Chapter 1 & 2 :

Describing Motion: Kinematics in One Dimension

- *Department of Physics*
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Chapter 1 & 2 Topics

Ch1:

1-5: Units, Standards, and the SI System
1-6: Converting Units
1-8: Dimensions and Dimensional Analysis

Ch2:

2-1: Reference Frames and Displacement
2-2: Average Velocity
2-3: Instantaneous Velocity
2-4: Acceleration

1-5 Units, Standards, and the SI System

SI –Systém International (Main system used in this text)

We will be working in the SI system, where the basic units are kilograms, meters, and seconds.

<u>Other systems</u>: cgs; units are grams, centimeters, and seconds

TABLE 1–5 SI Base Quantities and Units

Quantity	Unit	Unit Abbreviation
Length	meter	m
Time	second	s
Mass	kilogram	kg
Electric current	ampere	A
Temperature	kelvin	K
Amount of substance	mole	mol
Luminous intensity	candela	cd

1-6 Converting Units

Converting between metric units, for example from kg to g, is easy, as all it involves is powers of 10.

Conversion Factors

Fractions in which the numerator and denominator are EQUAL quantities expressed in different units

Example: 1 in. = 2.54 cm

Factors: $\frac{1\text{ in.}}{2.54\text{ cm}}$ and $\frac{2.54\text{ cm}}{1\text{ in.}}$

How many minutes are in 2.5 hours?

Conversion factor

$$2.5\ \text{hr} \times \frac{60\ \text{min}}{1\ \text{hr}} = 150\ \text{min}$$

cancel

By using dimensional analysis / factor-label method, the UNITS ensure that you have the conversion right side up, and the UNITS are calculated as well as the numbers!

Sample Problem

- You have $7.25 in your pocket in quarters. How many quarters do you have?

$$7.25 \text{ dollars} \times \frac{4 \text{ quarters}}{1 \text{ dollar}} = \mathbf{29\ quarters}$$

Learning Check

A rattlesnake is 2.44 m long. How long is the snake in cm?

a) 2440 cm
b) 244 cm
c) 24.4 cm

Solution

A rattlesnake is 2.44 m long. How long is the snake in cm?

b) 244 cm

$$2.44 \text{ m} \times \frac{100 \text{ cm}}{1 \text{ m}} = 244 \text{ cm}$$

Learning Check

How many seconds are in 1.4 days?

Unit plan: days → hr → min → seconds

$$1.4 \text{ days} \times \frac{24 \text{ hr}}{1 \text{ day}} \times \frac{60 \text{ min}}{1 \text{ hr}} \times \frac{60 \text{ s}}{1 \text{ min}} = 1.2 \times 10^5 \text{ s}$$

1-8 Dimensions and Dimensional Analysis

- Dimension has a specific meaning –it denotes the physical nature of a quantity.
- Dimensions are often denoted with square brackets.
- Length [L] , Mass [M] , Time [T]

Example: Speed = distance / time

Dimensions of speed: [L/T]

Quantities that are being added or subtracted must have the same dimensions. In addition, a quantity calculated as the solution to a problem should have the correct dimensions.

Terminology

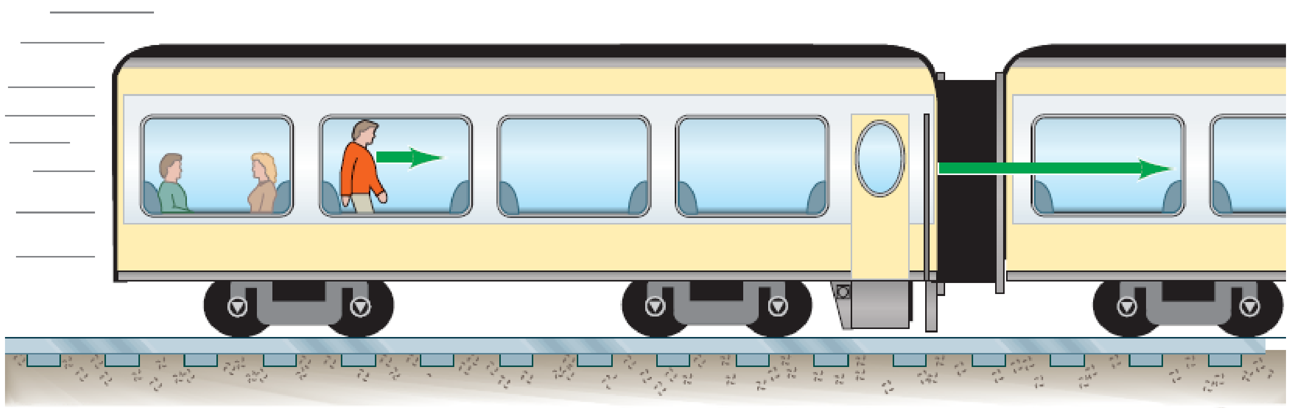
- **Mechanics** = Study of objects in motion.
  - 2 parts to mechanics.
- **Kinematics** = Description of ***HOW*** objects move.
  - Chapters 2 & 3
- **Dynamics** = ***WHY*** objects move.
  - Introduction of the concept of **FORCE**.
  - Causes of motion, Newton's Laws
  - Most of the course from Chapter 4 & beyond.

For a while, assume ideal point masses (no physical size).

Later, extended objects with size.

Section 2-1: Reference Frames

- Every measurement must be made with respect to a **reference frame**. Usually, speed is relative to the Earth.

