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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.***

2.1 Motion in one dimension (definitions)

In Chapter 2: All motion is along a 1D line and is called the x-axis.

YOU decide which direction along x is POSITIVE.

1D line can be Horizontal, for motion of a car, boat, or human.

1D line can be Vertical, for objects dropped or thrown upward.

ID line can be a Diagonal, for objects moving on a ramp.

Speed v : can only be positive	Instantaneous at the time t
Velocity v_x : speed with a sign indicating direction	

Absolute value of the velocity is the speed : $v = |v_x|$, and

the sign of v_x gives the direction of the 1D (straight line) motion

Example: Choose "to the right" as positive. An object's speed is $v = 20$ m/s.

If object is moving to the right, the velocity, $v_x = 20$ m/s.

If object is moving to the left, the velocity, $v_x = -20$ m/s.

2.1 Motion in one dimension (examples)

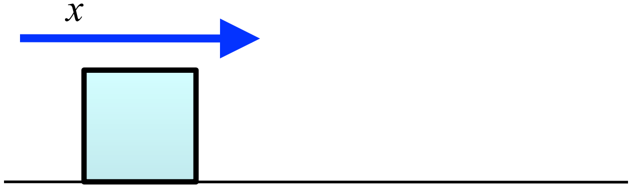
Speed v : is always positive

Horizontal motion

Direction choice

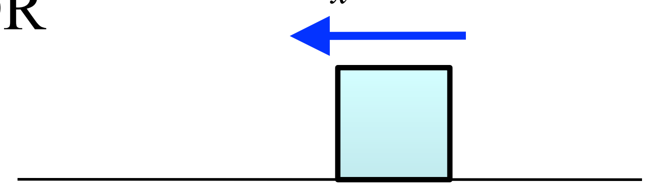
Sliding block

$v_x = +v$



OR

$v_x = -v$



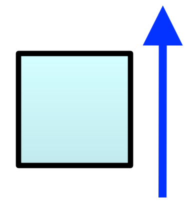
If you determine that $v_x = -20\text{m/s}$

it must be moving to the left.

Vertical motion

Direction choice

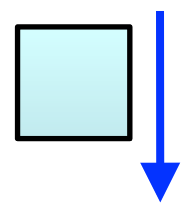
Thrown upward



$v_x = +v$

Later motion when falling downward

OR



$v_x = -v$

If you determine that $v_x = -20\text{m/s}$

it must be moving downward.

2.1 Motion in one dimension (definitions)

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

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

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

and see if the object is at the same place as it was at time t.

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

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

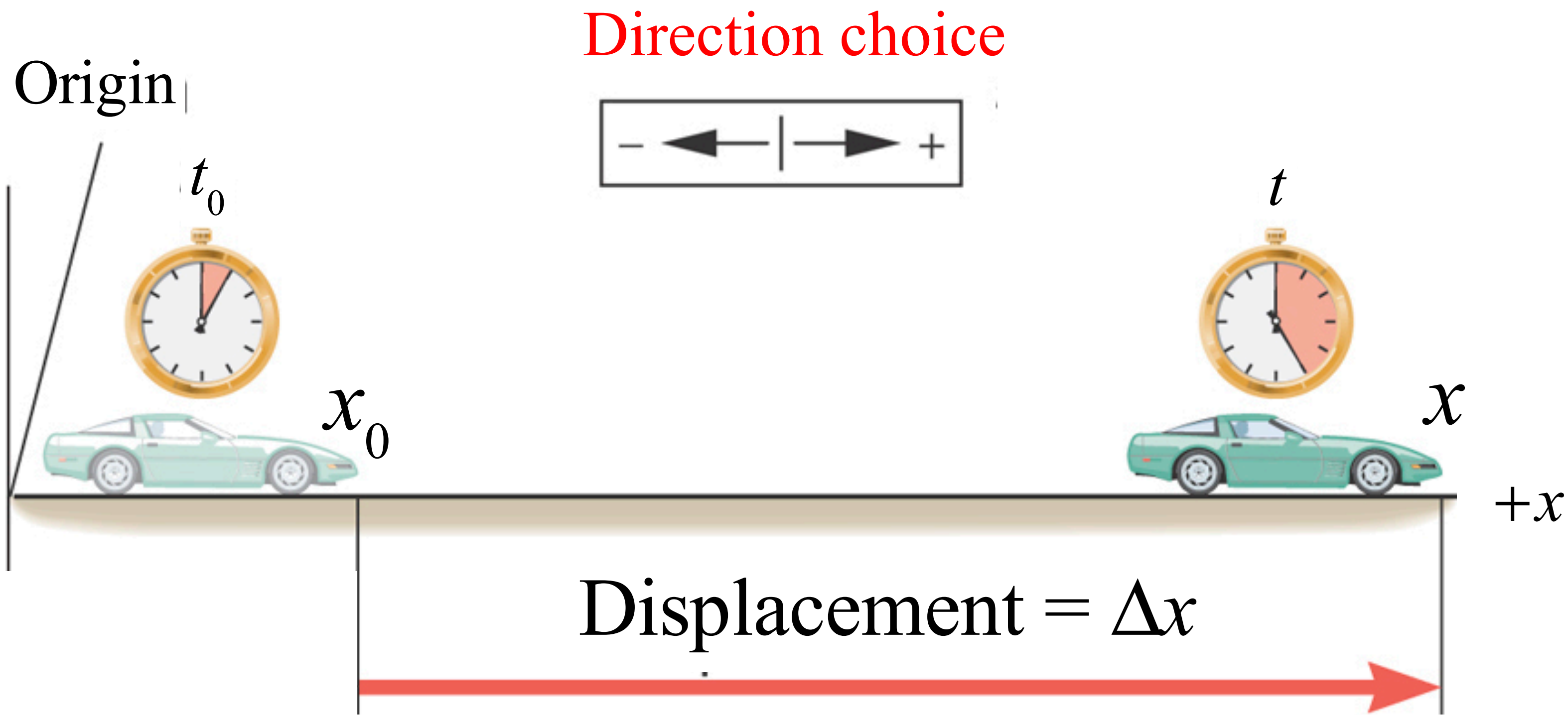
If an object is thrown upward, at the highest point its speed

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

Turning around to a new direction is *motion*. IT IS MOVING.

