\text{h}}
 \end{aligned}$$

EXAMPLE 2-4 Average acceleration. A car accelerates on a straight road from rest to 75 km/h in 5.0 s, Fig. 2-10. What is the magnitude of its average acceleration?

APPROACH Average acceleration is the change in velocity divided by the elapsed time, 5.0 s. The car starts from rest, so $v_1 = 0$. The final velocity is $v_2 = 75 \text{ km/h}$.

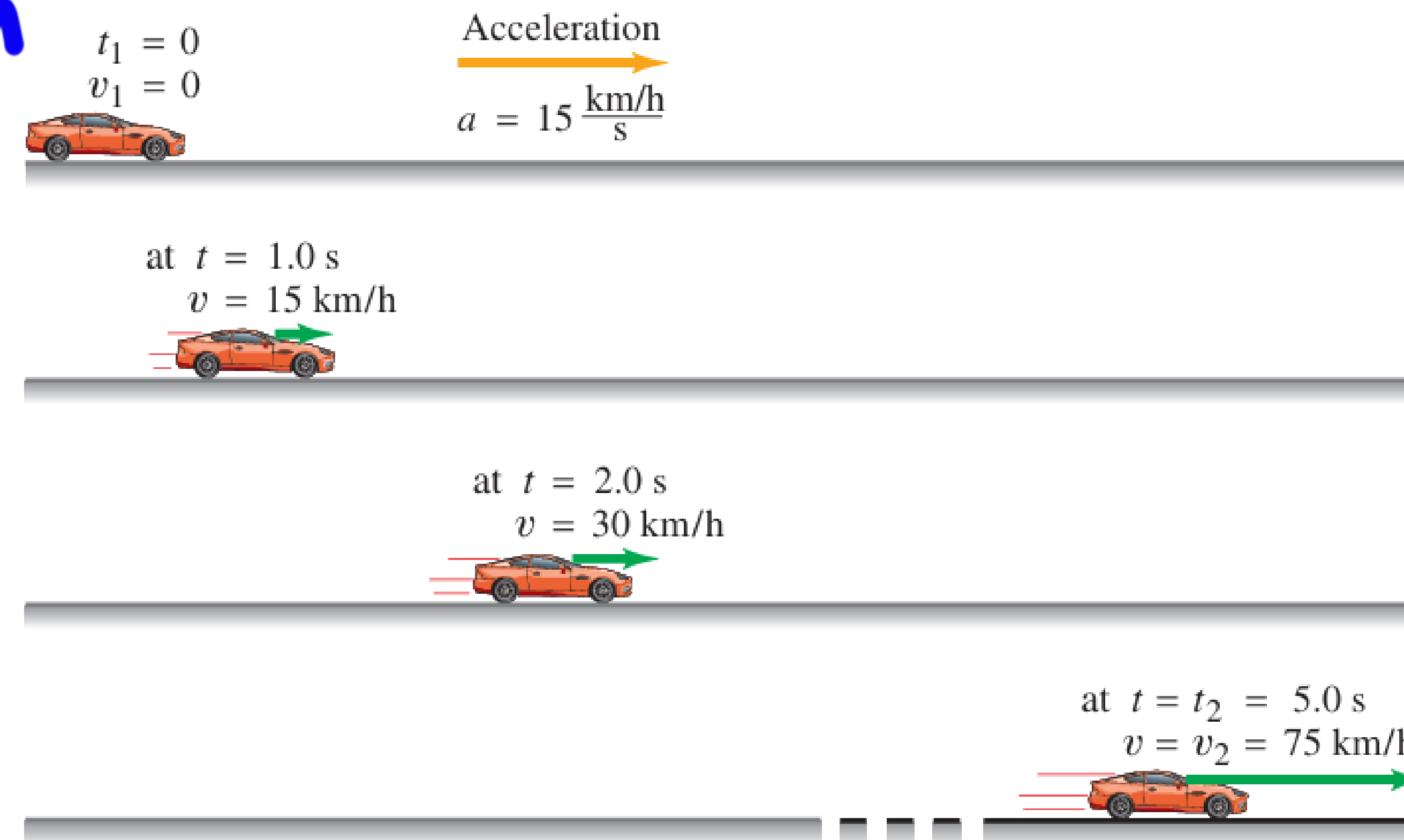
SOLUTION From Eq. 2-4, the average acceleration is

$$\bar{a} = \frac{v_2 - v_1}{t_2 - t_1} = \frac{75 \text{ km/h} - 0 \text{ km/h}}{5.0 \text{ s}} = 15 \frac{\text{km}}{\text{h} \cdot \text{s}}.$$

This is read as “fifteen kilometers per hour per second” and means that, on average, the velocity changed by 15 km/h during each second. That is, assuming the acceleration was constant, during the first second the car’s velocity increased from zero to 15 km/h. During the next second its velocity increased by another 15 km/h, reaching a velocity of 30 km/h at $t = 2.0 \text{ s}$, and so on. See Fig. 2-10.

$$\begin{aligned}
 75 \text{ km/h} &= \left(75 \frac{\text{km}}{\text{h}}\right) \left(\frac{1000 \text{ m}}{1 \text{ km}}\right) \left(\frac{1 \text{ h}}{3600 \text{ s}}\right) = 21 \text{ m/s} \\
 \bar{a} &= \frac{21 \text{ m/s} - 0.0 \text{ m/s}}{5.0 \text{ s}} = 4.2 \frac{\text{m}}{\text{s}^2} = 4.2 \frac{\text{m}}{\text{s}^2}.
 \end{aligned}$$

FIGURE 2-10 Example 2-4. The car is shown at the start with $v_1 = 0$ at $t_1 = 0$. The car is shown three more times, at $t = 1.0 \text{ s}$, $t = 2.0 \text{ s}$, and at the end of our time interval, $t_2 = 5.0 \text{ s}$. The green arrows represent the velocity vectors, whose length represents the magnitude of the velocity at that moment. The acceleration vector is the orange arrow, whose magnitude is constant and equals 15 km/h/s or 4.2 m/s^2 (see top of next page). Distances are not to scale.



تباطأ السرعة سقل

Deceleration →

العجلة سالبة
 $v_f < v_i$

- Deceleration does not mean the acceleration is negative.
- The velocity of an object moving to the right along the positive x axis is positive; if the object is slowing down the acceleration is negative.

