Chapter 2

Kinematics in One Dimension

Kinematics deals with the concepts that are needed to describe motion.

Dynamics deals with the effect that forces have on motion.

Together, kinematics and dynamics form the branch of physics known as ***Mechanics.***

2.0 Definitions

Speed v : is a positive scalar
Velocity $\vec{\mathbf{v}}$: is a vector.
} Instantaneous - at a time t.

Magnitude of the velocity vector is the speed, v .

Direction - for projectiles (2 or 3D), direction is an angle.

- for motion along a line (1D), direction is a sign.

$$\vec{\mathbf{v}} = +v \quad \text{or} \quad \vec{\mathbf{v}} = -v$$

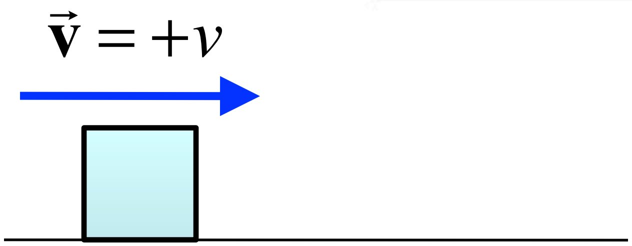
2.0 Definitions, continued

In Chapter 2: All motion is along a line. It could be horizontal (cars, boats, humans), or vertical (acceleration due to gravity)

MUST decide which direction is going to be POSITIVE

1D Examples:

Sliding block



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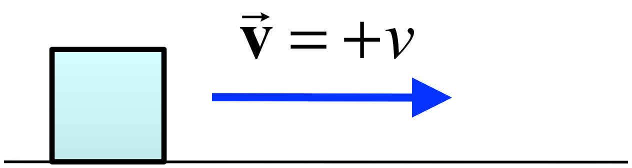
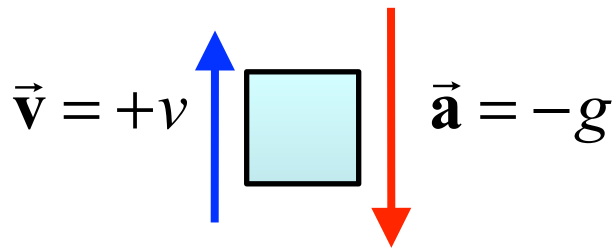


motion of block thrown upward



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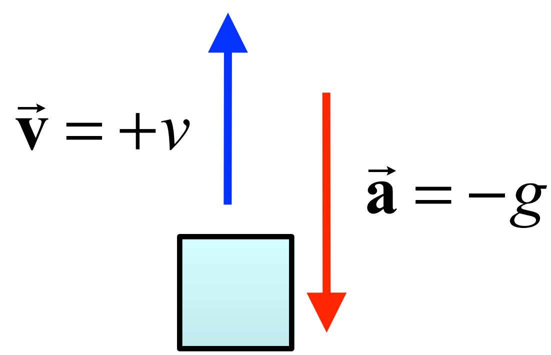


2.0 Definitions, continued

Moving: How can one tell if an object is moving at time, t ?

Look a little bitty time (ε) earlier, $t' = t - \varepsilon$,

or look a little bitty time (ε) later, $t' = t + \varepsilon$

and see if the object is at the same place.

If object is at the same place, it is not moving (stationary).

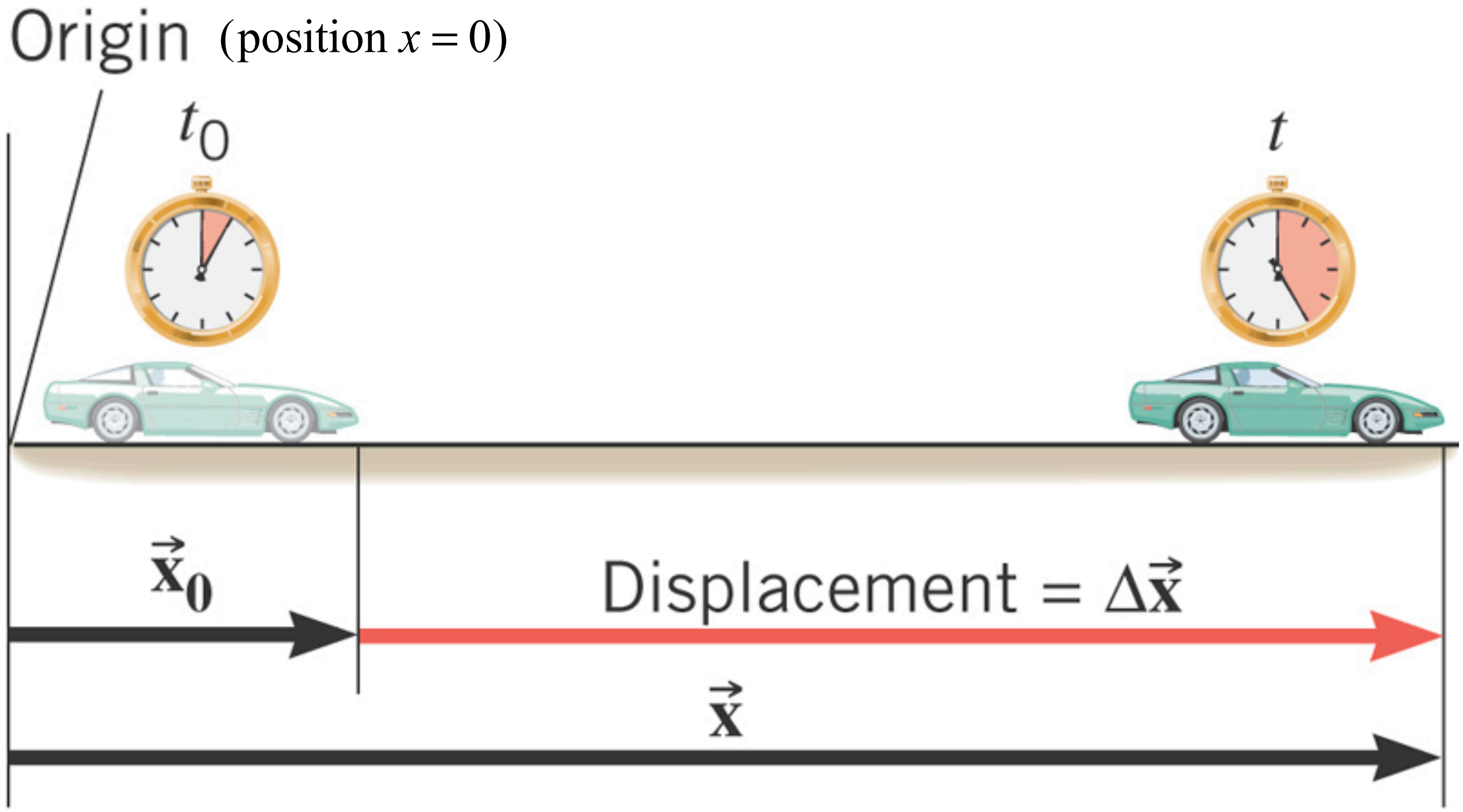
If object is NOT at the same place --- it is MOVING.

If an object is thrown upward, at the highest point

$v = 0$, instantaneously, but the object IS MOVING!

Turning around is motion, it is moving.