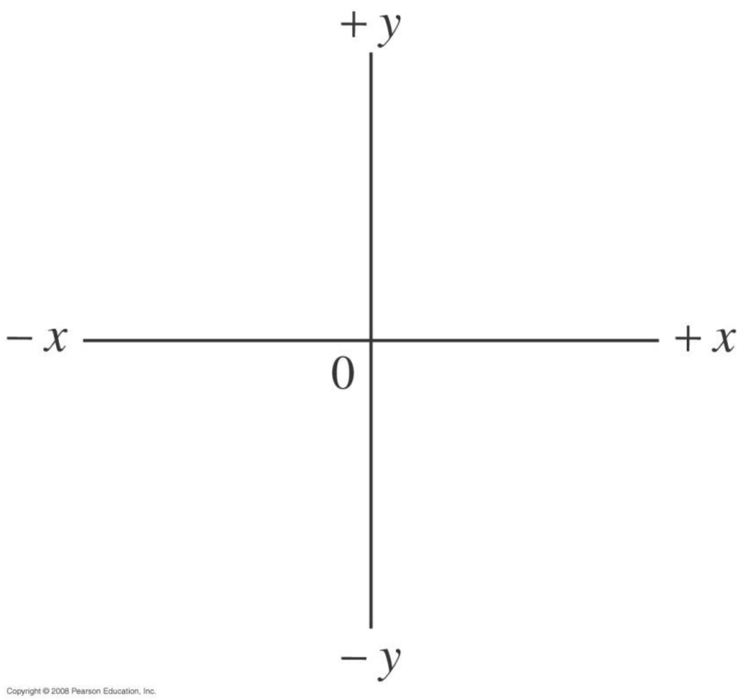


- For example, if you are sitting on a train & someone walks down the aisle, the person's speed with respect to the train is a few km/hr, at most. The person's speed with respect to the ground is much higher.
- ***Specifically***, if a person walks towards the front of a train at **5 km/h** (with respect to the train floor) & the train is moving **80 km/h** with respect to the ground. The person's speed, relative to the ground is **85 km/h**.

When specifying speed, always specify the frame of reference unless its obvious ("with respect to the Earth").

Coordinate Axes

- Define a reference frame using a standard coordinate axes.
- 2 Dimensions **(x,y)**
- Note, if its convenient, we could reverse + & - !

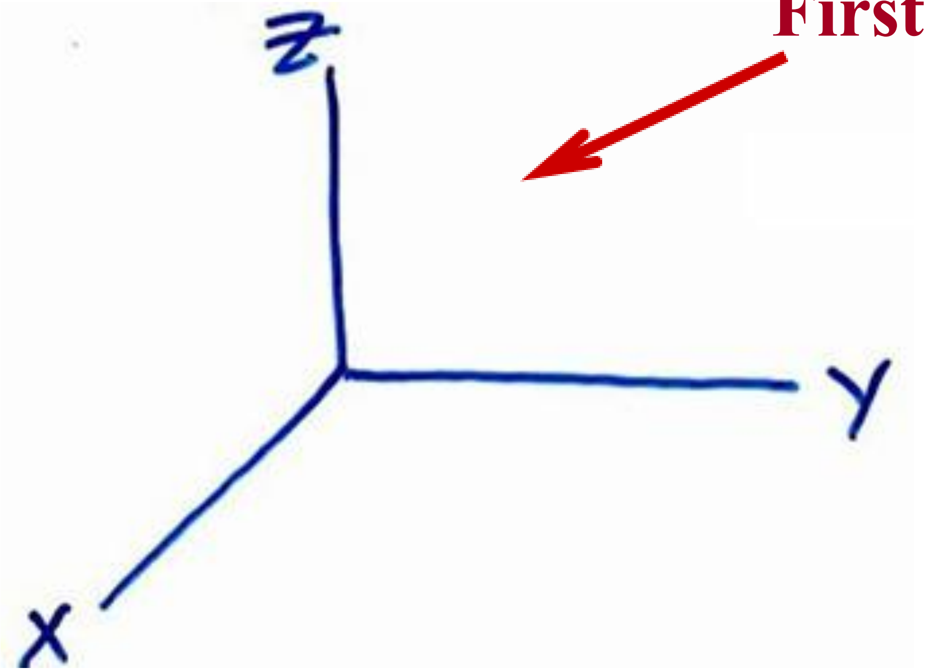


Standard set of xy coordinate axes

Coordinate Axes

- 3 Dimensions **(x,y,z)**

First Octant



- Define direction using these.

Displacement & Distance

- Distance traveled by an object

  ≠ displacement of the object!

Fgure1

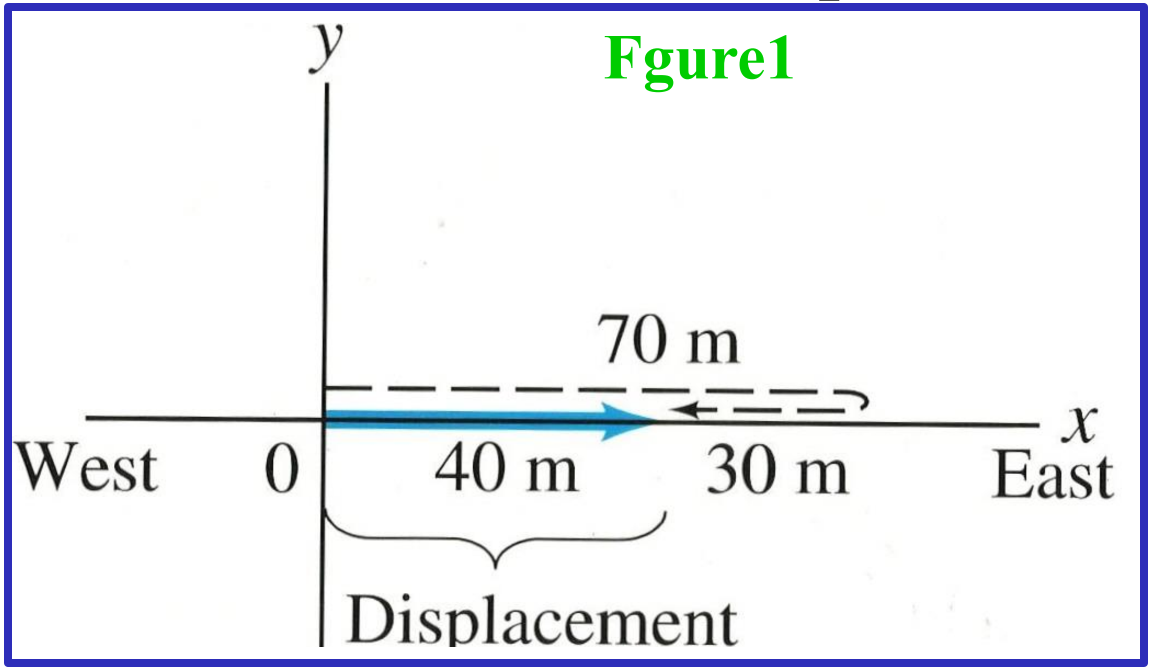
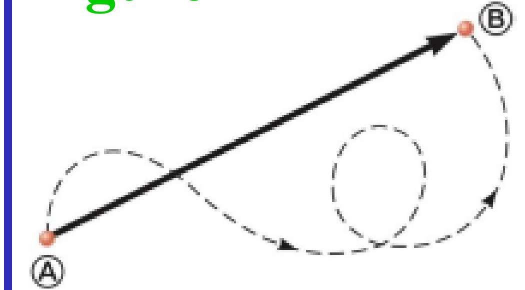
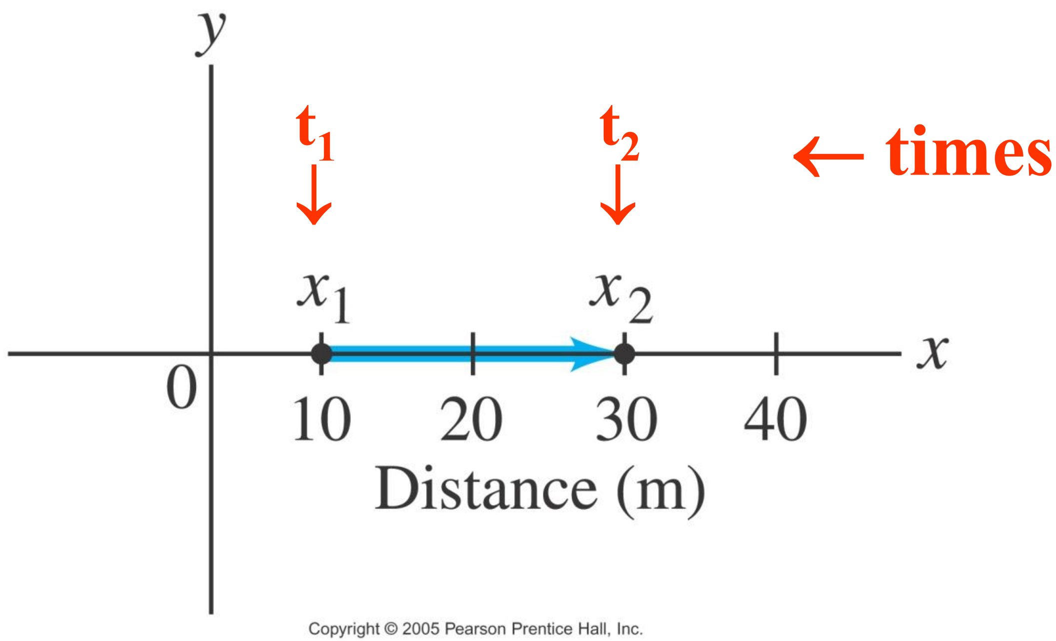