السرعة
 سقل
 $v_f < v_i$
 $a < 0$

سيارة

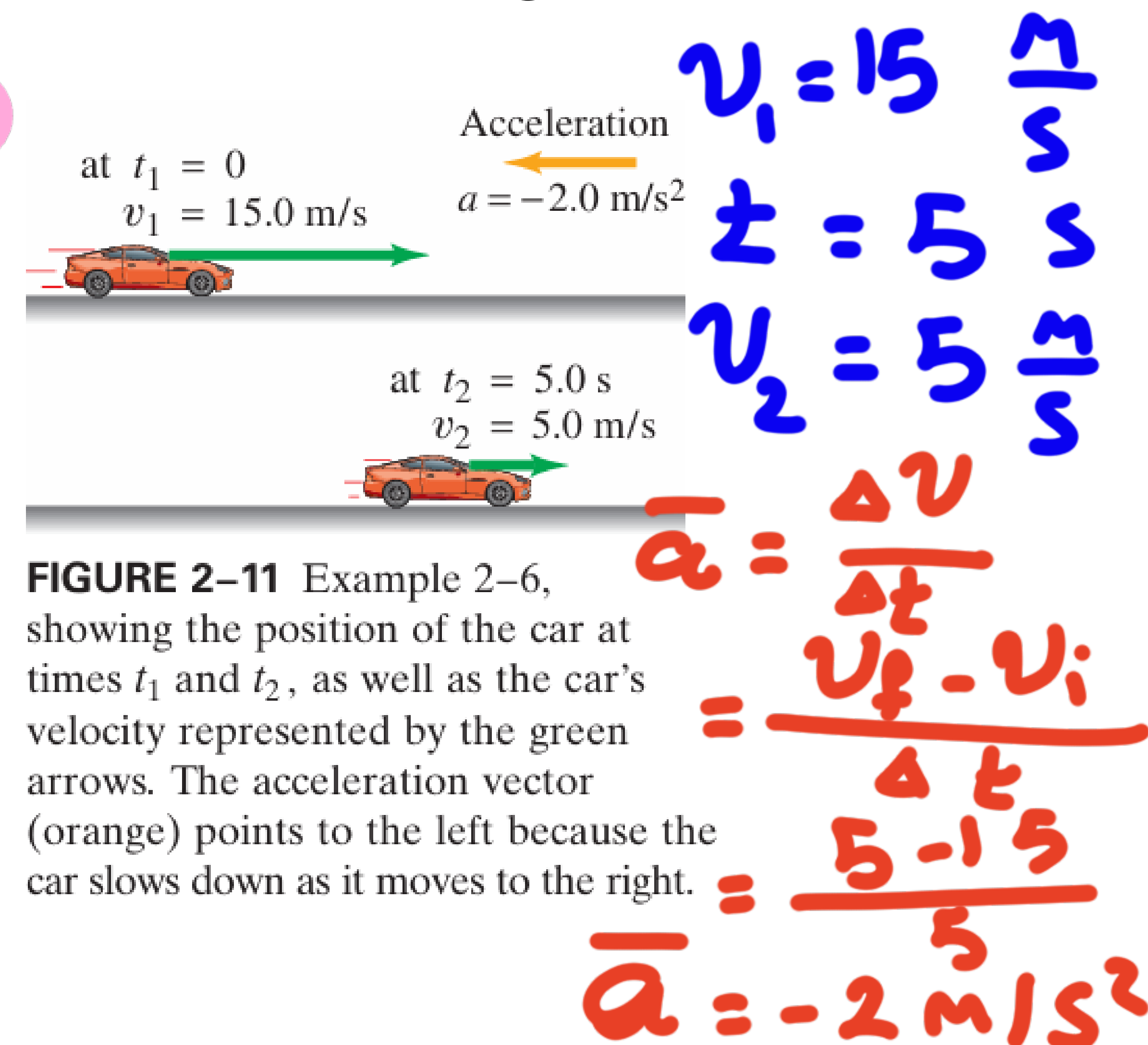
EXAMPLE 2-6 Car slowing down. An automobile is moving to the right along a straight highway, which we choose to be the positive x axis (Fig. 2-11). Then the driver steps on the brakes. If the initial velocity (when the driver hits the brakes) is $v_1 = 15.0$ m/s, and it takes 5.0 s to slow down to $v_2 = 5.0$ m/s, what was the car's average acceleration?

APPROACH We put the given initial and final velocities, and the elapsed time, into Eq. 2-4 for $\bar{a}$.

SOLUTION In Eq. 2-4, we call the initial time $t_1 = 0$, and set $t_2 = 5.0$ s:

$$\bar{a} = \frac{5.0 \text{ m/s} - 15.0 \text{ m/s}}{5.0 \text{ s}} = -2.0 \text{ m/s}^2.$$

The negative sign appears because the final velocity is less than the initial velocity. In this case the direction of the acceleration is to the left (in the negative x direction)—even though the velocity is always pointing to the right. We say that the acceleration is 2.0 m/s^2 to the left, and it is shown in Fig. 2-11 as an orange arrow.

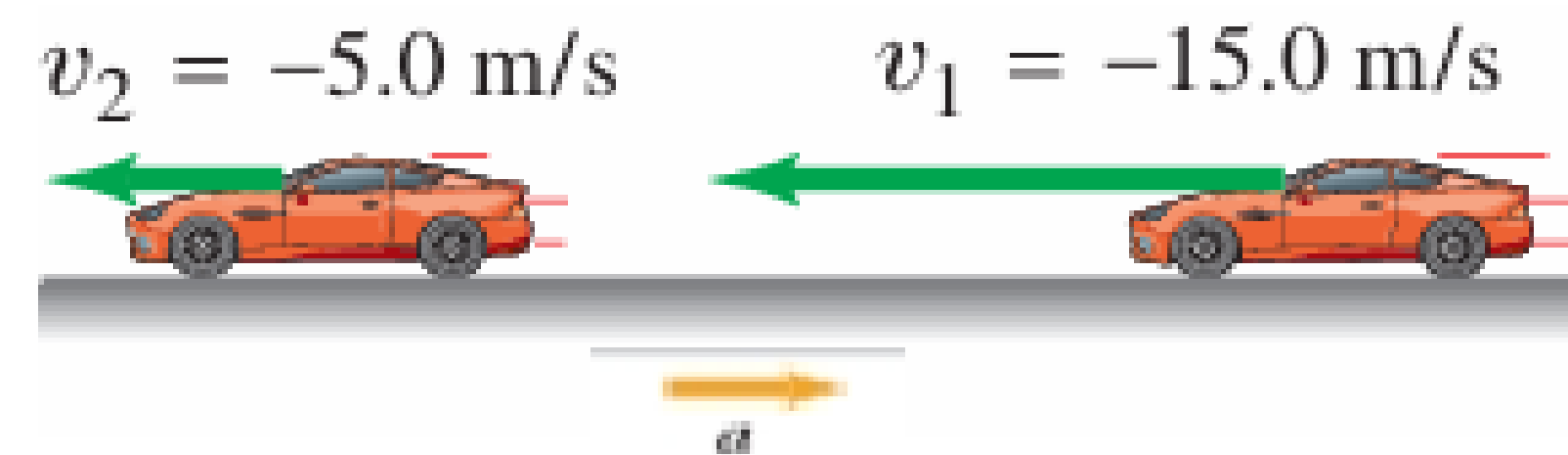


Deceleration

- If the object is moving to the left (decreasing x) and slowing down has positive acceleration that points to the right.