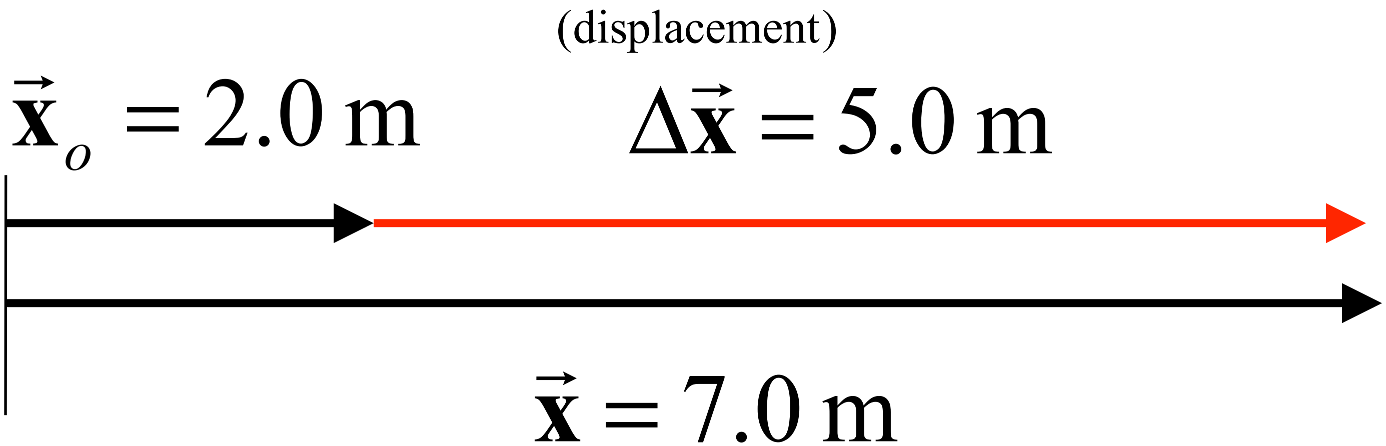
2.1 Displacement



$\vec{\mathbf{x}}_o =$ initial position (at $t = 0$) $\vec{\mathbf{x}} =$ final position

$$\Delta\vec{\mathbf{x}} = \vec{\mathbf{x}} - \vec{\mathbf{x}}_o = \text{displacement}$$

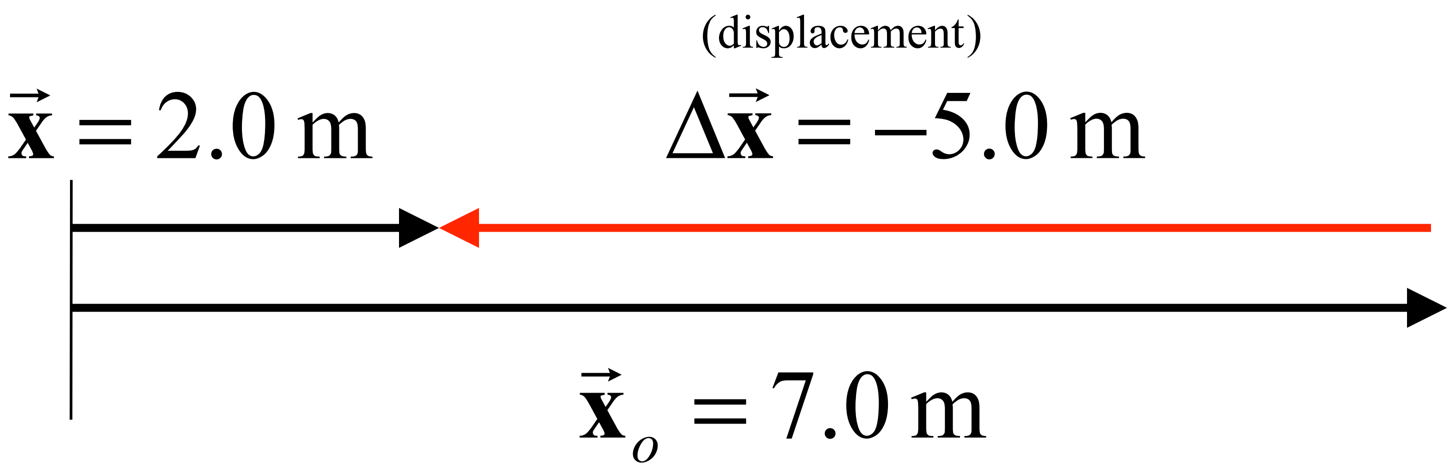
2.1 *Displacement*



$$\Delta\vec{\mathbf{x}} = \vec{\mathbf{x}} - \vec{\mathbf{x}}_o = 7.0\text{ m} - 2.0\text{ m} = 5.0\text{ m}$$

(Note: $\vec{\mathbf{x}}_0 + \Delta\vec{\mathbf{x}} = \vec{\mathbf{x}}$ initial position + displacement = final position)

2.1 Displacement



$$\Delta\vec{\mathbf{x}} = \vec{\mathbf{x}} - \vec{\mathbf{x}}_o = 2.0\ \text{m} - 7.0\ \text{m} = -5.0\ \text{m}$$

2.1 Displacement

$$\vec{\mathbf{x}}_o = -2.0\text{ m} \qquad \vec{\mathbf{x}} = 5.0\text{ m}$$

$$\Delta\vec{\mathbf{x}} = 7.0\text{ m}$$

(displacement)

$$\Delta\vec{\mathbf{x}} = \vec{\mathbf{x}} - \vec{\mathbf{x}}_o = 5.0\text{ m} - (-2.0)\text{m} = 7.0\text{ m}$$

2.2 Speed and Velocity

Average speed is the distance traveled divided by the time required to cover the distance.

$$\text{Average speed} = \frac{\text{Distance}}{\text{Elapsed time}}$$

SI units for speed: meters per second (m/s)

Example 1 Distance Run by a Jogger

How far does a jogger run in 1.5 hours (5400 s) if his average speed is 2.22 m/s?

$$\text{Average speed} = \frac{\text{Distance}}{\text{Elapsed time}}$$

$$\text{Distance} = (\text{Average speed})(\text{Elapsed time})$$

$$= (2.22\ \text{m/s})(5400\ \text{s}) = 12000\ \text{m}$$

Clicker Question 2.1

A jogger travels 1500 m at an average speed of 2.00 m/s. How long did it take to cover the distance ?

a) 300 seconds

b) 750 seconds

c) 3000 seconds

d) 1700 seconds

e) 10 minutes

Clicker Question 2.1

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a) 300 seconds

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e) 10 minutes

Average speed

$$\bar{v} = \frac{d \text{ (distance)}}{t \text{ (elapsed time)}}$$

$$t = \frac{d}{\bar{v}} = \frac{1500 \text{ m}}{2.00 \text{ m/s}} = 750 \text{ s}$$

2.2 Speed and Velocity

Average velocity is the displacement divided by the elapsed time.