Figure 2



- Displacement = change in position of object.
- Displacement is a **vector** (magnitude & direction). Distance is a **scalar** (magnitude).
- Figure: distance = 100 m, displacement = 40 m East

Displacement



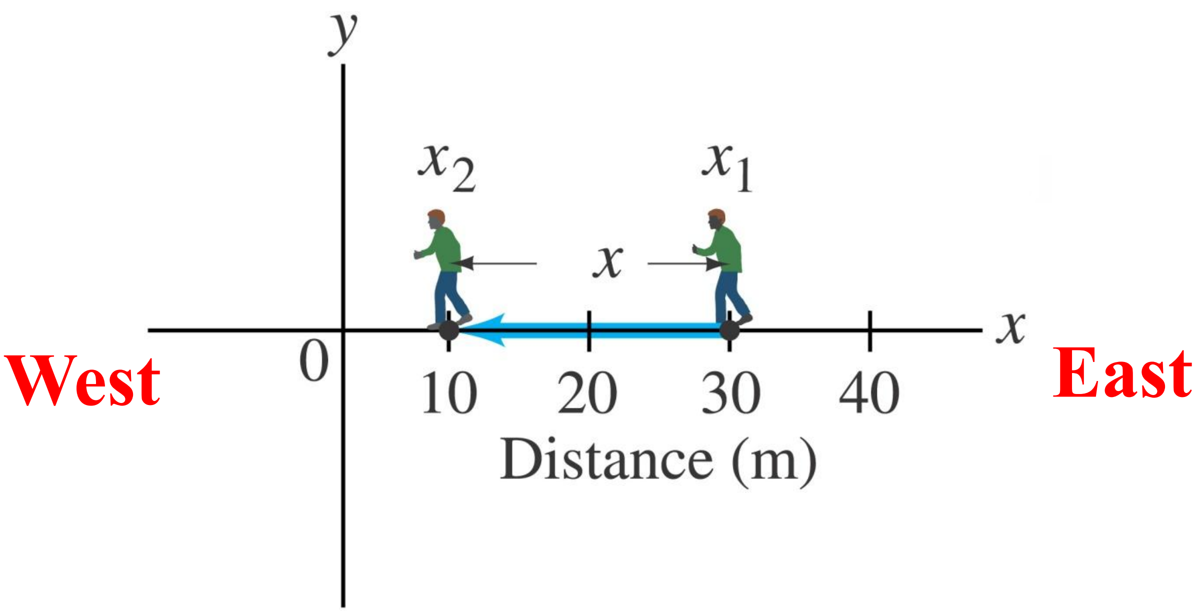
The arrow represents the displacement (in meters).

x_1 = 10 m, x_2 = 30 m

Displacement ≡ $\Delta x = x_2 - x_1$ = 20 m

Δ ≡ Greek letter “delta” meaning “change in”

FIGURE 2–6 For the displacement $\Delta x = x_2 - x_1 = 10.0\text{ m} - 30.0\text{ m}$, the displacement vector points to the left.



$x_1 = 30$ m, $x_2 = 10$ m

Displacement $\equiv \Delta x = x_2 - x_1 = -20$ m

Displacement is a **VECTOR**

Vectors and Scalars

- Many quantities in physics, like displacement, have a ***magnitude and a direction***. Such quantities are called ***VECTORS***.
  - Other quantities which are vectors: velocity, acceleration, force, momentum, ...
- Many quantities in physics, like distance, have a ***magnitude only***. Such quantities are called ***SCALARS***.
  - Other quantities which are scalars: speed, temperature, mass, volume, ...

- **The Text** uses BOLD letters to denote vectors.
- I usually denote vectors with arrows over the symbol.

$$\vec{V}$$

- In one dimension, we can drop the arrow and remember that a + sign means the vector points to right & a minus sign means the vector points to left.