FIGURE 2-12 The car of Example 2-6, now moving to the *left* and decelerating. The acceleration is $a = (v_2 - v_1)/\Delta t$, or

$$a = \frac{(-5.0 \text{ m/s}) - (-15.0 \text{ m/s})}{5.0 \text{ s}} \\ = \frac{-5.0 \text{ m/s} + 15.0 \text{ m/s}}{5.0 \text{ s}} = +2.0 \text{ m/s}^2.$$



$$v_1 = -15 \text{ m/s} \\ v_2 = -5 \text{ m/s} \\ t = 5 \text{ s} \\ a = \frac{-5 - (-15)}{5} \\ = 2 \text{ m/s}^2$$

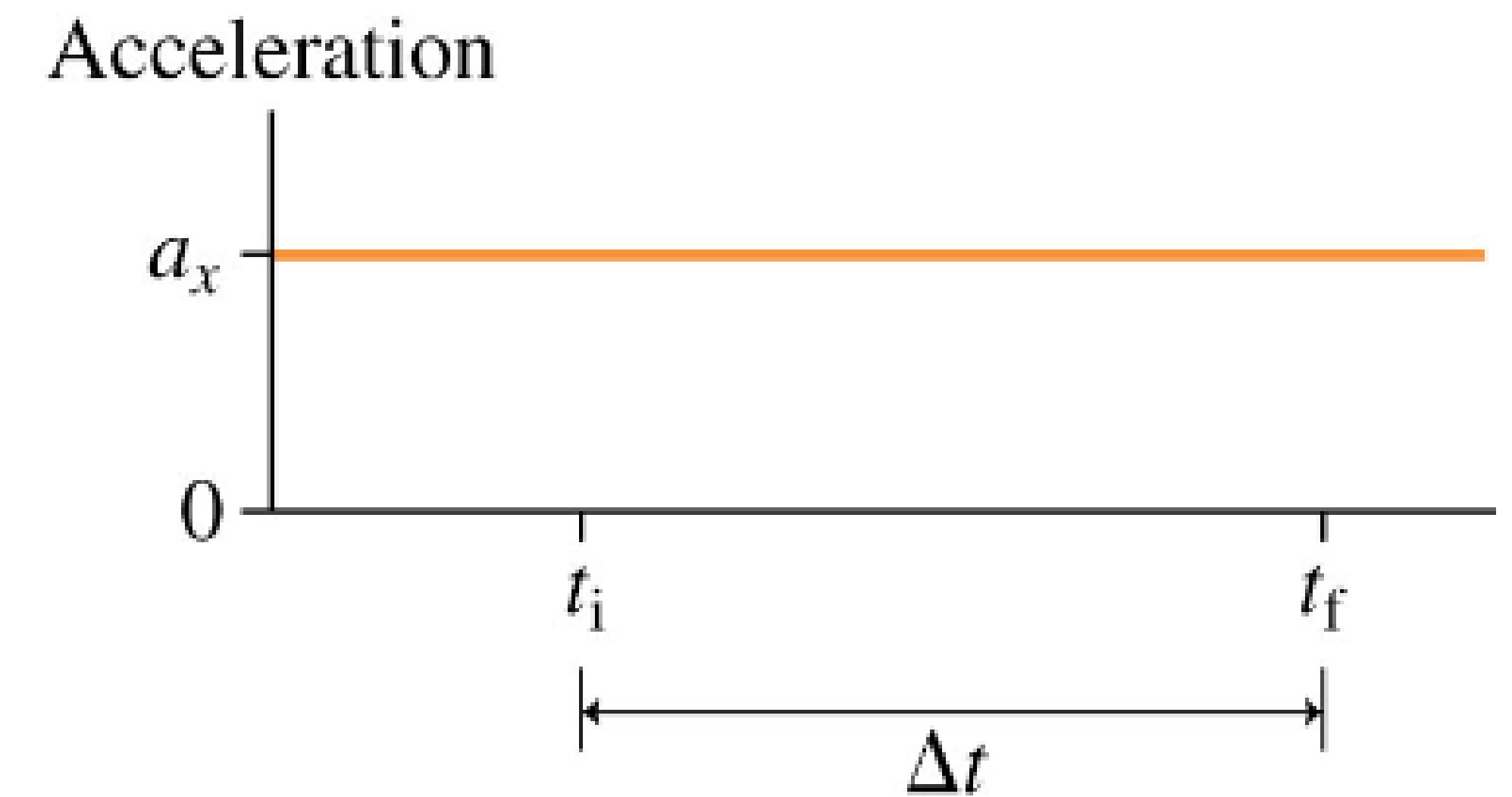
Deceleration is whenever the magnitude of the velocity is decreasing; the velocity and acceleration point in opposite directions when there is deceleration

عند تغيير اتجاه
الحركة تغير
إشارة السرعة

الحركة عند عجلة ثابتة

2-5 Motion at Constant Acceleration

For motion with **constant acceleration**



First basic equation

When the acceleration is constant, the **average and instantaneous accelerations** are **equal**

$$a = a_{\text{avg}} = \frac{v - v_0}{t - 0}$$

$$v = v_0 + at$$

Second basic equation

$$x - x_0 = v_0 t + \frac{1}{2} at^2$$

$$v = v_0 + at$$

[$a = \text{constant}$]

$$x = x_0 + v_0 t + \frac{1}{2} at^2$$

[$a = \text{constant}$]

$$v^2 = v_0^2 + 2a(x - x_0)$$

[$a = \text{constant}$]

$$\bar{v} = \frac{v + v_0}{2}$$

[$a = \text{constant}$]