"Zero speed at one time t" is NOT EQUIVALENT to "not moving".

2.1 *Motion in one dimension (Displacement and Distance)*



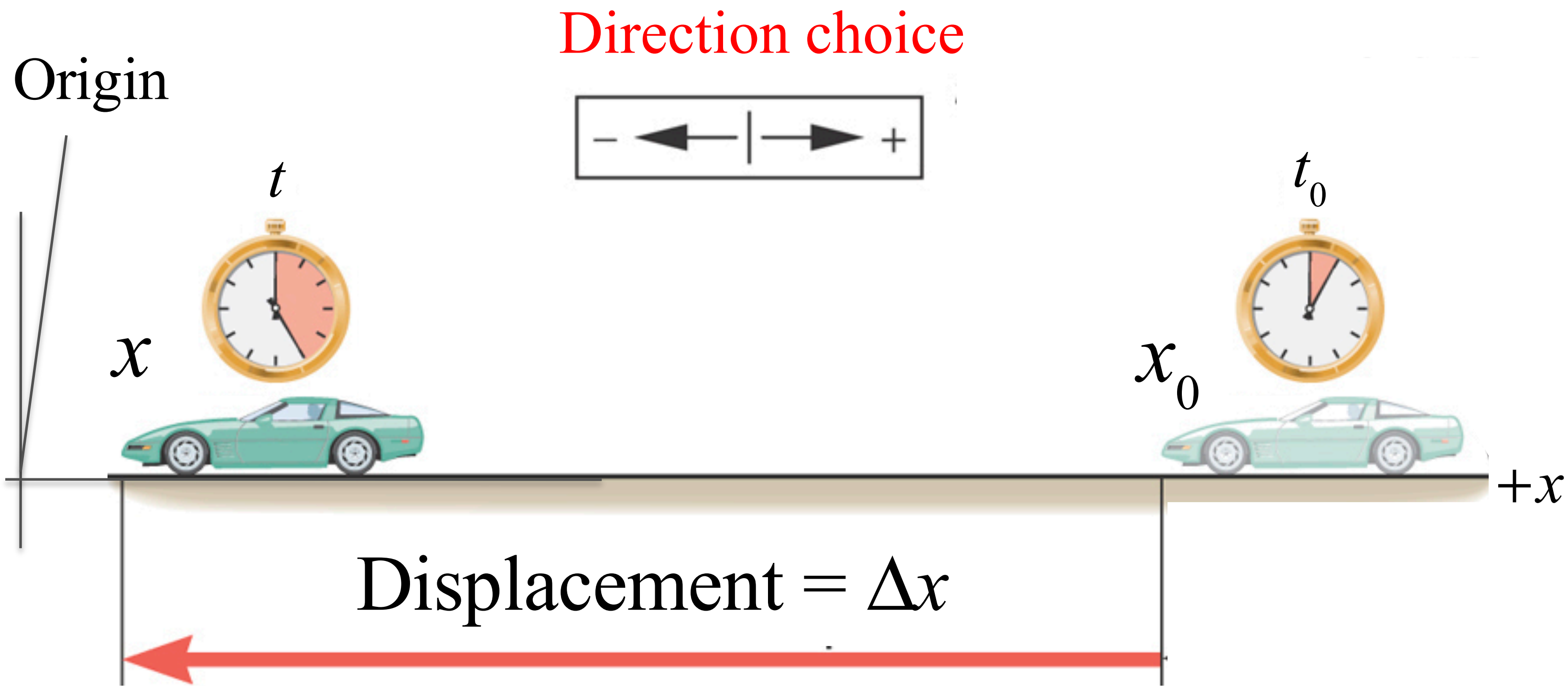
$x_0 =$ position (at $t = 0$) $\qquad x =$ final position

$$\Delta x = x - x_0 = \text{ displacement}$$

Since $x > x_0$, then displacement Δx is positive

The travel distance $d = |\Delta x|$ is always positive.