Sect. 2-2: Average Velocity

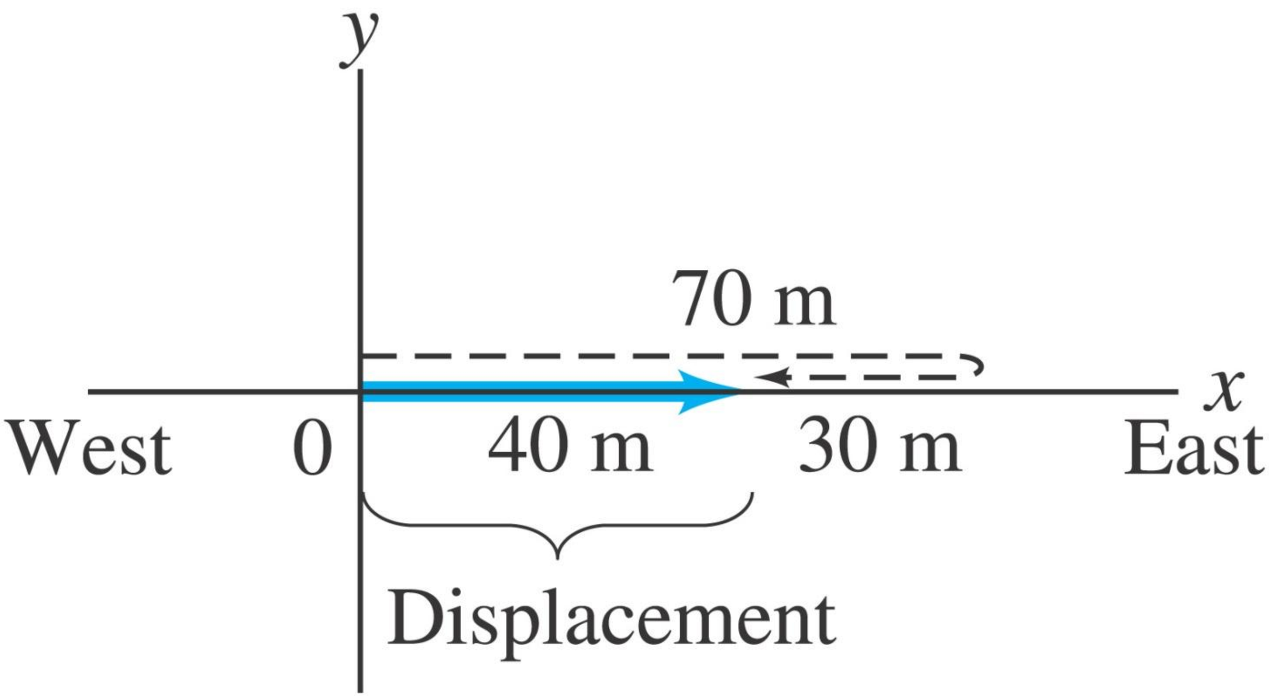
Scalar→Average ***Speed*** ≡ (Distance traveled)/(Time taken)

Vector→Average ***Velocity*** ≡ (Displacement)/(Time taken)

- **Velocity:** Both magnitude & direction describing how fast an object is moving. A ***VECTOR***. (Similar to displacement).
- **Speed:** Magnitude only describing how fast an object is moving. A ***SCALAR*****.** (Similar to distance).
- **Units: distance/time = m/s**

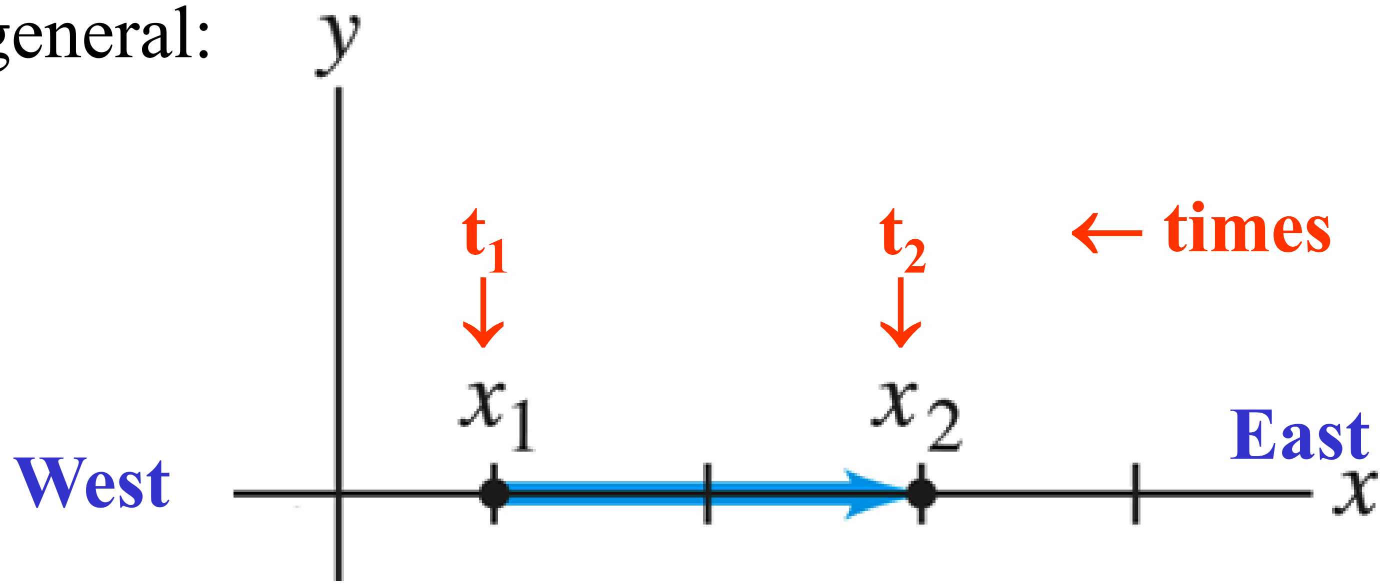
Average Velocity, Average Speed

- Displacement from before. Walk for 70 s.