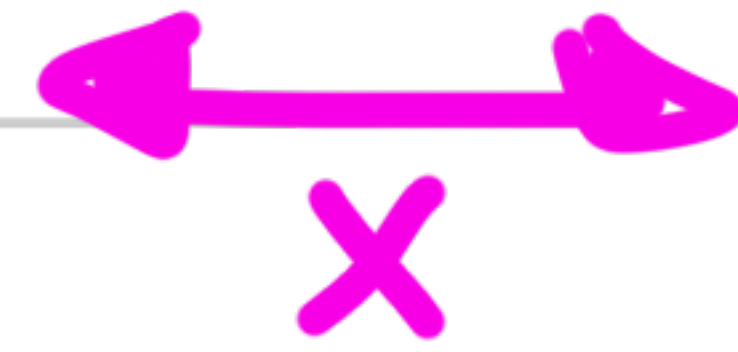
Third basic equation

$$v^2 = v_0^2 + 2a(x - x_0)$$

Equations of motion in 1D

في حالة العجله
ثابتة

$$① \quad v = v_0 + a t$$



v سرعة نهائية

$$② \quad \Delta x = v_0 t + \frac{1}{2} a t^2$$

v سرعة ابتدائية

$$③ \quad v^2 = v_0^2 + 2a \Delta x$$

a عجله

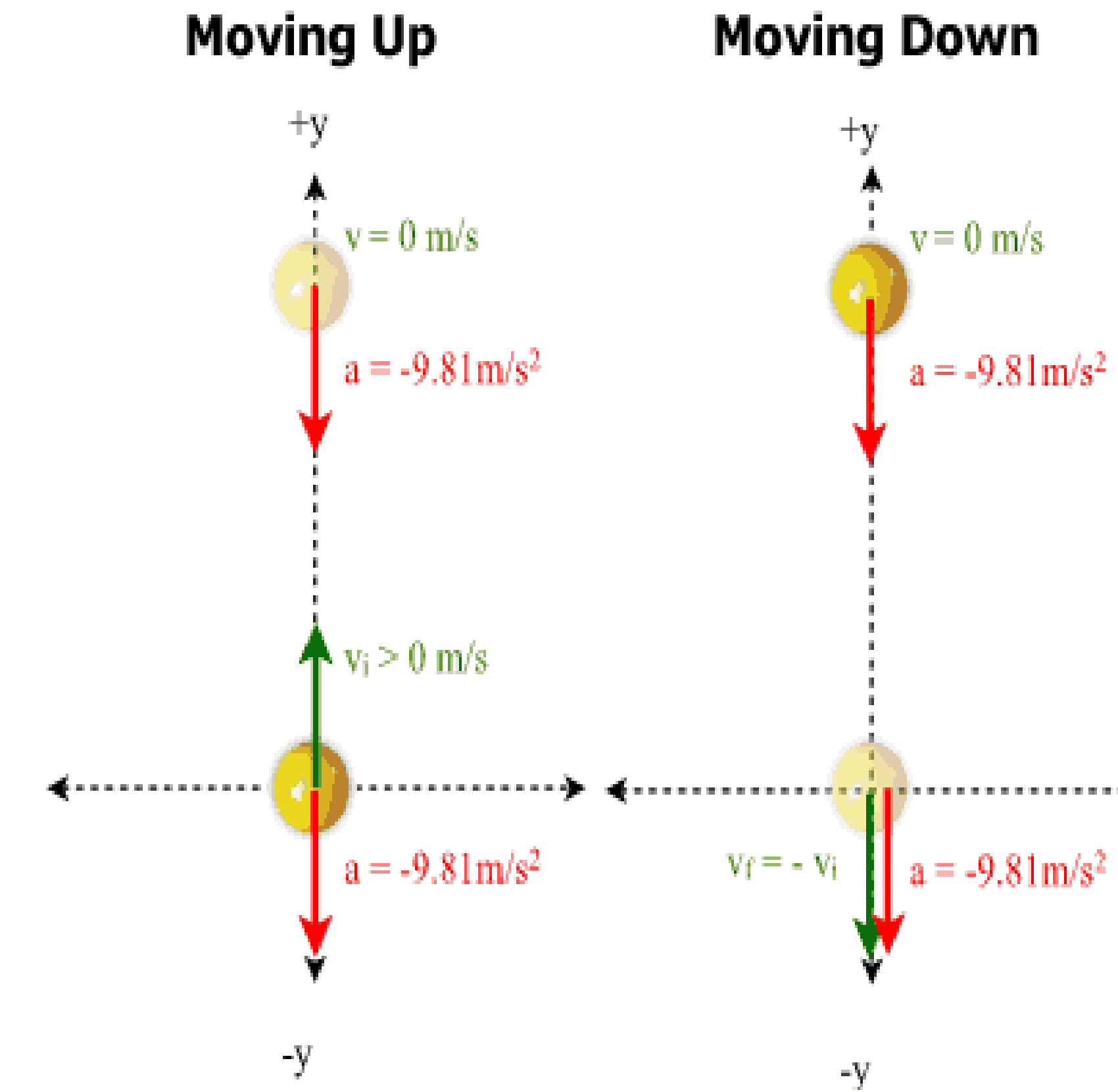
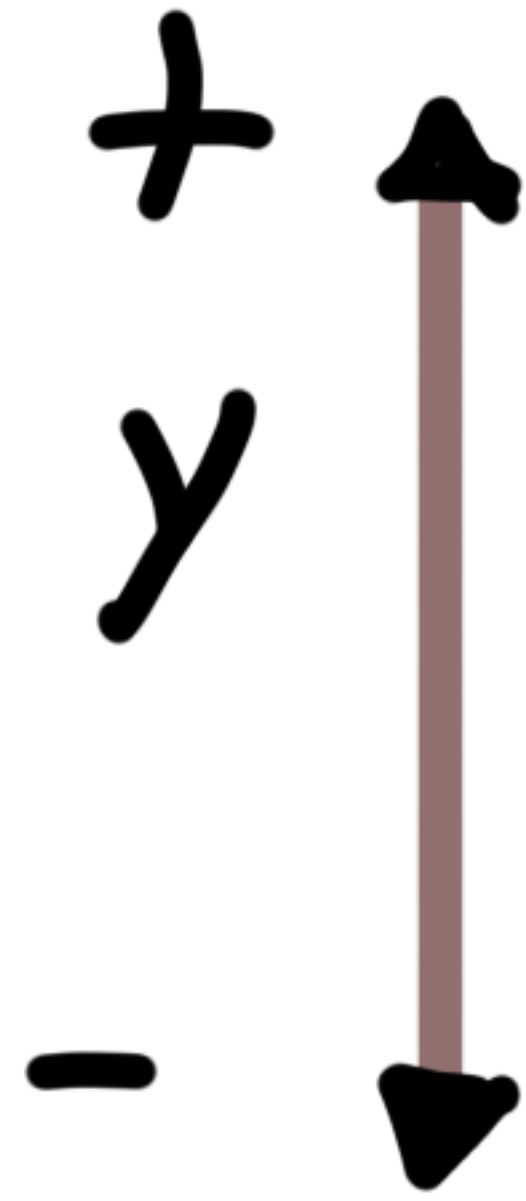
$$\bar{v} = \frac{v_f + v_i}{2}$$

Δx المسافة

السقوط الحر

2-7 Freely Falling objects

- Free fall is the motion of an object in which it is affected only by the **influence of gravity**.
- Acceleration due to gravity $g = 9.8 \text{ m/s}^2$.
- In the absence of air resistance **all objects (independent of mass, size, shape)** fall to earth with constant acceleration pointing downwards.
- If the object is moving upward, its velocity at highest point of its motion is Zero.
- If the object is dropped, its initial velocity is zero.



$$v = v_0 - gt$$

$$v = gt$$

$$\Delta y = \Delta x = v_0 t - \frac{1}{2} g t^2$$

$$\Delta x = \frac{1}{2} g t^2$$

$$v^2 = v_0^2 - 2g \Delta x$$

$$v^2 = 2g \Delta x$$

Δy

$$a = g = 9.8 \frac{\text{m}}{\text{s}^2}$$

$$+9.8 \frac{\text{m}}{\text{s}^2}$$

$$-9.8 \frac{\text{m}}{\text{s}^2}$$

$$v \uparrow \downarrow g$$

$$+ \downarrow \downarrow 9.8 \frac{\text{m}}{\text{s}^2}$$

Very important Notes

انفرتوئے
الہ جیو

① rest or Dropped $\rightarrow v_0 = 0$

② max height or object stop $\rightarrow v = 0$

③ uniform velocity or const acceleration
 $\rightarrow a = 0$

Example Problem 2-10

كم البعد

EXAMPLE 2-10 **Falling from a tower.** Suppose that a ball is dropped ($v_0 = 0$) from a tower. How far will it have fallen after a time $t_1 = 1.00$ s, $t_2 = 2.00$ s, and $t_3 = 3.00$ s? Ignore air resistance.

APPROACH Let us take y as positive downward, so the acceleration is $a = g = +9.80$ m/s². We set $v_0 = 0$ and $y_0 = 0$. We want to find the position y of the ball after three different time intervals. Equation 2-11b, with x replaced by y , relates the given quantities (t , a , and v_0) to the unknown y .