2.1 Motion in one dimension (Displacement and Distance)



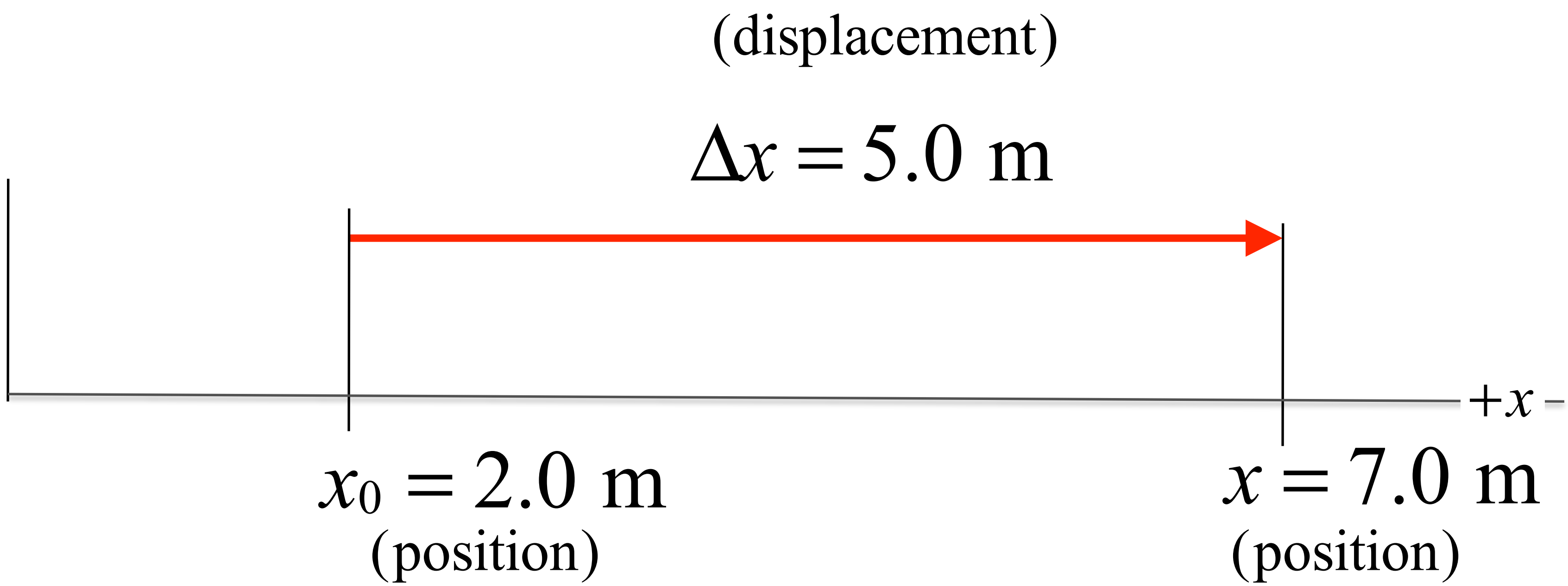
$x =$ final position $\qquad x_0 =$ initial position (at $t = 0$)

$$\Delta x = x - x_0 = \text{ displacement}$$

Since $x_0 > x$, then displacement Δx is negative

The travel distance, $d = |\Delta x|$ is always positive.

2.1 Displacement Examples



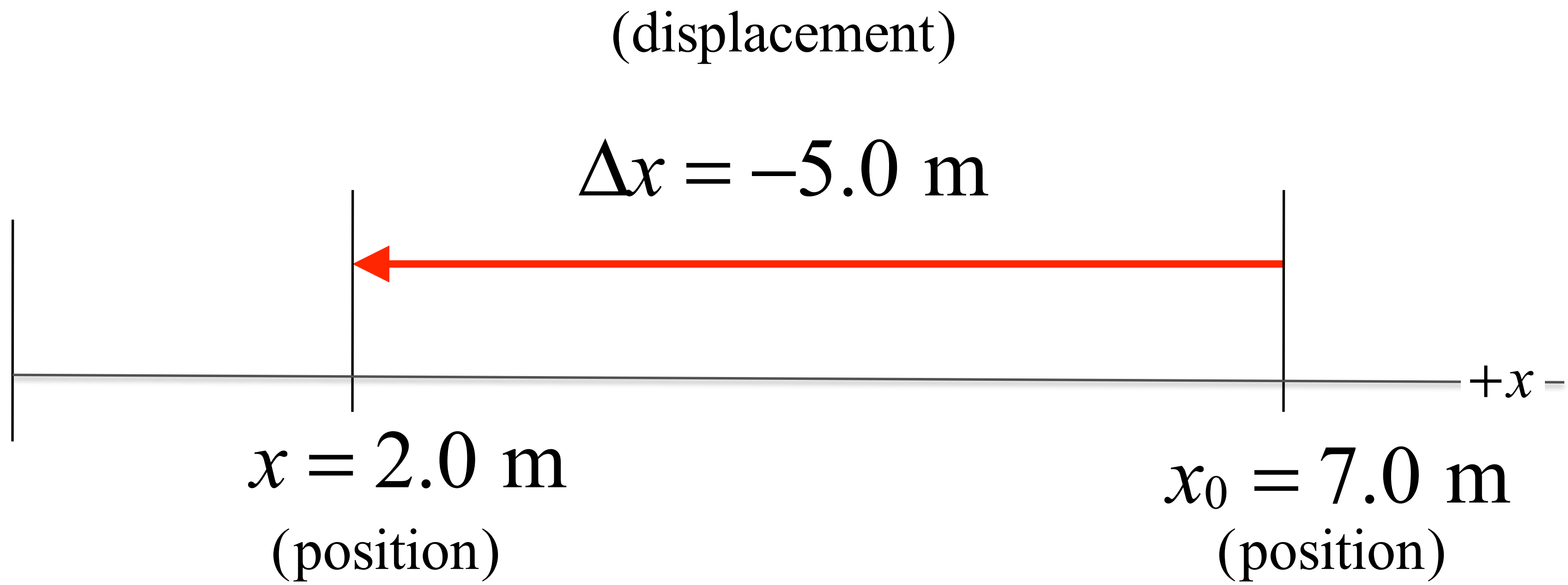
$$\Delta x = x - x_0 = 7.0\ \text{m} - 2.0\ \text{m} = 5.0\ \text{m}$$