- Average Speed = (100 m)/(70 s) = 1.4 m/s
- Average **velocity** = (40 m)/(70 s) = 0.57 m/s **East**

- In general:



$\Delta \mathbf{x} = \mathbf{x_2} - \mathbf{x_1}$ = displacement

$\Delta \mathbf{t} = \mathbf{t_2} - \mathbf{t_1}$ = elapsed time

Average Velocity:

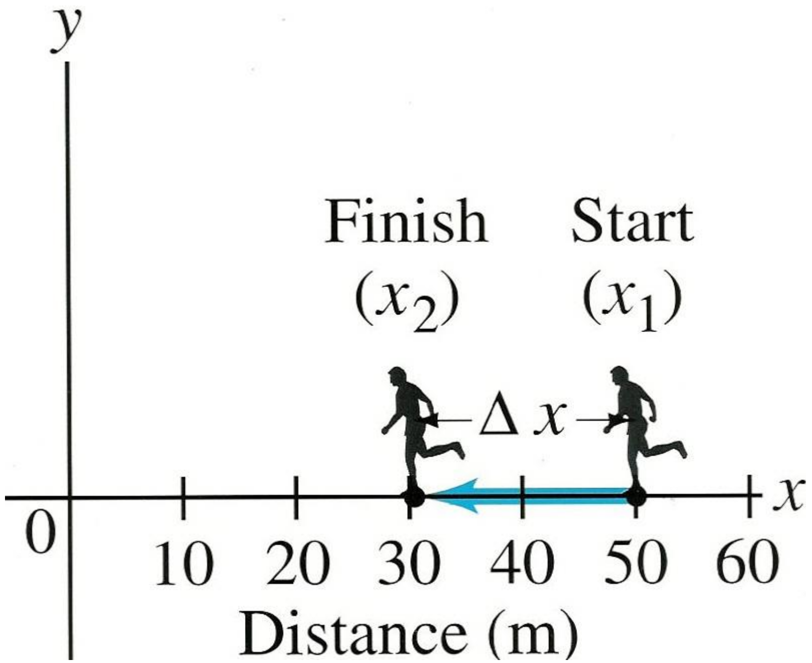
$$\bar{v} = \frac{\Delta x}{\Delta t} = (\mathbf{x_2} - \mathbf{x_1})/(\mathbf{t_2} - \mathbf{t_1})$$

Bar denotes average

Example 2-1

- Person runs from $\mathbf{x_1 = 50.0\ m}$ to $\mathbf{x_2 = 30.5\ m}$ in $\mathbf{\Delta t = 3.0\ s.}$ $\mathbf{\Delta x = -19.5\ m}$

West



East

Average velocity = $\overline{v}$ = **(Δx)/(Δt)**

= -(19.5 m)/(3.0 s) = -6.5 m/s. Negative sign indicates DIRECTION, (negative x direction)

Sect. 2-3: Instantaneous Velocity

- **Instantaneous velocity** ≡ velocity at any instant of time ≡ average velocity over an infinitesimally short time
- Mathematically, instantaneous velocity:

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

$\lim_{\Delta t \to 0}$ ≡ ratio $\frac{\Delta x}{\Delta t}$ considered as a whole for smaller & smaller Δ**t**.

Mathematicians call this a derivative.

Do not set Δ**t** = **0** because Δ**x** = **0** then & **0/0** is undefined!

⇒ **Instantaneous velocity v**

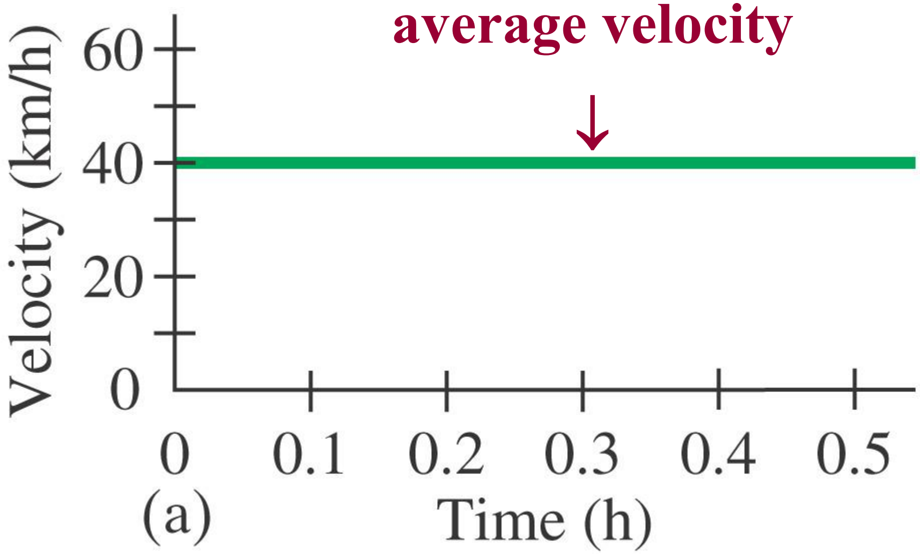
These graphs show

(a) constant velocity →

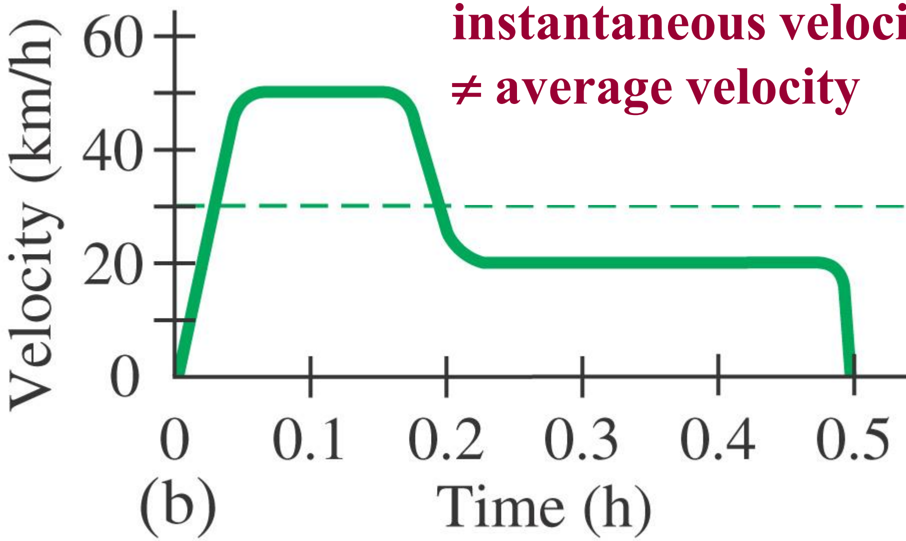
and

(b) varying velocity →

instantaneous velocity = average velocity



instantaneous velocity ≠ average velocity



Finding Velocity from a Position-Versus-Time Graph

Time interval 0 s to 0.5 s:

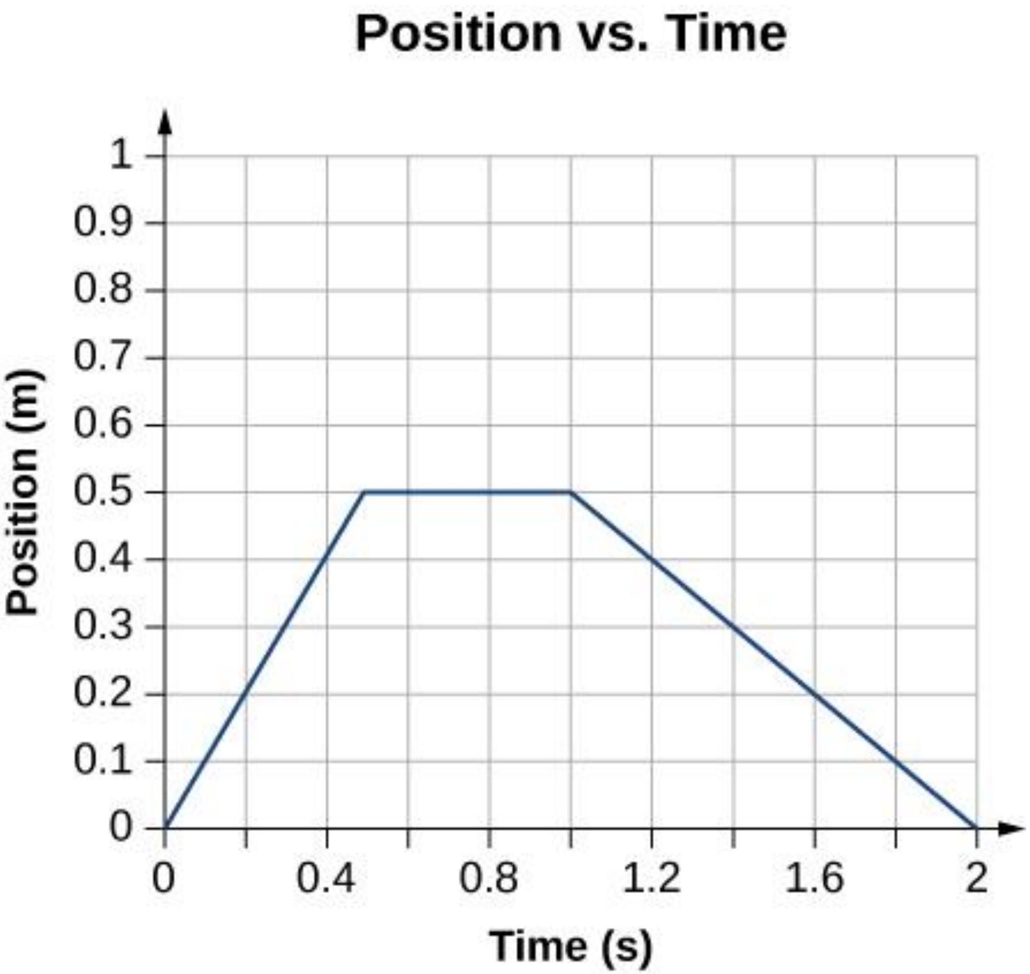
$$\bar{v} = \frac{x}{t} = \frac{0.5\,\text{m} - 0.0\,\text{m}}{0.5\,\text{s} - 0.0\,\text{s}} = 1.0\,\text{m/s}$$

Time interval 0.5 s to 1.0 s:

$$\bar{v} = \frac{x}{t} =$$ **0 m/s**

Time interval 1.0 s to 2.0 s:

$$\bar{v} = \frac{x}{t} = \frac{0.0\,\text{m} - 0.5\,\text{m}}{2.0\,\text{s} - 1.0\,\text{s}} = -0.5\,\text{m/s}$$



The position of a particle is given by $x(t) = 3.0t + 0.5t^3$ m.

Calculate the average velocity between 1.0 s and 3.0 s.

To determine the average velocity of the particle between 1.0 s and 3.0 s, we calculate the values of x(1.0 s) and x(3.0 s):

$$x(1.0\,\mathrm{s}) = \left[(3.0)(1.0) + 0.5(1.0)^3\right]\mathrm{m} = 3.5\,\mathrm{m}$$

$$x(3.0\,\mathrm{s}) = \left[(3.0)(3.0) + 0.5(3.0)^3\right]\mathrm{m} = 22.5\,\mathrm{m}.$$

Then the average velocity is

$$\bar{v} = \frac{x(3.0\,\mathrm{s}) - x(1.0\,\mathrm{s})}{t(3.0\,\mathrm{s}) - t(1.0\,\mathrm{s})} = \frac{22.5 - 3.5\,\mathrm{m}}{3.0 - 1.0\,\mathrm{s}} = 9.5\,\mathrm{m/s}.$$

Sect. 2-4: Acceleration

- Velocity can change with time. An object with velocity that is changing with time is said to be ***accelerating.***
- Definition: **Average acceleration** = ratio of change in velocity to elapsed time.

$$\bar{a} = \frac{\Delta v}{\Delta t} = (v_2 - v_1)/(t_2 - t_1)$$

Acceleration is a **vector**.