$$\text{Average velocity} = \frac{\text{Displacement}}{\text{Elapsed time}}$$

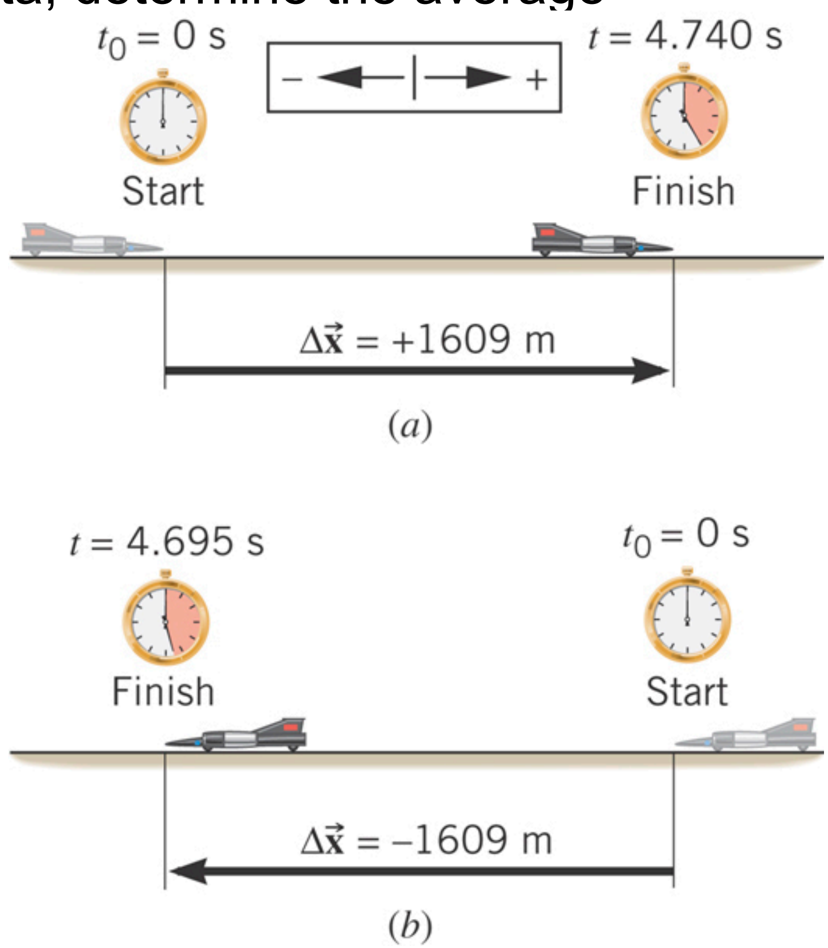
$$\overline{\vec{\mathbf{v}}} = \frac{\vec{\mathbf{x}} - \vec{\mathbf{x}}_o}{t - t_o} = \frac{\Delta\vec{\mathbf{x}}}{\Delta t}$$

A vector divided by a scalar is another vector
Note: division by a 2D or 3D vector is not allowed

2.2 *Speed and Velocity*

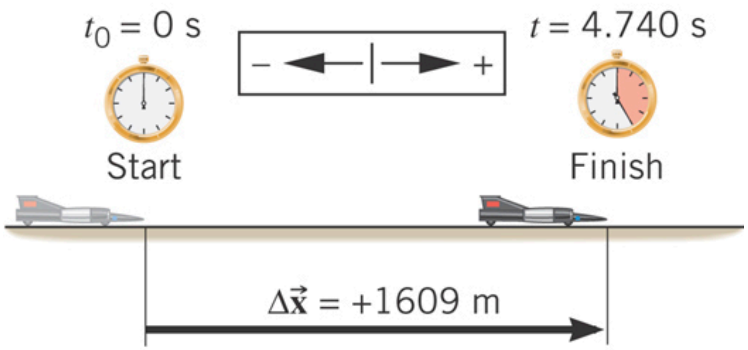
Example 2 The World's Fastest Jet-Engine Car

Andy Green in the car *ThrustSSC* set a world record of 341.1 m/s in 1997. To establish such a record, the driver makes two runs through the course, one in each direction, to nullify wind effects. From the data, determine the average velocity for each run.



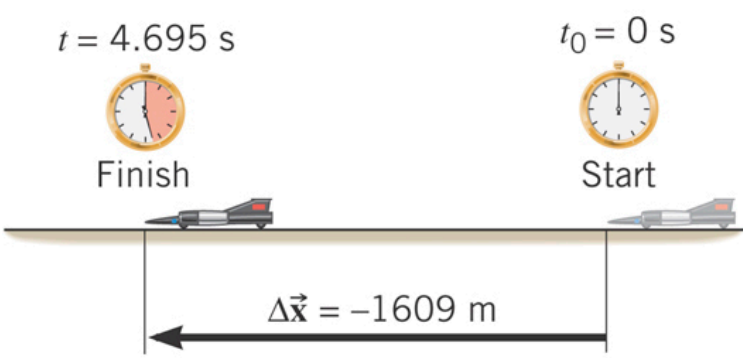
2.2 Speed and Velocity

$$\bar{\vec{\mathbf{v}}} = \frac{\Delta \vec{\mathbf{x}}}{\Delta t} = \frac{+1609\ \text{m}}{4.740\ \text{s}} = +339.5\ \text{m/s}$$



(a)

$$\bar{\vec{\mathbf{v}}} = \frac{\Delta \vec{\mathbf{x}}}{\Delta t} = \frac{-1609\ \text{m}}{4.695\ \text{s}} = -342.7\ \text{m/s}$$



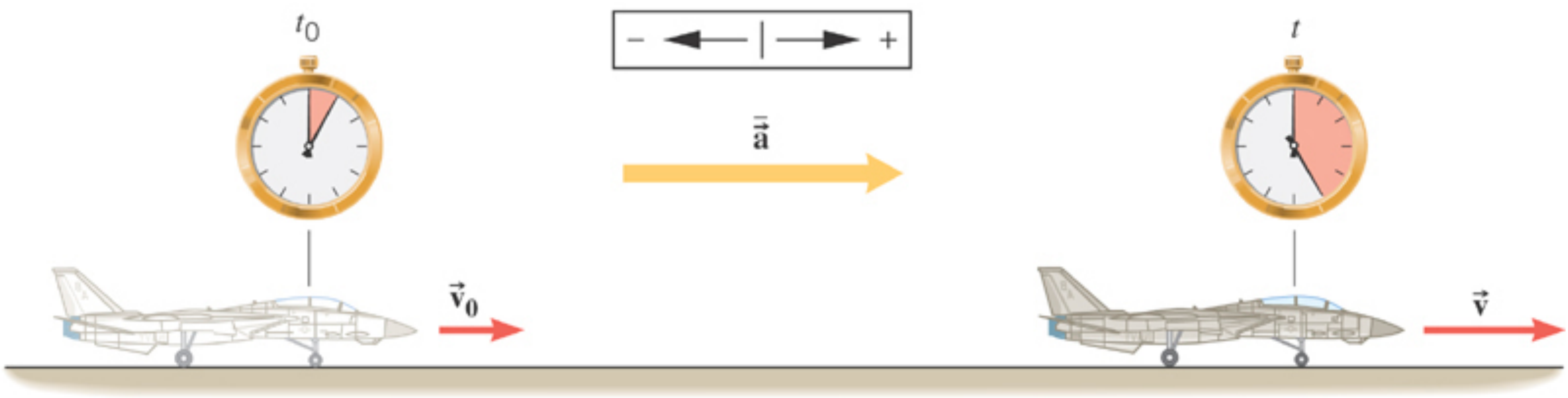
(b)

The ***instantaneous velocity*** indicates how fast the car moves and the direction of motion at each instant of time.