Note: the <u>final</u> position = the <u>initial</u> position + the displacement

$$x = x_0 + \Delta x$$

Also, $x_0 = x - \Delta x$

2.1 Displacement Examples

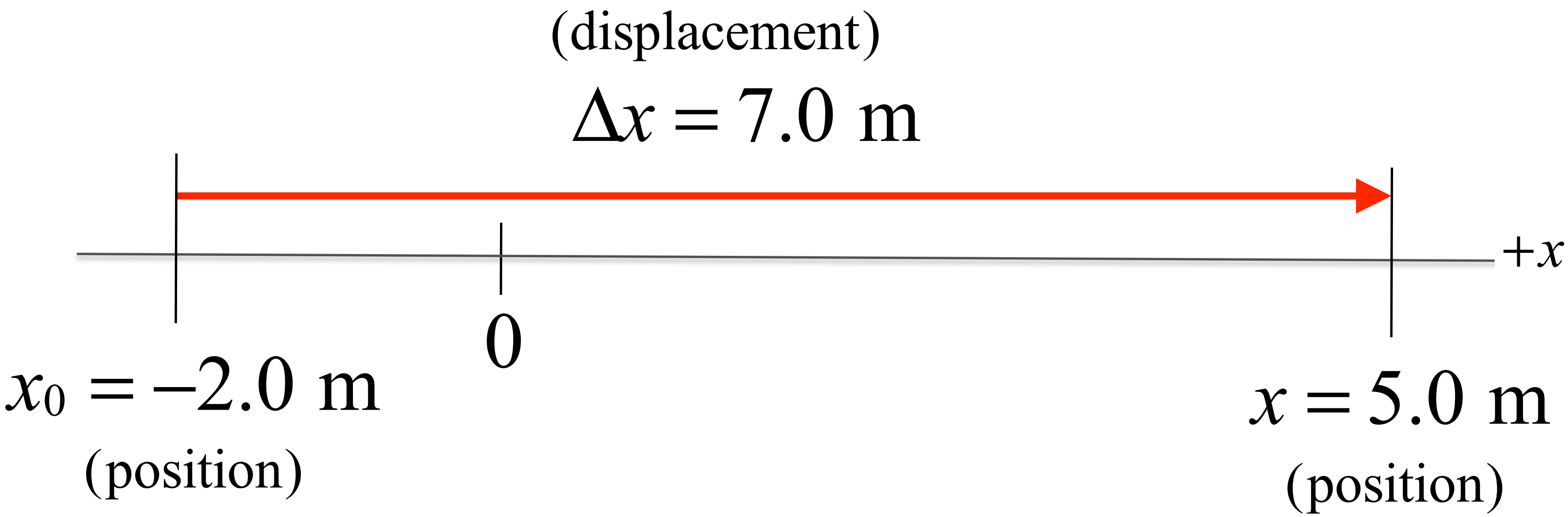


$$\Delta x = x - x_0 = 2.0\ \text{m} - 7.0\ \text{m} = -5.0\ \text{m}$$

Negative!

2.1 *Displacement Examples*

What if initial position, x_0 (at time $t = 0$) is negative?



$$\Delta x = x - x_0 = 5.0\text{ m} - (-2.0)\text{ m} = 7.0\text{ m}$$

Displacement formula ($\Delta x = x - x_0$) will still work

2.2 Speed and Velocity

Average speed is the distance traveled divided by the time (t - t_0) required to cover the distance.

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

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

Example: 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?

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

Rewrite the formula using algebra to get the distance on the left, and everything else on the right.

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

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

2.2 *Speed and Velocity*

Average value of any variable, such as z, is written as $\bar{z}$ (z - bar)

Average velocity is the displacement divided by the elapsed time.

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

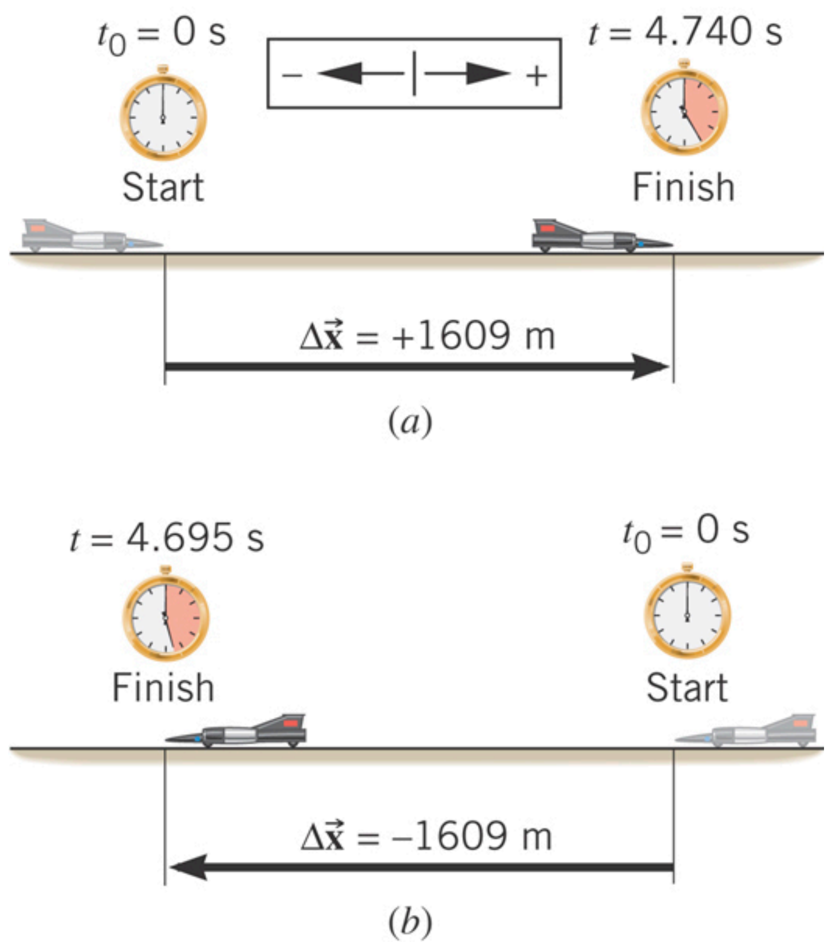
$$\bar{v}_x = \frac{x - x_0}{t - t_0} = \frac{\Delta x}{\Delta t}$$

This average places no restriction on how the velocity has changed over time. For example, it could reverse direction a number of times over the time of the displacement.

2.2 Speed and Velocity

Example: 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.