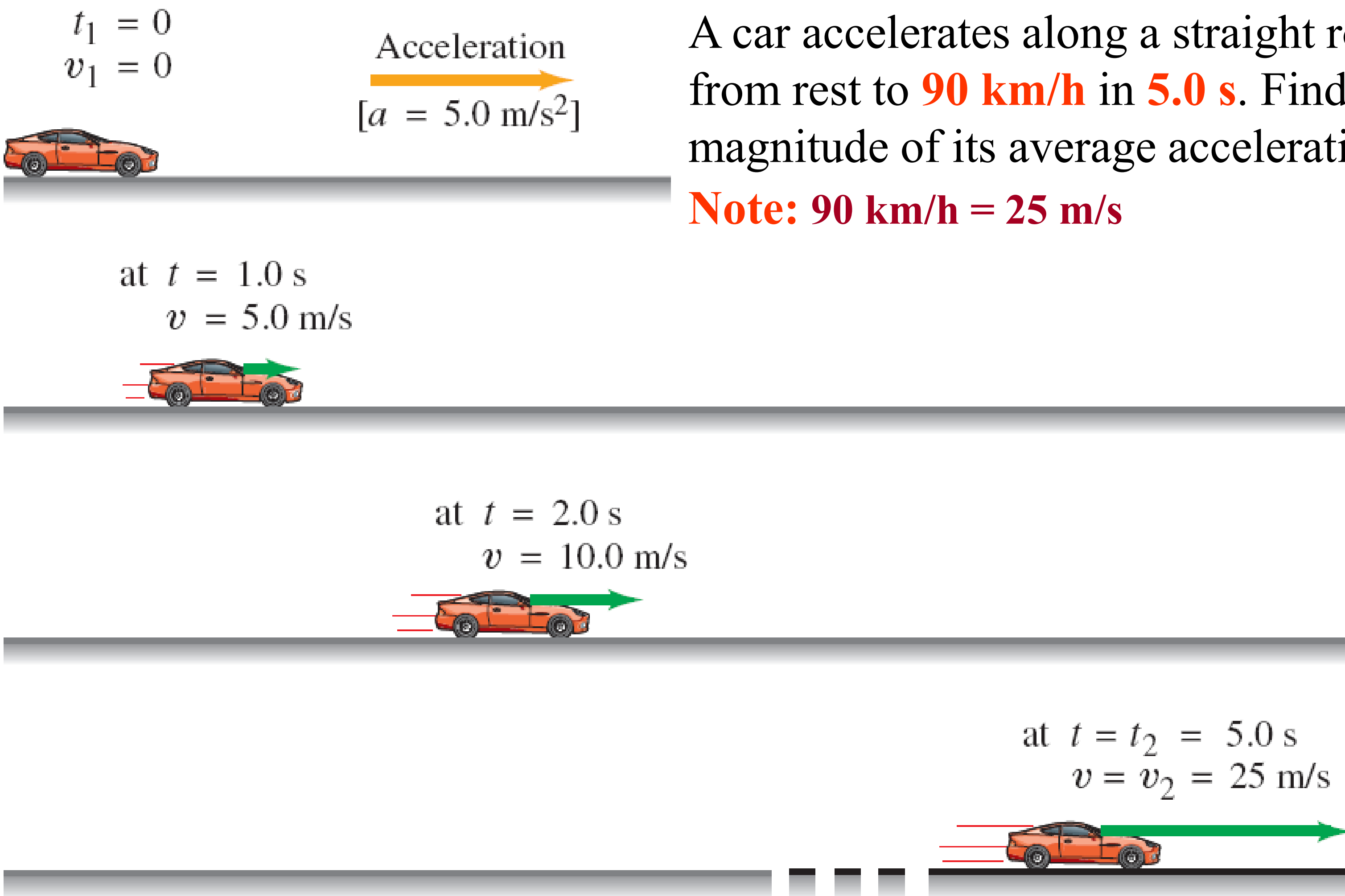
- **Instantaneous acceleration**

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

Example 2-3: Average Acceleration

A car accelerates along a straight road from rest to **90 km/h** in **5.0 s**. Find the magnitude of its average acceleration.

Note: 90 km/h = 25 m/s



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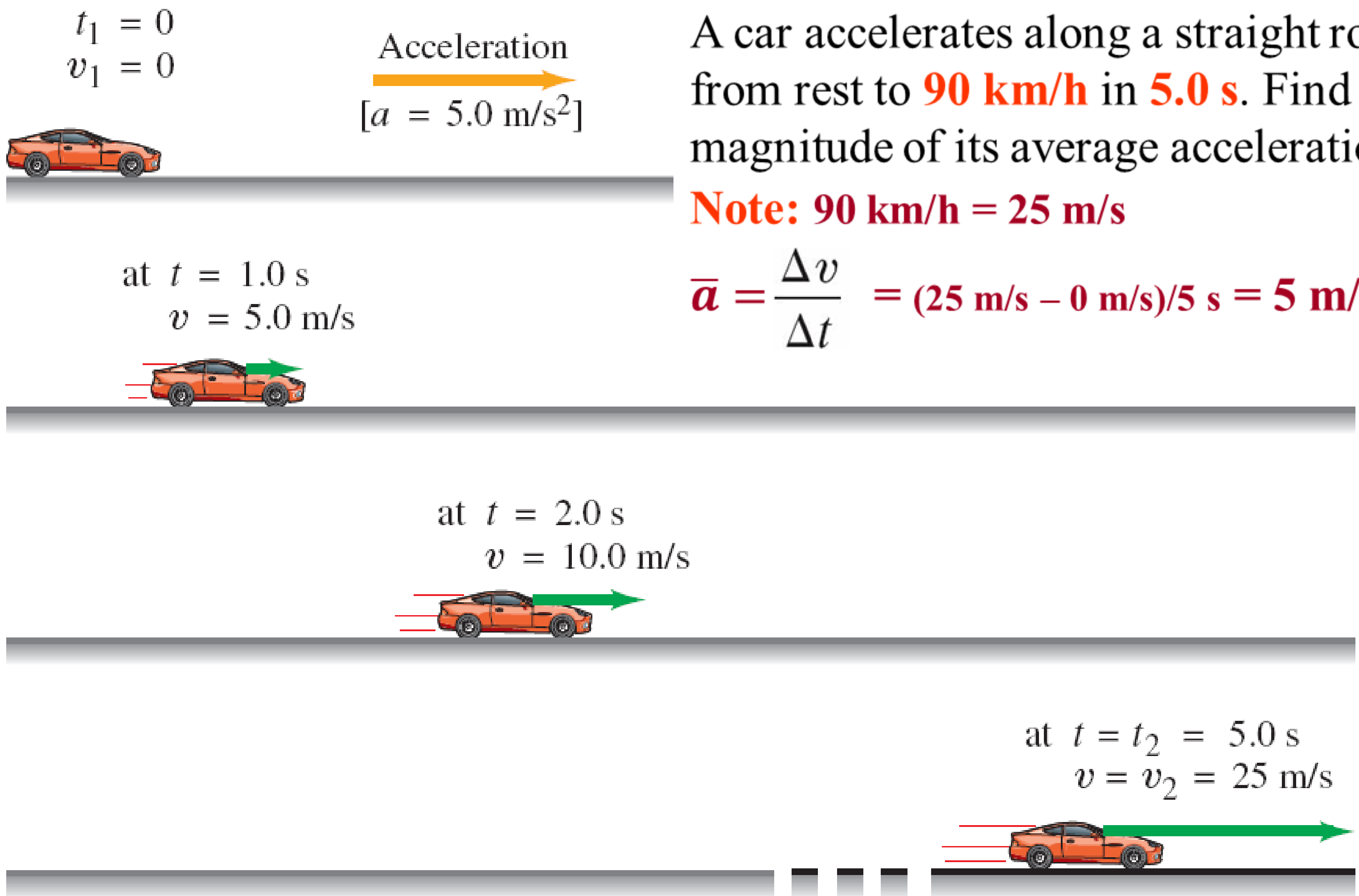

A car accelerates along a straight road from rest to **90 km/h** in **5.0 s**. Find the magnitude of its average acceleration.