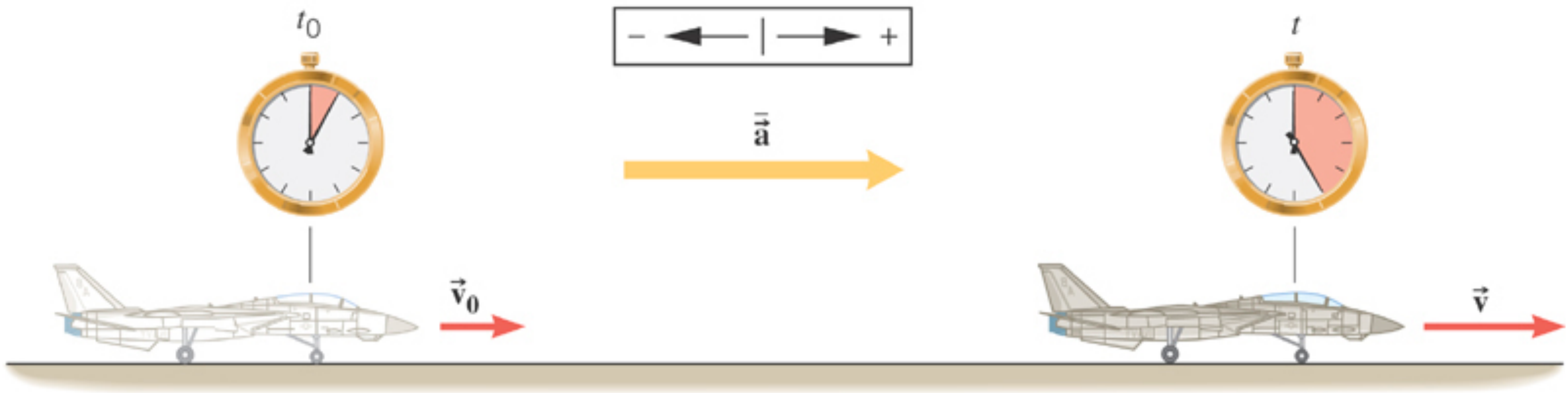
$$\vec{\mathbf{v}} = \lim_{\Delta t \to 0} \frac{\Delta \vec{\mathbf{x}}}{\Delta t}$$

2.3 Acceleration

The notion of *acceleration* emerges when a change in velocity is combined with the time during which the change occurs.



2.3 Acceleration

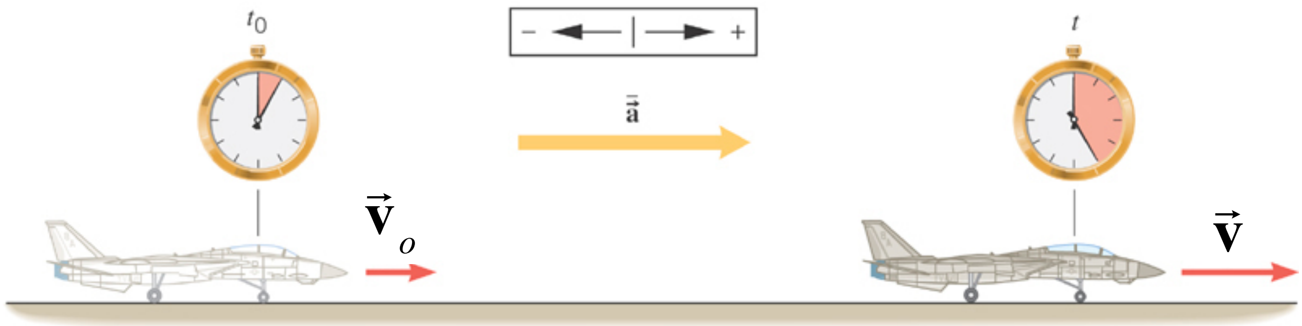


DEFINITION OF AVERAGE ACCELERATION

$$\bar{\vec{a}} = \frac{\vec{v} - \vec{v}_o}{t - t_o} = \frac{\Delta \vec{v}}{\Delta t}$$

$$\left(\begin{array}{l} \text{rate that velocity} \\ \text{is changing in time} \end{array} \right)$$

2.3 *Acceleration*



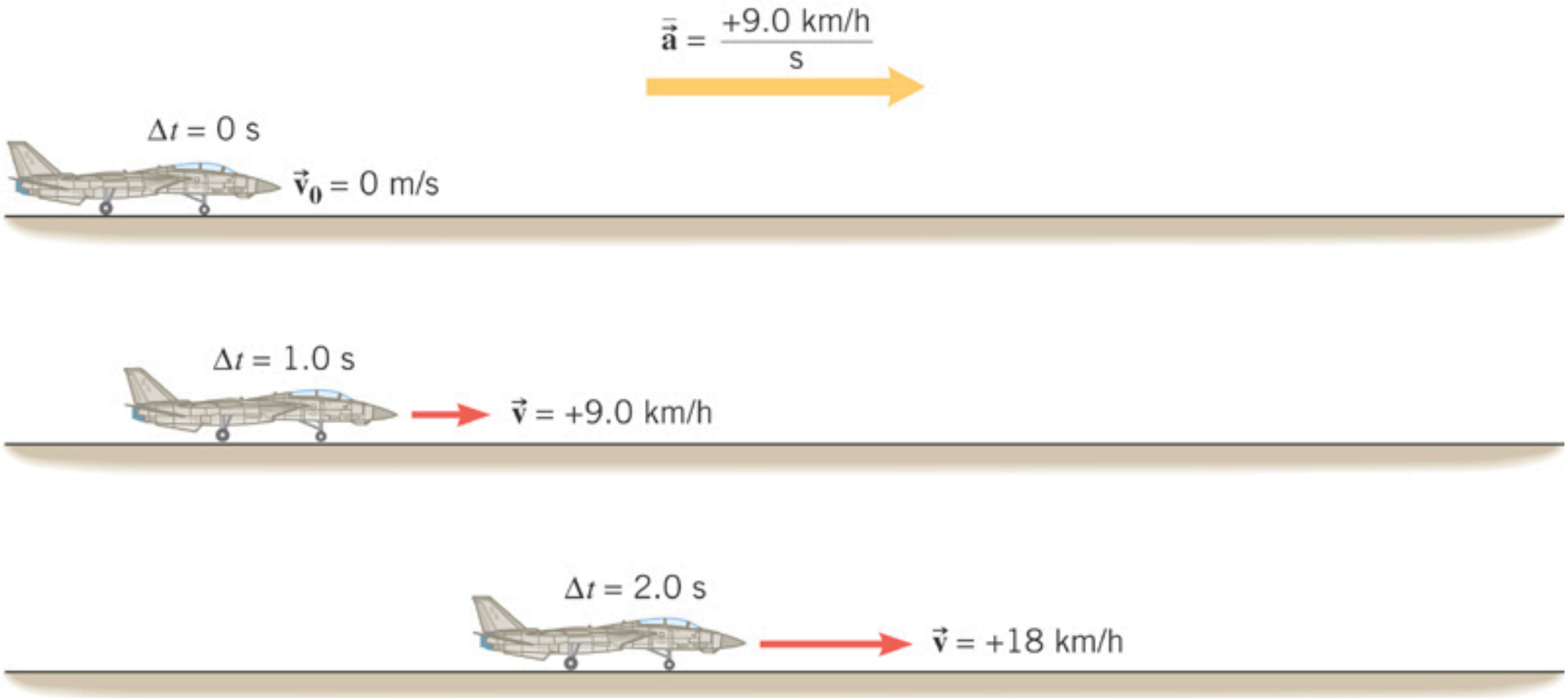
Example 3 Acceleration and Increasing Velocity