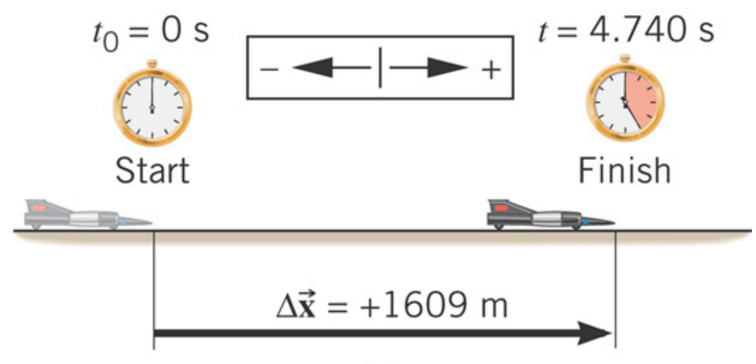
2.2 Speed and Velocity

$$\bar{v} = +339.5\,\text{m/s}$$

Average velocity run 1

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

Also is the average speed

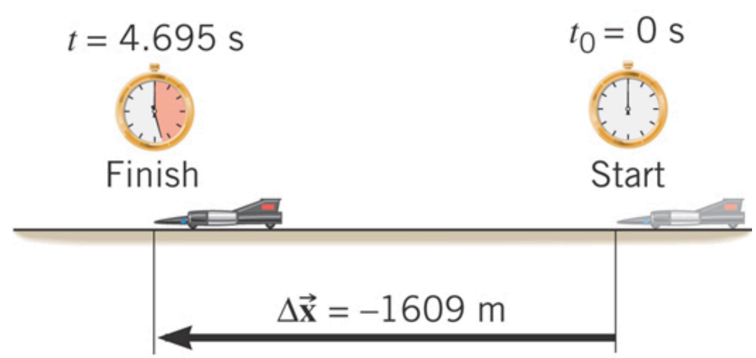


(a)

Average velocity run 2

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

negative



(b)

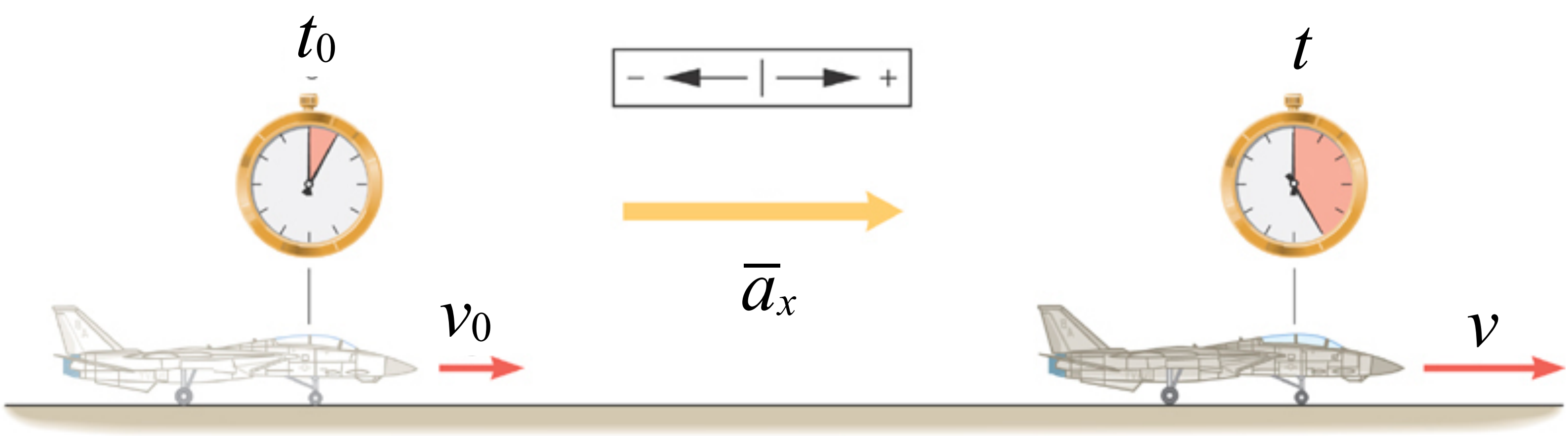
Average speed run 2 is absolute value of velocity: +342.7 m/s

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

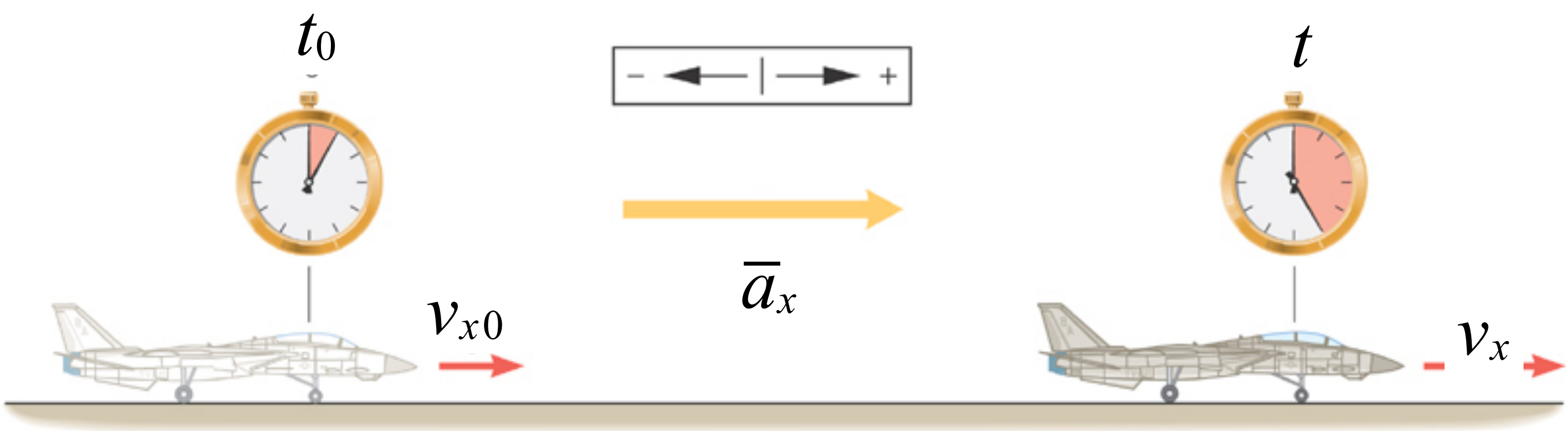
$$v_x = \lim_{\Delta t \to 0} \frac{\Delta x}{\Delta t}$$