SOLUTION We set $t = t_1 = 1.00$ s in Eq. 2-11b:

$$\begin{aligned} y_1 &= v_0 t_1 + \frac{1}{2} a t_1^2 \\ &= 0 + \frac{1}{2} a t_1^2 = \frac{1}{2} (9.80 \text{ m/s}^2) (1.00 \text{ s})^2 = 4.90 \text{ m.} \end{aligned}$$

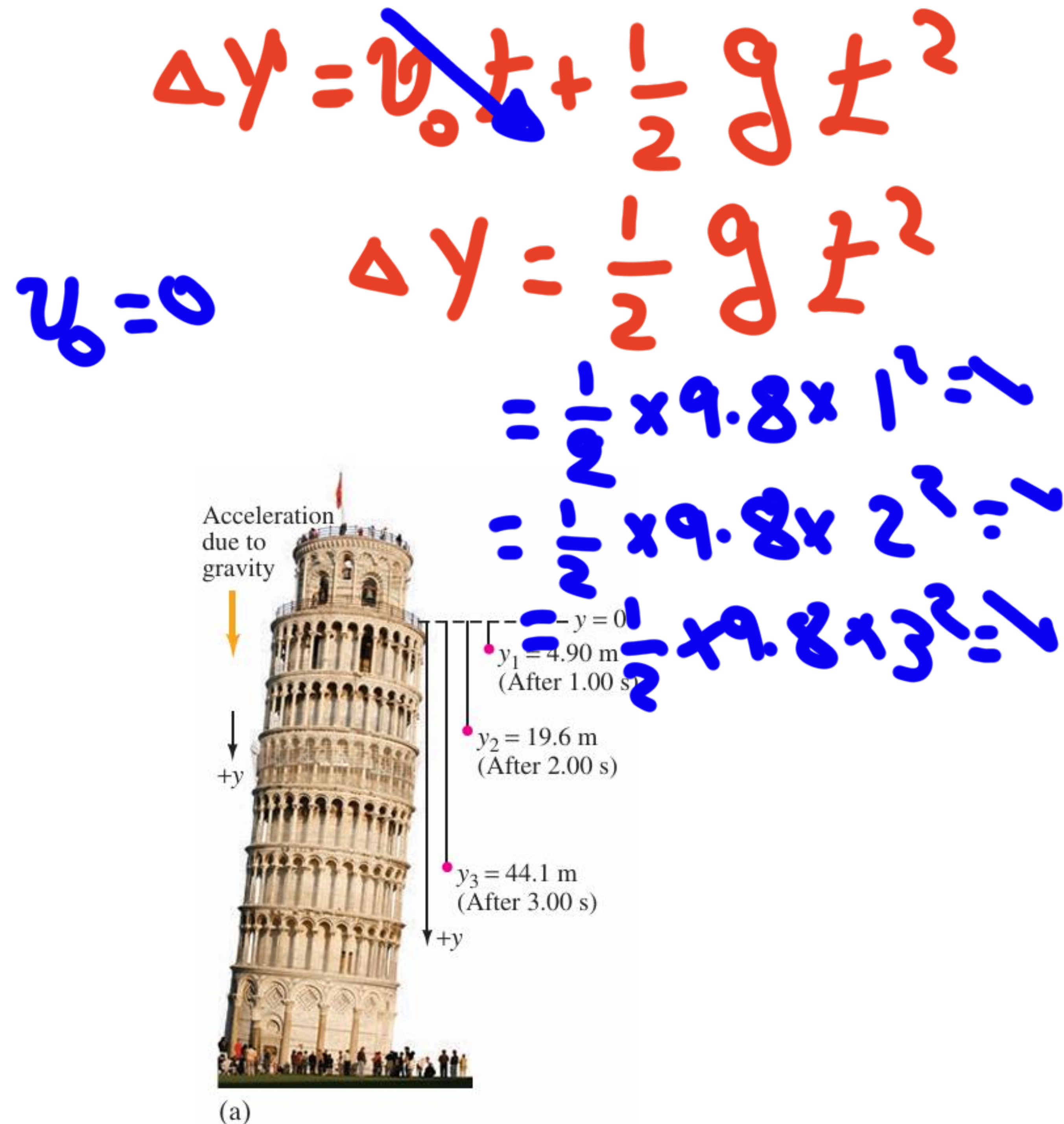
The ball has fallen a distance of 4.90 m during the time interval $t = 0$ to $t_1 = 1.00$ s. Similarly, after 2.00 s ($= t_2$), the ball's position is

$$y_2 = \frac{1}{2} a t_2^2 = \frac{1}{2} (9.80 \text{ m/s}^2) (2.00 \text{ s})^2 = 19.6 \text{ m.}$$

Finally, after 3.00 s ($= t_3$), the ball's position is (see Fig. 2-22)

$$y_3 = \frac{1}{2} a t_3^2 = \frac{1}{2} (9.80 \text{ m/s}^2) (3.00 \text{ s})^2 = 44.1 \text{ m.}$$

NOTE Whenever we say “dropped,” it means $v_0 = 0$. Note also the graph of y vs. t (Fig. 2-22b): the curve is not straight but bends upward because y is proportional to t^2 .



Example Problem 2-11

EXAMPLE 2-11 **Thrown down from a tower.** Suppose the ball in Example 2-10 is *thrown* downward with an initial velocity of 3.00 m/s, instead of being dropped. (a) What then would be its position after 1.00 s and 2.00 s? (b) What would its speed be after 1.00 s and 2.00 s? Compare with the speeds of a dropped ball. $v_0 = 0$

APPROACH Again we use Eq. 2-11b, but now v_0 is not zero, it is $v_0 = 3.00$ m/s.

SOLUTION (a) At $t_1 = 1.00$ s, the position of the ball as given by Eq. 2-11b is

$$y = v_0 t + \frac{1}{2} a t^2 = (3.00 \text{ m/s})(1.00 \text{ s}) + \frac{1}{2} (9.80 \text{ m/s}^2)(1.00 \text{ s})^2 = 7.90 \text{ m}.$$

At $t_2 = 2.00$ s (time interval $t = 0$ to $t = 2.00$ s), the position is

$$y = v_0 t + \frac{1}{2} a t^2 = (3.00 \text{ m/s})(2.00 \text{ s}) + \frac{1}{2} (9.80 \text{ m/s}^2)(2.00 \text{ s})^2 = 25.6 \text{ m}.$$

As expected, the ball falls farther each second than if it were dropped with $v_0 = 0$.

(b) The velocity is obtained from Eq. 2-11a:

$$\begin{aligned} v &= v_0 + at \\ &= 3.00 \text{ m/s} + (9.80 \text{ m/s}^2)(1.00 \text{ s}) = 12.8 \text{ m/s} \quad [\text{at } t_1 = 1.00 \text{ s}] \\ &= 3.00 \text{ m/s} + (9.80 \text{ m/s}^2)(2.00 \text{ s}) = 22.6 \text{ m/s}. \quad [\text{at } t_2 = 2.00 \text{ s}] \end{aligned}$$