Determine the average acceleration of the plane.

$$\vec{\mathbf{v}}_o = 0\,\mathrm{m/s} \qquad \vec{\mathbf{v}} = 260\,\mathrm{km/h} \qquad t_o = 0\,\mathrm{s} \qquad t = 29\,\mathrm{s}$$

$$\bar{\vec{\mathbf{a}}} = \frac{\vec{\mathbf{v}} - \vec{\mathbf{v}}_o}{t - t_o} = \frac{260\,\mathrm{km/h} - 0\,\mathrm{km/h}}{29\ \mathrm{s} - 0\ \mathrm{s}} = +9.0\frac{\mathrm{km/h}}{\mathrm{s}}$$

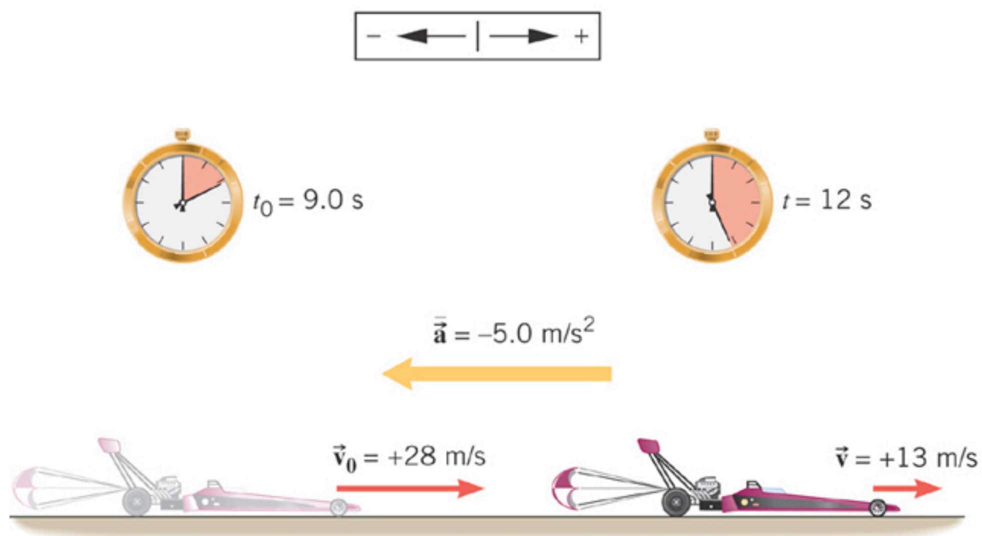
2.3 Acceleration



2.3 Acceleration

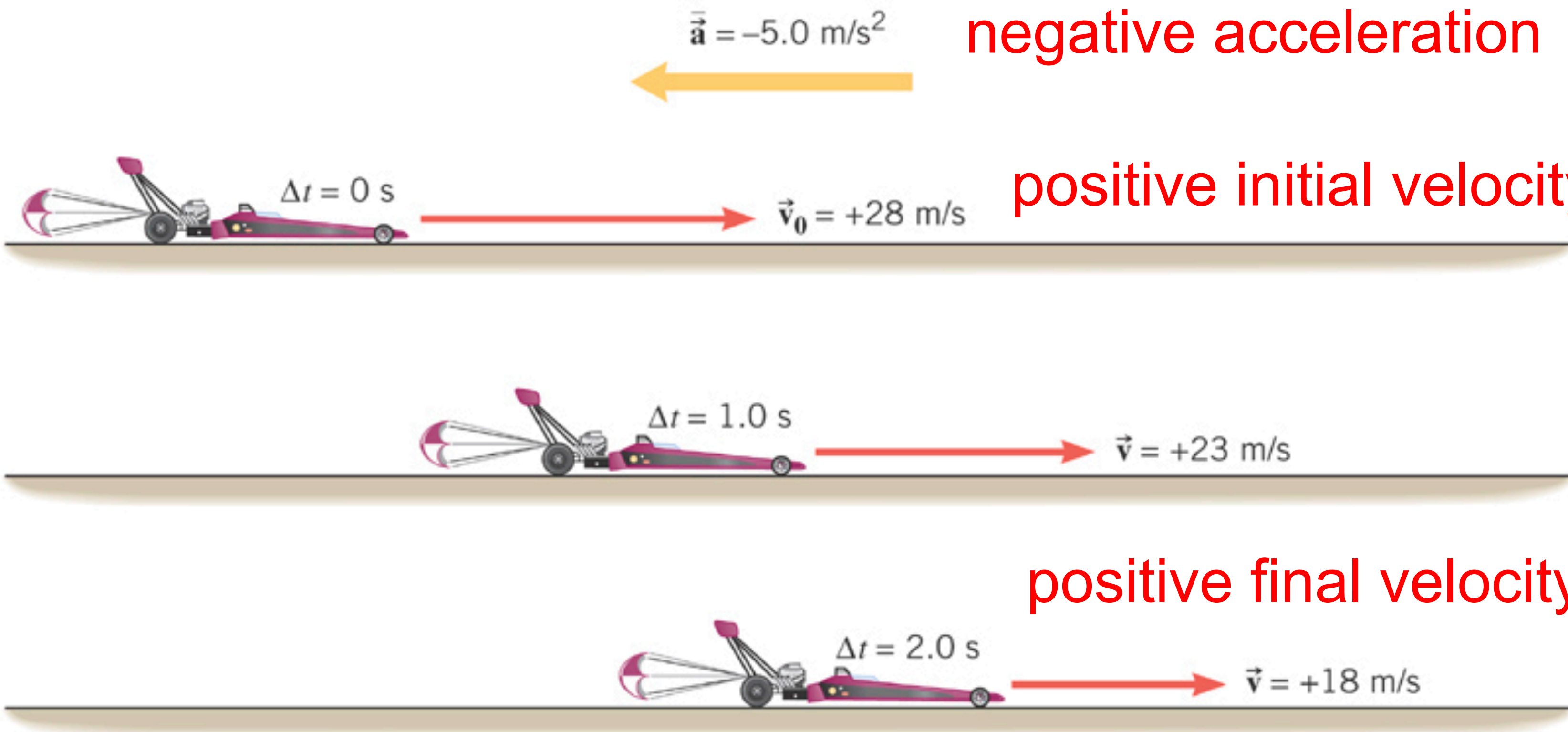
Example 3 Acceleration and Decreasing Velocity

$$\bar{\vec{\mathbf{a}}} = \frac{\vec{\mathbf{v}} - \vec{\mathbf{v}}_o}{t - t_o} = \frac{13\,\text{m/s} - 28\,\text{m/s}}{12\,\text{s} - 9\,\text{s}} = -5.0\,\text{m/s}^2$$



(b)

2.3 Acceleration



negative acceleration

positive initial velocity

positive final velocity

Acceleration was $\vec{\mathbf{a}} = -5.0\,\mathrm{m}/\mathrm{s}^2$ throughout the motion

2.4 *Equations of Kinematics for Constant Acceleration*

$$\bar{\vec{\mathbf{v}}} = \frac{\vec{\mathbf{x}} - \vec{\mathbf{x}}_o}{t - t_o} \qquad \bar{\vec{\mathbf{a}}} = \frac{\vec{\mathbf{v}} - \vec{\mathbf{v}}_o}{t - t_o}$$