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



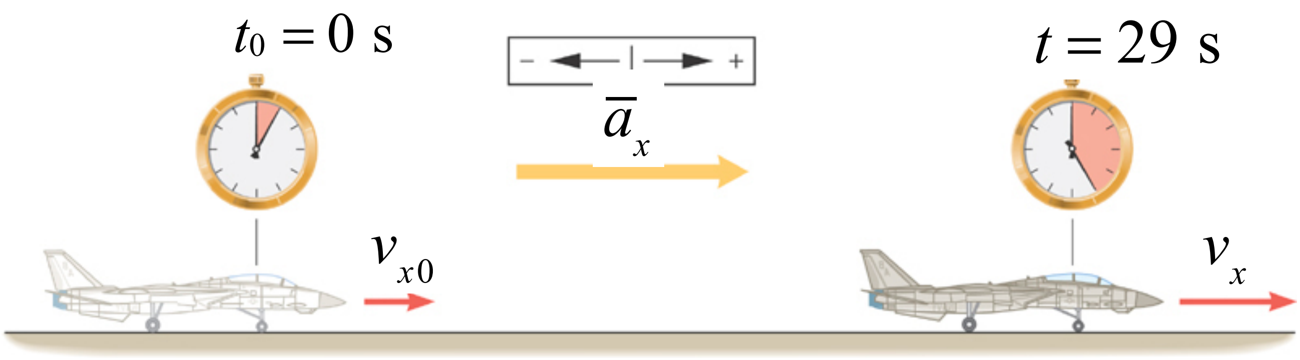
DEFINITION OF AVERAGE ACCELERATION

$$\bar{a}_x = \frac{v_x - v_{x0}}{t - t_0} = \frac{\Delta v_x}{\Delta t} \quad \left(\begin{array}{l}\text{average rate of change}\\ \text{of the velocity}\end{array}\right)$$

Note for the entire course:

$$\Delta(\mathit{Anything}) = \text{Final } \mathit{Anything} - \text{Initial } \mathit{Anything}$$

2.3 Acceleration



Example: Acceleration and increasing velocity of a plane taking off.

Determine the average acceleration of this plane's take-off.

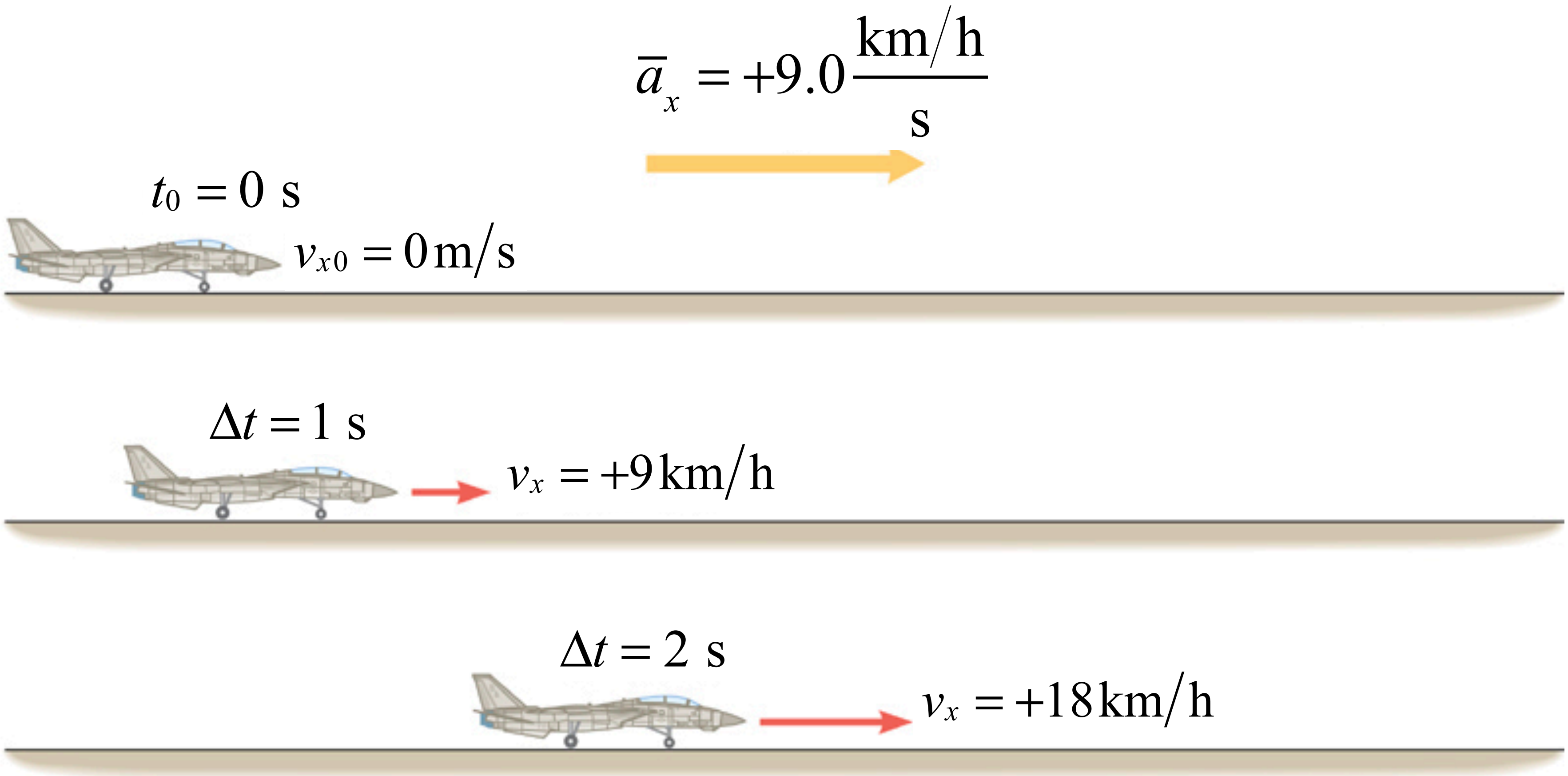
$$t_0 = 0 \text{ s} \qquad t = 29 \text{ s}$$