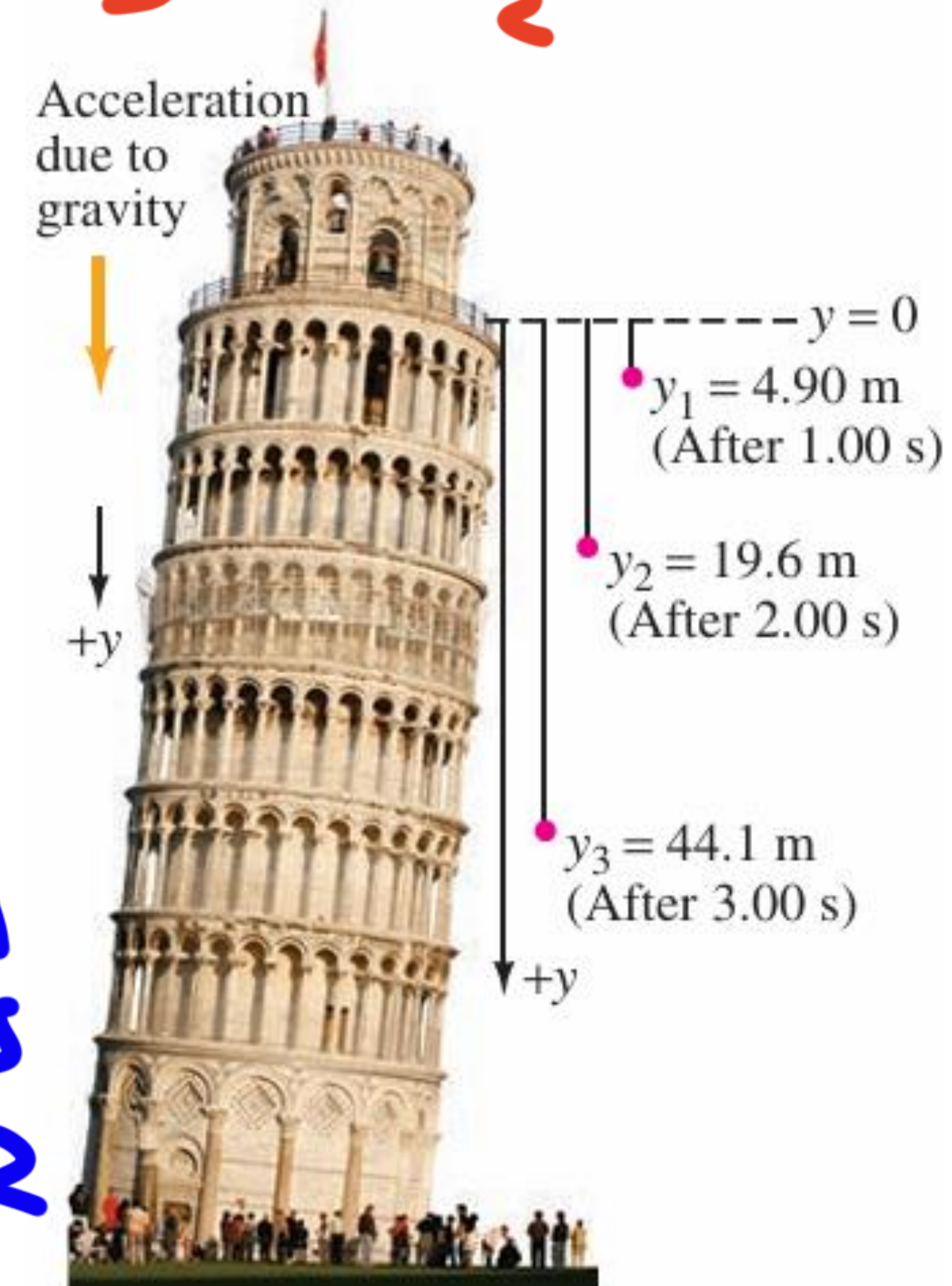
In Example 2-10, when the ball was *dropped* ($v_0 = 0$), the first term (v_0) in these equations was zero, so

$$\begin{aligned} v &= 0 + at \\ &= (9.80 \text{ m/s}^2)(1.00 \text{ s}) = 9.80 \text{ m/s} \quad [\text{at } t_1 = 1.00 \text{ s}] \\ &= (9.80 \text{ m/s}^2)(2.00 \text{ s}) = 19.6 \text{ m/s}. \quad [\text{at } t_2 = 2.00 \text{ s}] \end{aligned}$$

NOTE For both Examples 2-10 and 2-11, the speed increases linearly in time by 9.80 m/s during each second. But the speed of the downwardly thrown ball at any instant is always 3.00 m/s (its initial speed) higher than that of a dropped ball.

$$v_i = 3 \text{ m/s}$$

$$\begin{aligned} \Delta y &= v_0 t + \frac{1}{2} g t^2 \\ &= 3 \times 1 + \frac{1}{2} \times 9.8 \times 1^2 \end{aligned}$$



(a)

$$\begin{aligned} v &= v_0 + g t \\ &= 0 + 9.8 \times 1 \\ &= 9.8 \text{ m/s} \\ v &= 0 + 9.8 \times 2 \\ &= 19.6 \frac{\text{m}}{\text{s}} \end{aligned}$$

Example Problem 2-12 $v \uparrow \downarrow g$

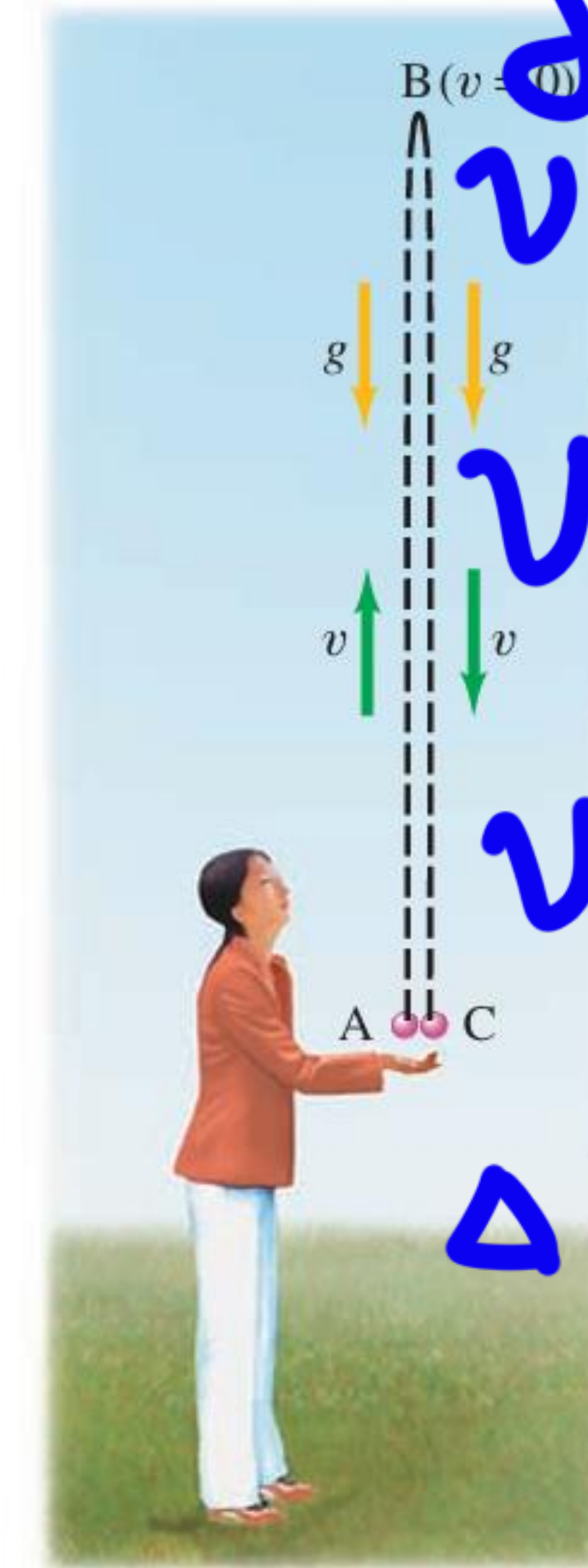
EXAMPLE 2-12 **Ball thrown upward.** A person throws a ball *upward* into the air with an initial velocity of 15.0 m/s. Calculate how high it goes. Ignore air resistance.