For motion along a straight line

it is customary to dispense with the use of boldface symbols overdrawn with arrows for the displacement, velocity, and acceleration vectors. We will, however, continue to convey the directions with a plus or minus sign.

$$v = \frac{x - x_o}{t - t_o} \qquad a = \frac{v - v_o}{t - t_o}$$

a, v and v_o are STILL vectors (values will have + or – for direction)

2.4 Equations of Kinematics for Constant Acceleration

From now on unless stated otherwise

Let the object be at the origin when the clock starts.

$$x_o = 0 \quad \left(t_o = 0\right)$$

Simplifies things a great deal

$$\bar{v} = \frac{x - x_o}{t - t_o} \Rightarrow \bar{v} = \frac{x}{t}$$

$$x = \bar{v}t = \tfrac{1}{2}\left(v_o + v\right)t$$

Note: average is (initial + final)/2

2.4 Equations of Kinematics for Constant Acceleration

A constant acceleration can be measured at any time

$$a = \frac{v - v_o}{t - t_o} \quad \Rightarrow \quad a = \frac{v - v_o}{t}$$

$$\Downarrow$$

$$at = v - v_o$$

$$\Downarrow$$

$$v = v_o + at$$

2.4 Equations of Kinematics for Constant Acceleration

Five kinematic variables:

1. displacement, x

2. acceleration (constant), a

3. final velocity (at time *t*), v

4. initial velocity, v_0

5. elapsed time, t

2.4 Equations of Kinematics for Constant Acceleration

$$v = v_o + at$$

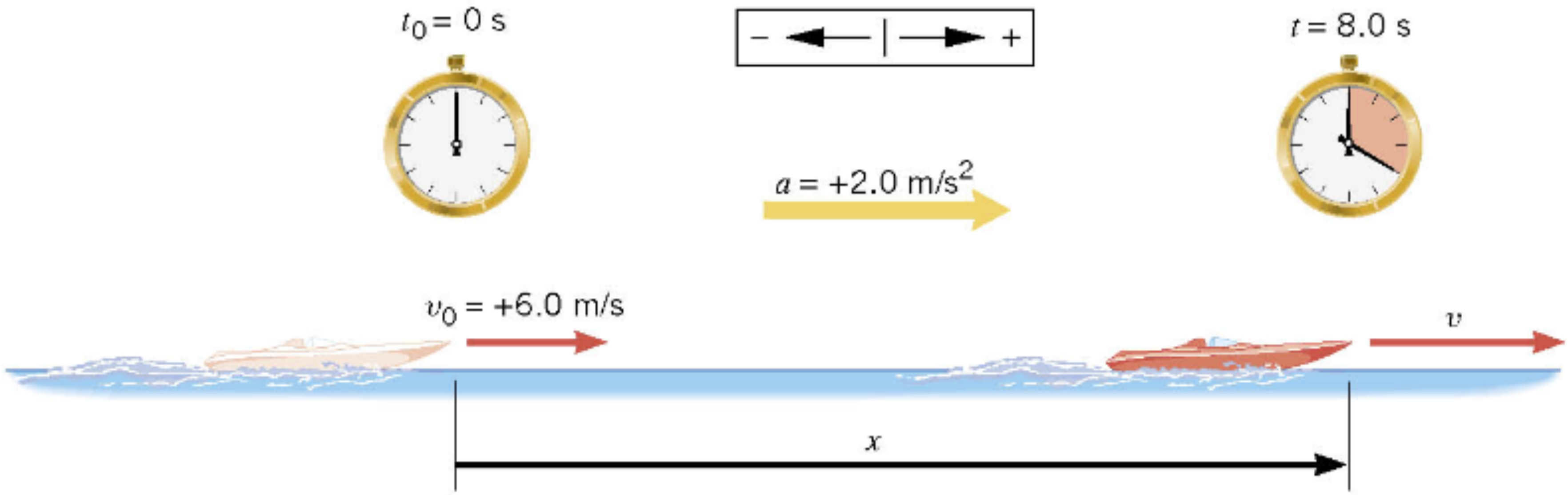
$$\downarrow$$

$$x = \tfrac{1}{2}\left(v_o + v\right)t = \tfrac{1}{2}\left(v_o + v_o + at\right)t$$

$$\Downarrow$$

$$x = v_o t + \tfrac{1}{2}at^2$$

2.4 Equations of Kinematics for Constant Acceleration



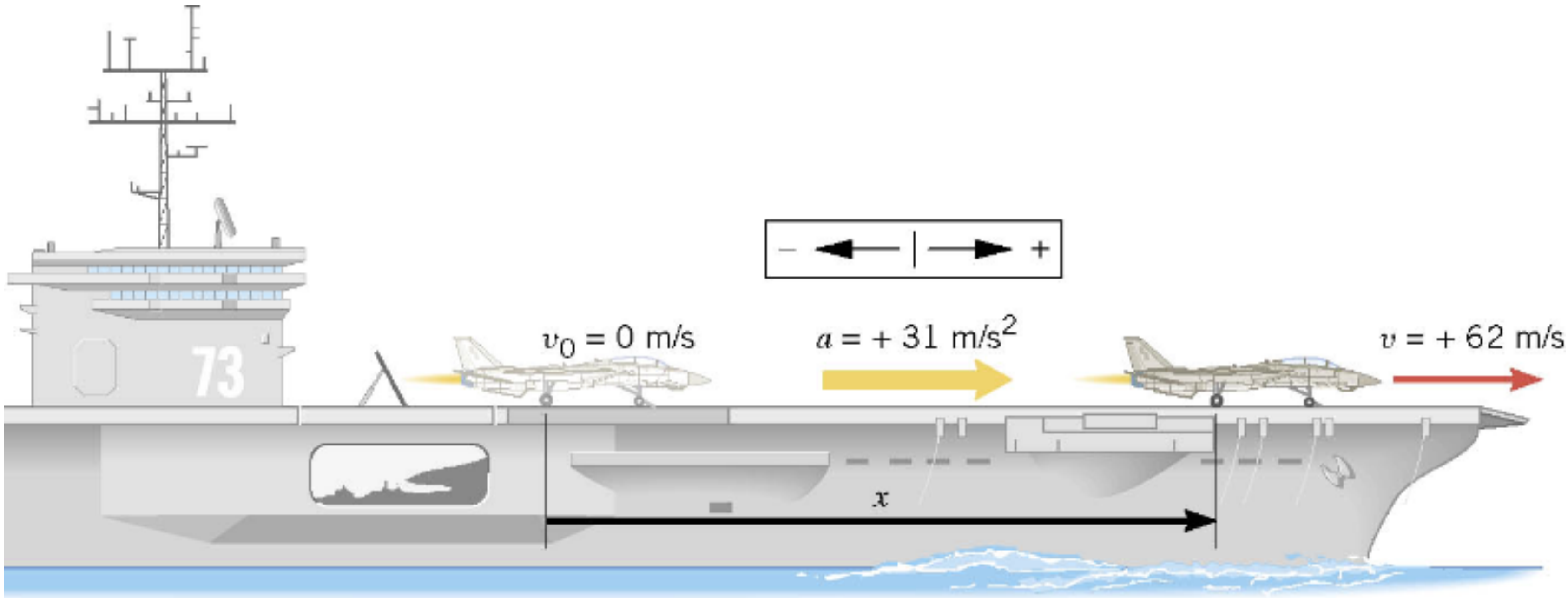
(b)

$$x = v_o t + \tfrac{1}{2} a t^2$$

$$= (6.0\,\text{m/s})(8.0\,\text{s}) + \tfrac{1}{2}(2.0\,\text{m/s}^2)(8.0\,\text{s})^2$$

$$= +110\,\text{m}$$

2.4 *Equations of Kinematics for Constant Acceleration*



(*b*)