$$v_{x0} = 0 \text{ m/s} \qquad v_x = 260 \text{ km/h}$$

$$\bar{a}_x = \frac{v_x - v_{x0}}{t - t_0} = \frac{260 \text{ km/h} - 0 \text{ km/h}}{29 \text{ s} - 0 \text{ s}} = +9.0 \frac{\text{km/h}}{\text{s}}$$

This calculation of the average acceleration works even if the acceleration is not constant throughout the motion.

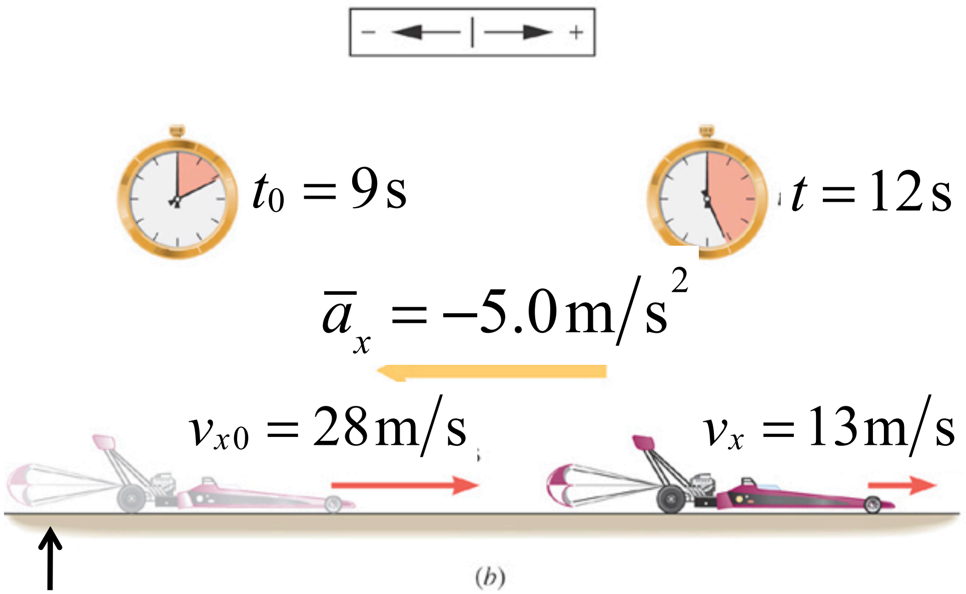
2.3 Acceleration (velocity increasing)



2.3 Acceleration

Example: Average acceleration with Decreasing Velocity

Dragster at the end of a run



Parachute deployed to slow safely.