APPROACH We are not concerned here with the throwing action, but only with the motion of the ball *after* it leaves the thrower's hand (Fig. 2-23) and until it comes back to the hand again. Let us choose y to be positive in the upward direction and negative in the downward direction. (This is a different convention from that used in Examples 2-10 and 2-11, and so illustrates our options.) The acceleration due to gravity is downward and so will have a negative sign, $a = -g = -9.80 \text{ m/s}^2$. As the ball rises, its speed decreases until it reaches the highest point (B in Fig. 2-23), where its speed is zero for an instant; then it descends, with increasing speed.

SOLUTION We consider the time interval from when the ball leaves the thrower's hand until the ball reaches the highest point. To determine the maximum height, we calculate the position of the ball when its velocity equals zero ($v = 0$ at the highest point). At $t = 0$ (point A in Fig. 2-23) we have $y_0 = 0$, $v_0 = 15.0 \text{ m/s}$, and $a = -9.80 \text{ m/s}^2$. At time t (maximum height), $v = 0$, $a = -9.80 \text{ m/s}^2$, and we wish to find y . We use Eq. 2-11c, replacing x with y : $v^2 = v_0^2 + 2ay$. We solve this equation for y :

$$y = \frac{v^2 - v_0^2}{2a} = \frac{0 - (15.0 \text{ m/s})^2}{2(-9.80 \text{ m/s}^2)} = 11.5 \text{ m.}$$

The ball reaches a height of 11.5 m above the hand.



$$\begin{aligned} v_i &= 15 \frac{\text{m}}{\text{s}} \\ \Delta y &= ??? \\ g &= -9.8 \sim 15^2 \\ v &= 0 \\ v^2 &= v_0^2 + 2a \Delta y \\ v^2 - v_0^2 &= 2a \Delta y \\ \Delta y &= \frac{v^2 - v_0^2}{2a} \\ &= \frac{0^2 - 15^2}{2(-9.8)} = 11.5 \text{ m} \end{aligned}$$

Example Problem 2-13

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EXAMPLE 2-13 **Ball thrown upward, II.** In Fig. 2-23, Example 2-12, how long is the ball in the air before it comes back to the hand?

APPROACH We need to choose a time interval to calculate how long the ball is in the air before it returns to the hand. We could do this calculation in two parts by first determining the time required for the ball to reach its highest point, and then determining the time it takes to fall back down. However, it is simpler to consider the time interval for the entire motion from A to B to C (Fig. 2-23) in one step and use Eq. 2-11b. We can do this because y is position or displacement, and not the total distance traveled. Thus, at both points A and C, $y = 0$.

SOLUTION We use Eq. 2-11b with $a = -9.80 \text{ m/s}^2$ and find

$$y = y_0 + v_0 t + \frac{1}{2} a t^2$$

$$0 = 0 + (15.0 \text{ m/s})t + \frac{1}{2}(-9.80 \text{ m/s}^2)t^2.$$

This equation can be factored (we factor out one t):

$$(15.0 \text{ m/s} - 4.90 \text{ m/s}^2 t)t = 0.$$

There are two solutions:

$$t = 0 \quad \text{and} \quad t = \frac{15.0 \text{ m/s}}{4.90 \text{ m/s}^2} = 3.06 \text{ s}.$$

The first solution ($t = 0$) corresponds to the initial point (A) in Fig. 2-23, when the ball was first thrown from $y = 0$. The second solution, $t = 3.06 \text{ s}$, corresponds to point C, when the ball has returned to $y = 0$. Thus the ball is in the air 3.06 s.

NOTE We have ignored air resistance in these last two Examples, which could be significant, so our result is only an approximation to a real, practical situation.