Example 6 Catapulting a Jet

Find its displacement.

$$v_o = 0\,\text{m/s} \qquad a = +31\,\text{m/s}^2$$

$$x = ?? \qquad v = +62\,\text{m/s}$$

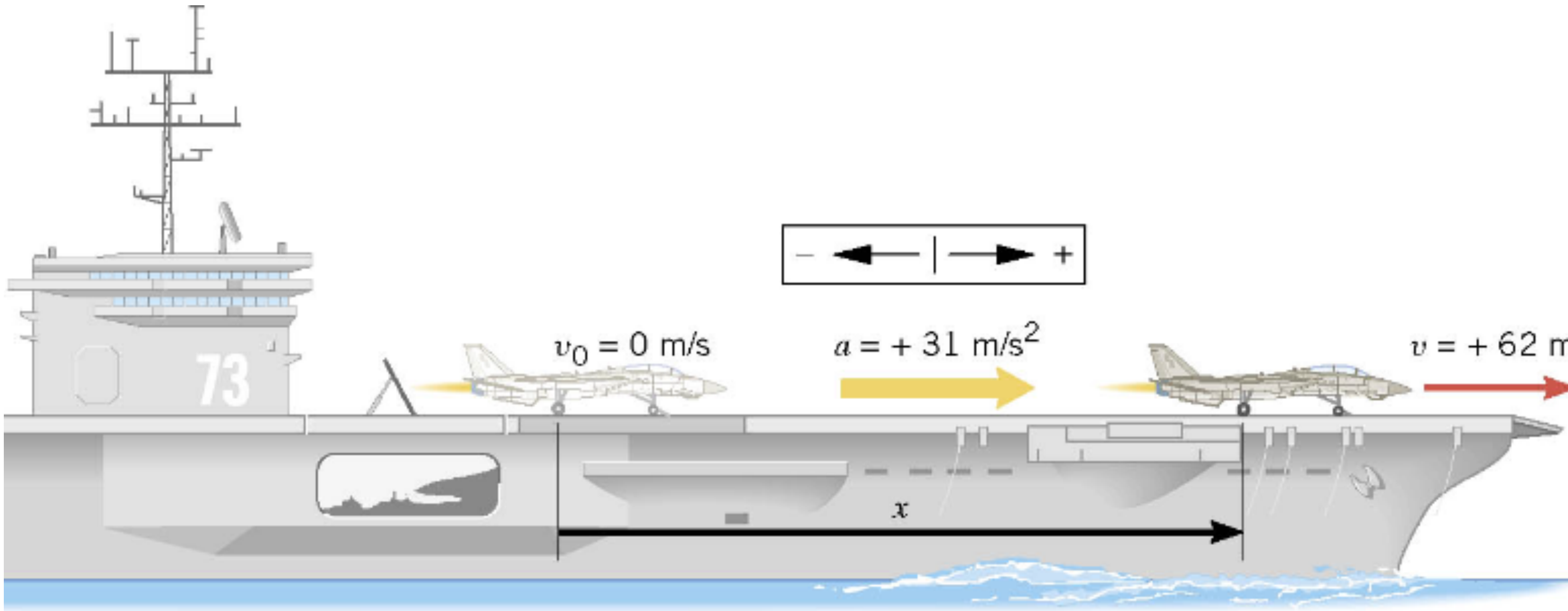
2.4 Equations of Kinematics for Constant Acceleration

$$a = \frac{v - v_o}{t} \quad \Rightarrow \quad t = \frac{v - v_o}{a}$$

$$x = \tfrac{1}{2}\left(v_o + v\right)t = \tfrac{1}{2}\left(v_o + v\right)\frac{\left(v - v_o\right)}{a}$$

$$x = \frac{v^2 - v_o^2}{2a}$$

2.4 Equations of Kinematics for Constant Acceleration



(*b*)

$$x = \frac{v^2 - v_o^2}{2a} = \frac{(62\,\text{m/s})^2 - (0\,\text{m/s})^2}{2(31\,\text{m/s}^2)} = +62\,\text{m}$$

2.4 Equations of Kinematics for Constant Acceleration

Equations of Kinematics for Constant Acceleration

$$v = v_o + at$$

$$x = \tfrac{1}{2}\left(v_o + v\right)t$$

$$v^2 = v_o^2 + 2ax$$

$$x = v_o t + \tfrac{1}{2}at^2$$

2.5 *Applications of the Equations of Kinematics*

Reasoning Strategy

1. Make a drawing.

2. Decide which directions are to be called positive (+) and negative (-).

3. Write down the values that are given for any of the five kinematic variables.

4. Verify that the information contains values for at least three of the five kinematic variables. Select the appropriate equation.

5. When the motion is divided into segments, remember that the final velocity of one segment is the initial velocity for the next.

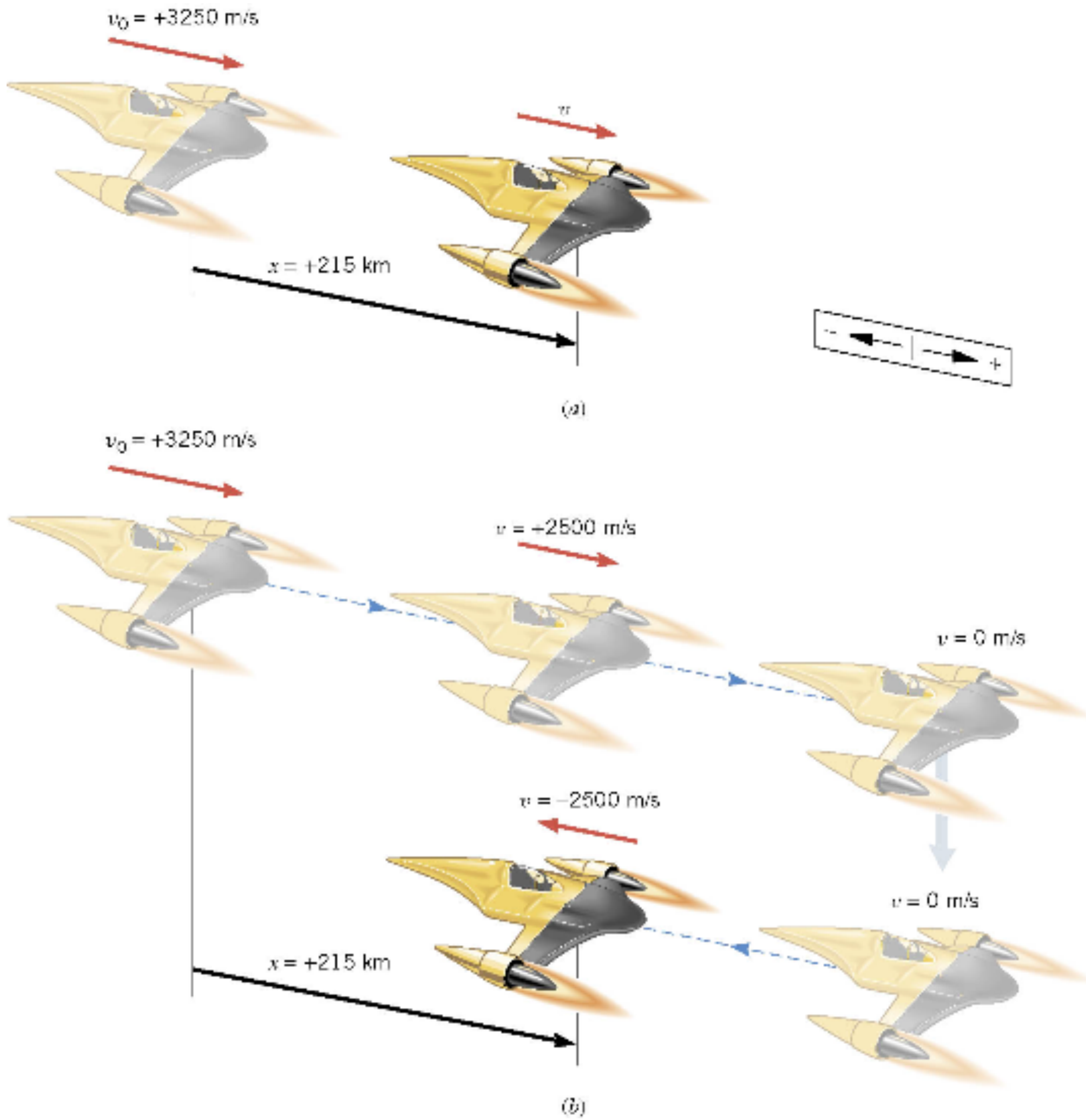
6. Keep in mind that there may be two possible answers to a kinematics problem.