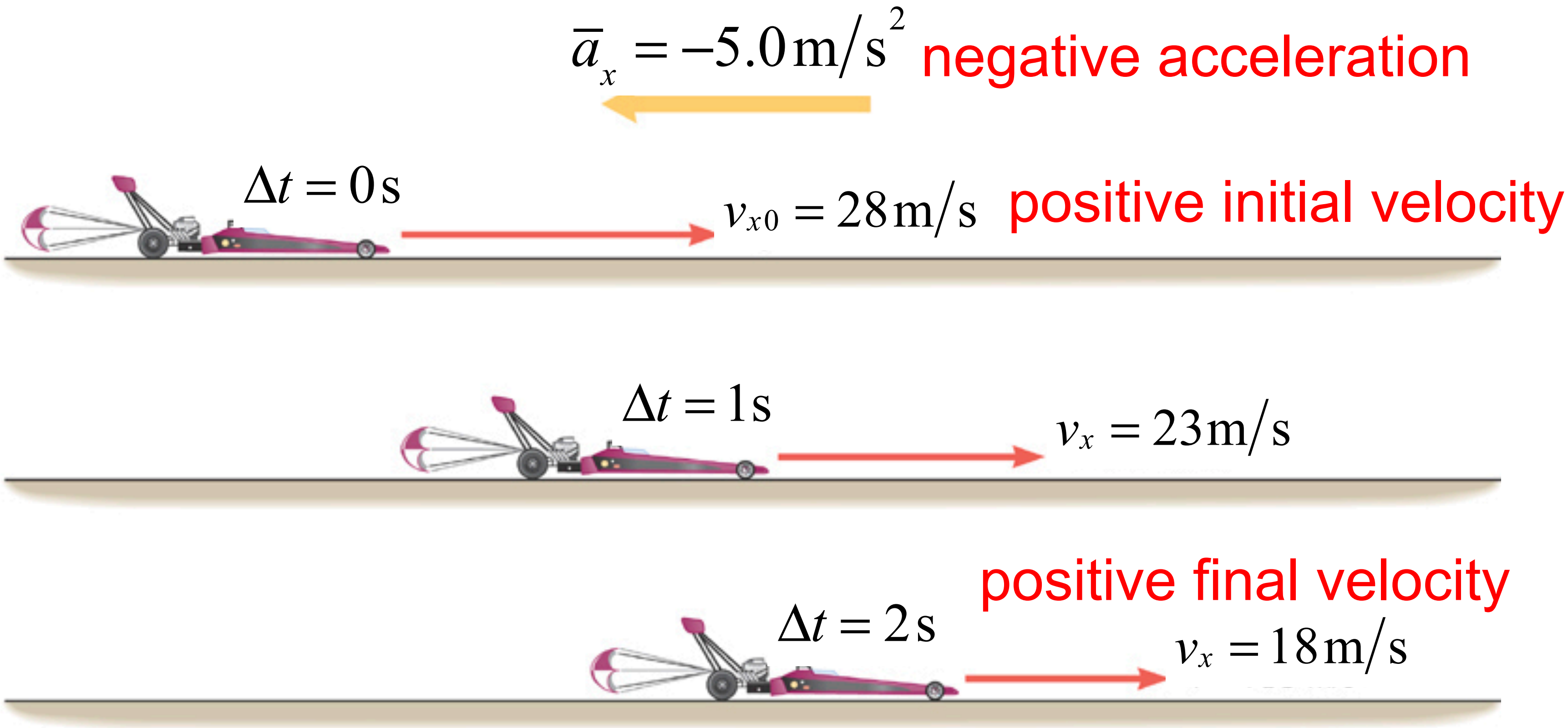
Finish Line

$$\bar{a}_x = \frac{v_x - v_{x0}}{t - t_0} = \frac{13\,\text{m/s} - 28\,\text{m/s}}{12\ \text{s} - 9\ \text{s}} = -5.0\,\text{m/s}^2$$

Units: L/T^2

Positive accelerations: velocities become more positive.
Negative accelerations: velocities become more negative.
(Don't use the word deceleration)

2.3 Acceleration (velocity decreasing)



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

2.4 *Equations of Kinematics for Constant Acceleration*

From now on unless stated otherwise

The clock starts when the object is at the initial position.

$$t_0 = 0$$

Simplifies things a great deal

$$\overline{v}_x = \frac{x - x_0}{t - t_0} \quad \Rightarrow \quad \overline{v}_x = \frac{\Delta x}{t}$$

$$\Downarrow$$

Note: average is (initial + final)/2

$$\Delta x = \overline{v}t = \tfrac{1}{2}\left(v_{xo} + v_x\right)t$$

2.4 *Equations of Kinematics for Constant Acceleration*

A constant acceleration (same value at at all times) can be measured at any time.

No average bar needed

$$a_x = \frac{v_x - v_{x0}}{t - t_o}$$

$$a_x = \frac{v_x - v_{x0}}{t}$$

$$a_x t = v_x - v_{x0}$$

$$v_x = v_{x0} + at$$

2.4 *Equations of Kinematics for Constant Acceleration*

Five kinematic variables:

Except for *t*, every variable has a direction and thus can have a positive or negative value.

1. displacement, Δx

2. acceleration (constant), a_x

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

4. initial velocity, v_{x0}

5. elapsed time, t

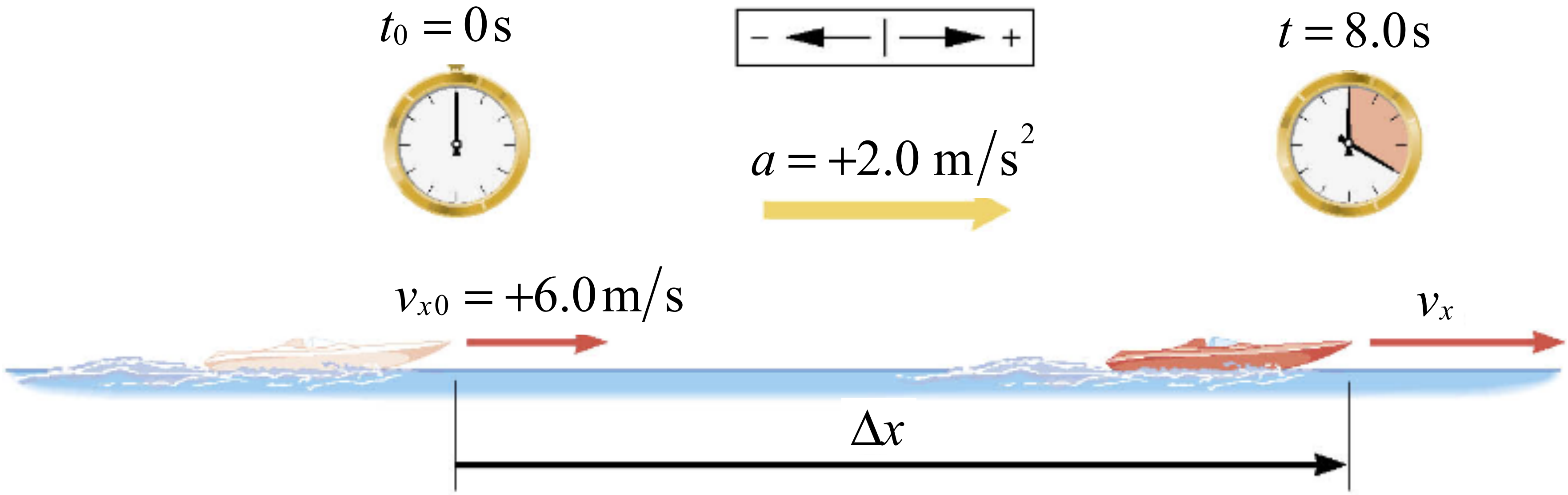
2.4 Equations of Kinematics for Constant Acceleration

$$v_x = v_{x0} + at$$

$$\Delta x = \tfrac{1}{2}\left(v_{x0} + v_x\right)t = \tfrac{1}{2}\left(v_{x0} + v_{x0} + at\right)t$$

$$\Delta x = v_{x0}t + \tfrac{1}{2}at^2$$

2.4 Equations of Kinematics for Constant Acceleration



$$\Delta x = v_{x0}t + \tfrac{1}{2}at^2$$

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

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