$$\Delta y = 0$$

$$\Delta y = y_f - y_i = 0$$

$$\Delta y = v_0 t + \frac{1}{2} g t^2$$

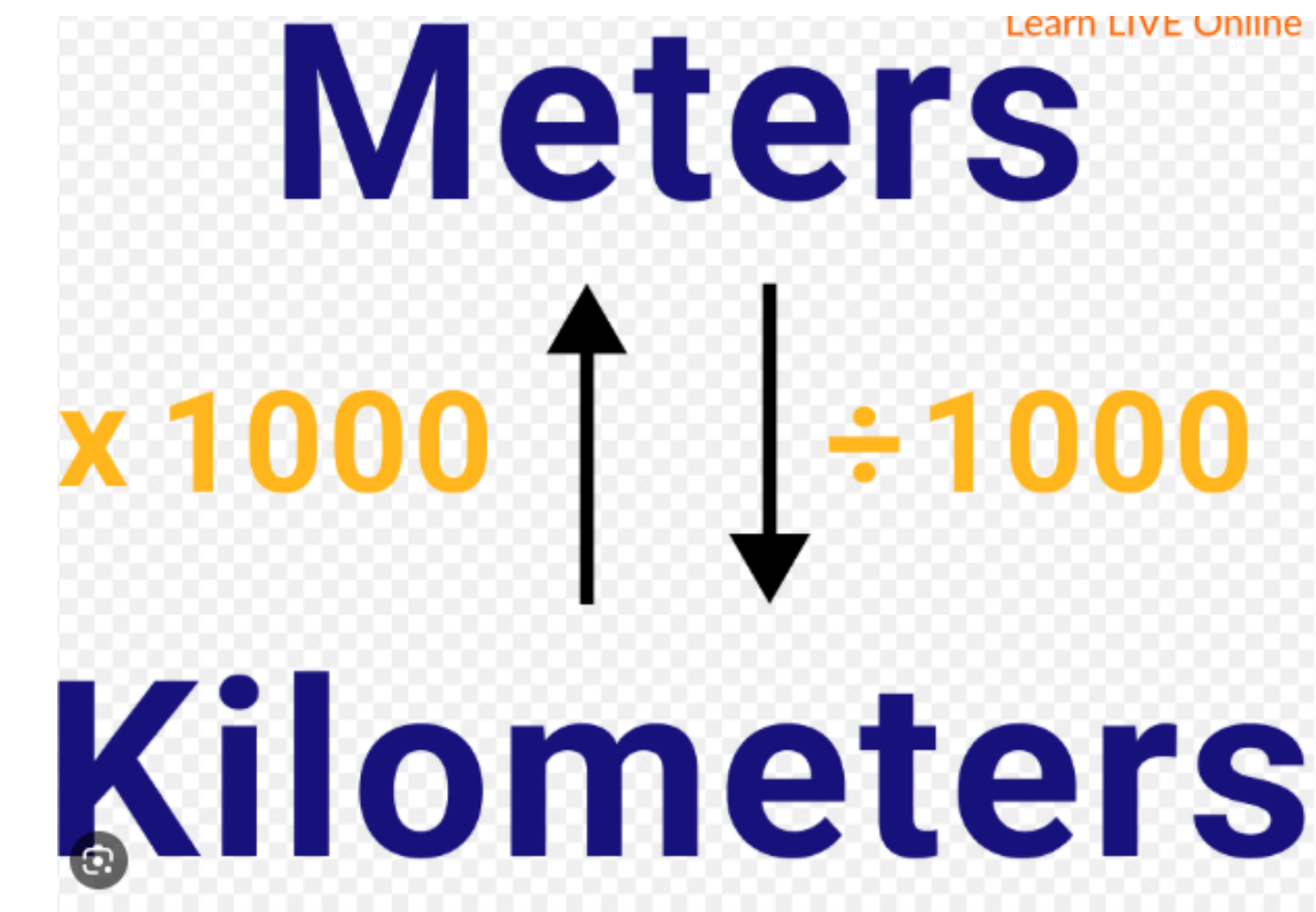
$$0 = 15 t + \frac{1}{2} (-9.8) t^2$$

$$\frac{1}{2} \times 9.8 t^2 = 15 t$$

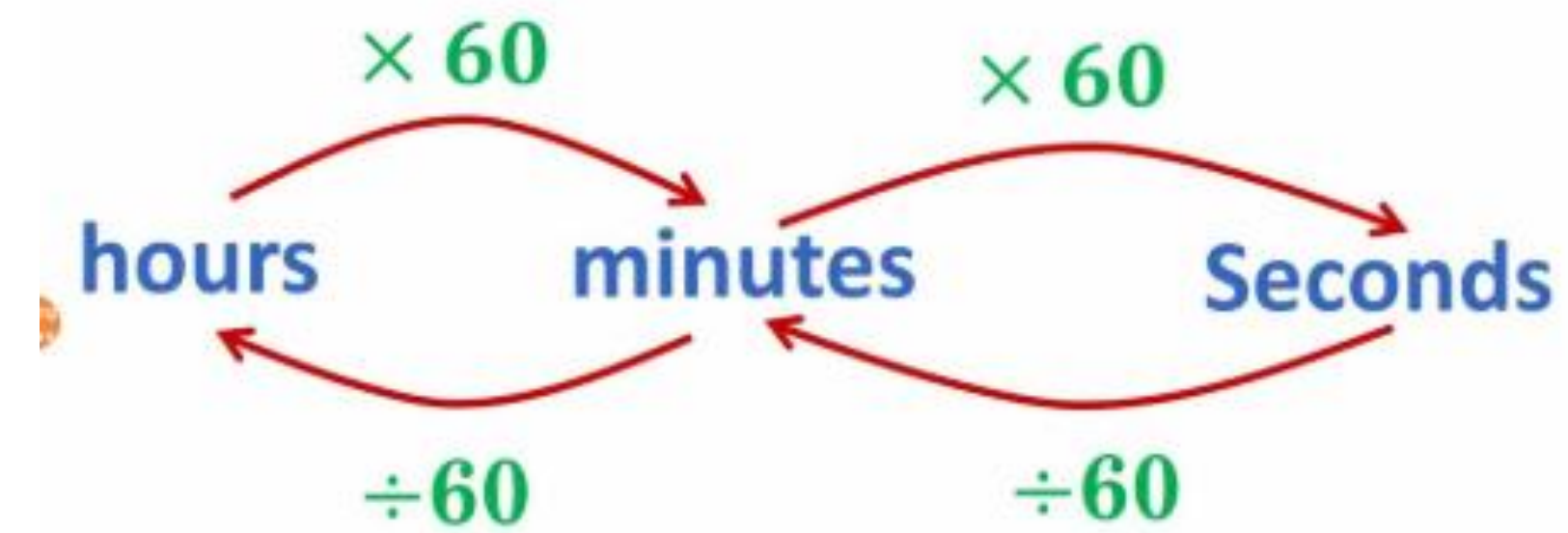
$$\frac{1}{2} \times 9.8 t = 15$$

$$t = 15 \times \frac{2}{9.8} = 3.06 \text{ sec}$$

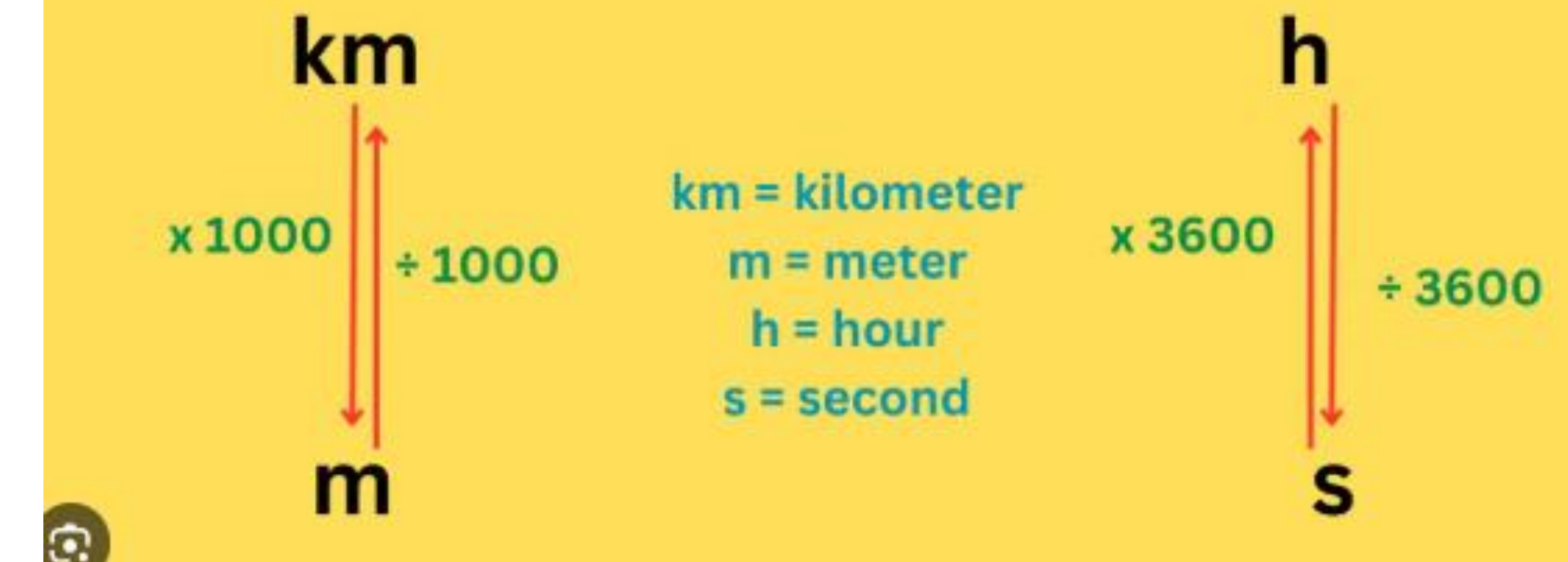




Converting Units of Time



How to Convert km/h to m/s



Kilometer [km]	Meter [m]
1 km	1000 m
2 km	2000 m
3 km	3000 m
5 km	5000 m
10 km	10000 m
20 km	20000 m
50 km	50000 m
100 km	100000 m

Convert 2.67 hours into seconds

$$\frac{2.67 \cancel{\text{h}}}{1} \times \frac{60 \text{ min}}{1 \cancel{\text{h}}} \times \frac{60 \text{ s}}{1 \text{ min}}$$

km/hr to m/s conversion:

$$1 \text{ kmph} = \frac{5}{18} \text{ m/s}$$

$$15 \frac{\cancel{\text{km}}}{\cancel{\text{h}}} \times \frac{1000 \text{ m}}{\cancel{1 \text{ km}}} \times \frac{\cancel{1 \text{ h}}}{60 \cancel{\text{ min}}} \times \frac{\cancel{1 \text{ min}}}{60 \text{ sec}}$$

$$15 \times 1000 \times \frac{1}{60} \times \frac{1}{60} = 4.16 \frac{\text{m}}{\text{s}}$$