Example 8 An Accelerating Spacecraft

A spacecraft is traveling with a velocity of +3250 m/s. Suddenly the retrorockets are fired, and the spacecraft begins to slow down with an acceleration whose magnitude is 10.0 m/s^2. What is the velocity of the spacecraft when the displacement of the craft is +215 km, relative to the point where the retrorockets began firing?

x	a	v	v_o	t
+215000 m	-10.0 m/s^2	?	+3250 m/s	

2.5 Applications of the Equations of Kinematics



2.5 Applications of the Equations of Kinematics

x	a	v	v_o	t
+215000 m	-10.0 m/s^2	?	+3250 m/s	

$$v^2 = v_o^2 + 2ax \longrightarrow v = \sqrt{v_o^2 + 2ax}$$

$$v = \pm\sqrt{(3250\,\text{m/s})^2 + 2(10.0\,\text{m/s}^2)(215000\,\text{m})}$$

$$= \pm 2500\,\text{m/s}$$

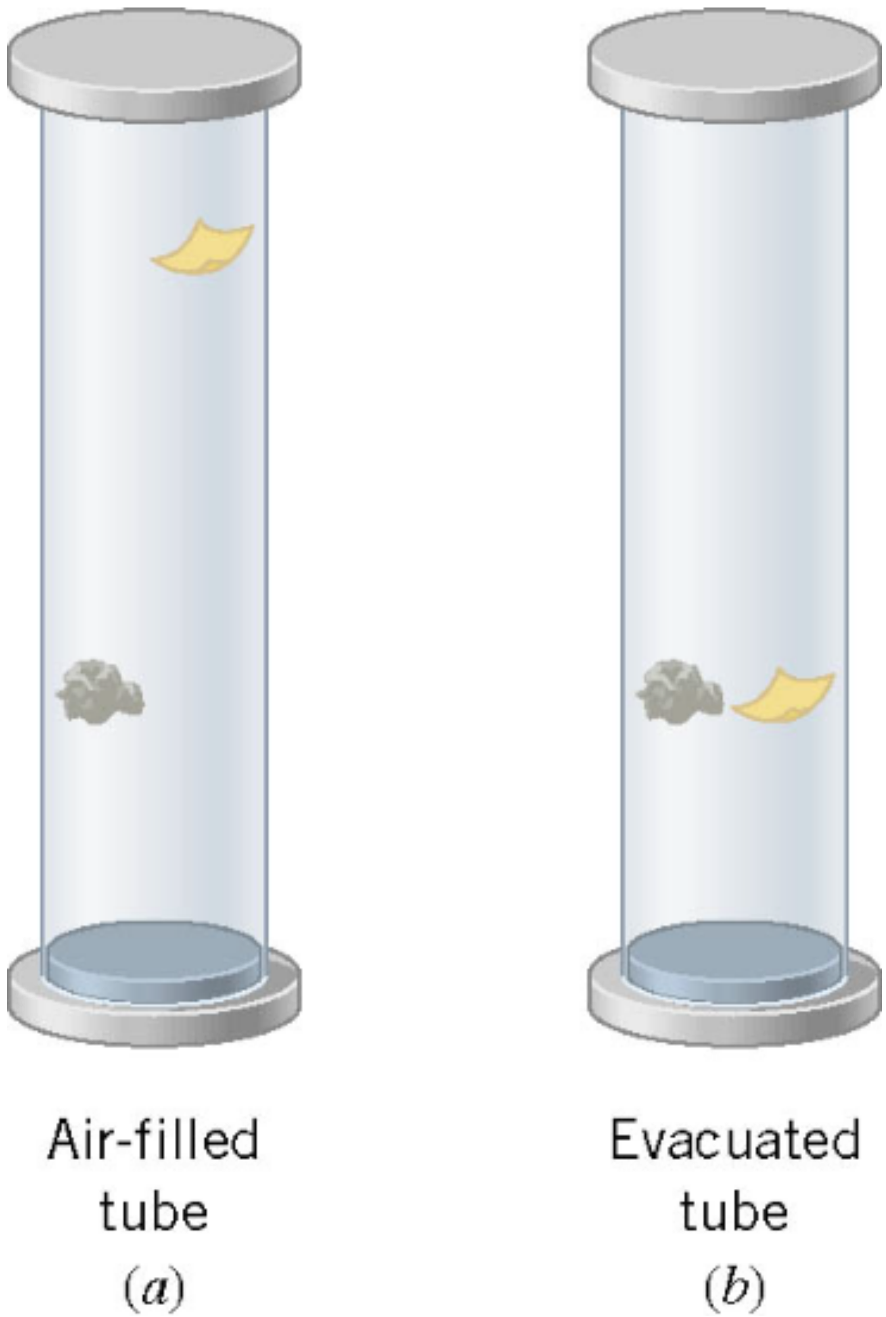
2.6 *Freely Falling Bodies*

In the absence of air resistance, it is found that all bodies at the same location above the Earth fall vertically with the same acceleration. If the distance of the fall is small compared to the radius of the Earth, then the acceleration remains essentially constant throughout the descent.

This idealized motion is called *free-fall* and the acceleration of a freely falling body is called the *acceleration due to gravity*.

$$g = 9.80\,\mathrm{m/s^2} \quad \text{or} \quad 32.2\,\mathrm{ft/s^2}$$

2.6 Freely Falling Bodies



acceleration due to gravity.

$$g = 9.80\,\mathrm{m/s^2}$$