Note: 90 km/h = 25 m/s

$$\bar{a} = \frac{\Delta v}{\Delta t} = (25\ \mathrm{m/s} - 0\ \mathrm{m/s})/5\ \mathrm{s} = 5\ \mathrm{m/s^2}$$

Conceptual Question

Velocity & Acceleration are both vectors.

Are the velocity and the acceleration always in the same direction?

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Velocity & Acceleration are both vectors.

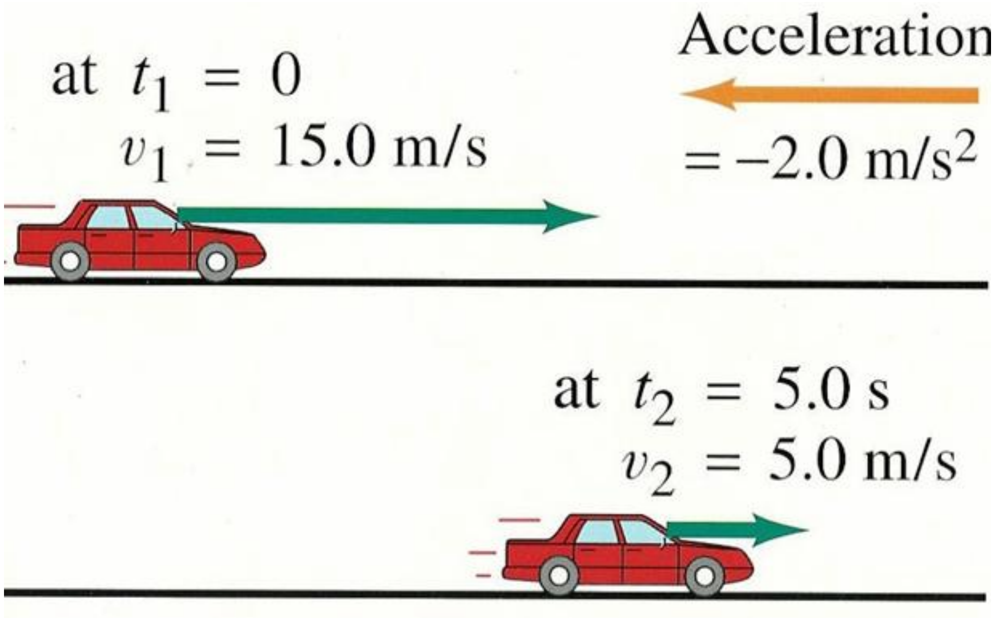
Are the velocity and the acceleration always in the same direction?

NO!!

If the object is ***slowing down***, the acceleration vector is in the opposite direction of the velocity vector!

Example 2-5: Car Slowing Down

A car moves to the right on a straight highway (positive **x-axis**). The driver puts on the brakes. If the initial velocity (when the driver hits the brakes) is **v_1 = 15.0 m/s**. It takes 5.0 s to slow down to **v_2 = 5.0 m/s**. Calculate the car's average acceleration.



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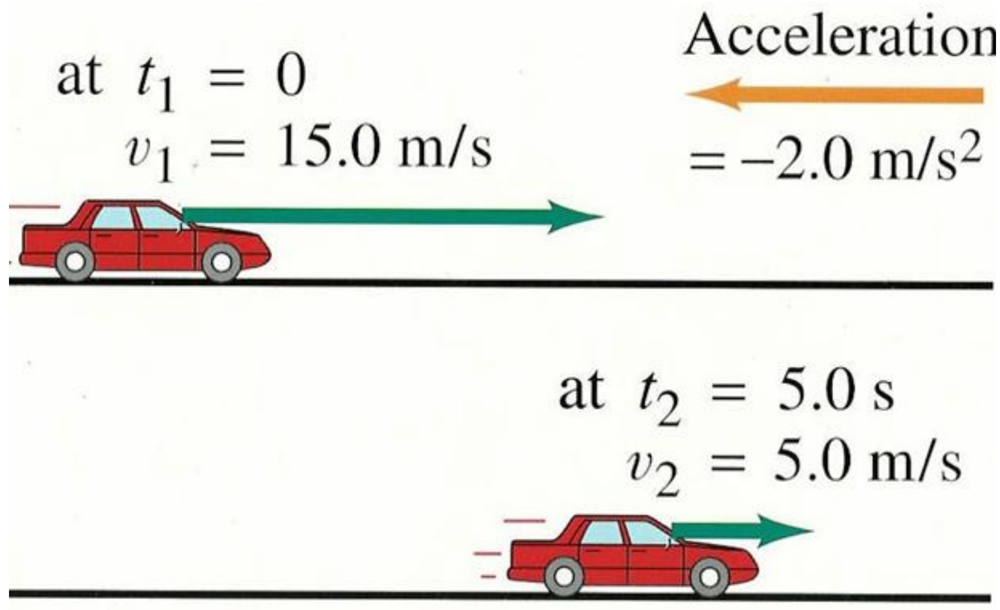
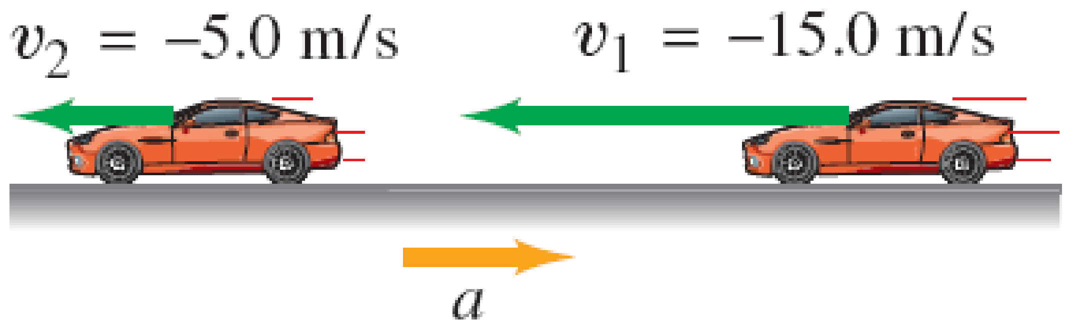


$$\mathbf{a} = \frac{\Delta v}{\Delta t} = (v_2 - v_1)/(t_2 - t_1) = (5\ m/s - 15\ m/s)/(5s - 0s)$$

$$\bar{a} = -2.0\ m/s^2$$

Deceleration

The same car is moving to the left instead of to the right. Still assume positive x is to the right. The car is decelerating & the initial & final velocities are the same as before. Calculate the average acceleration now.



$$a = \frac{v_2 - v_1}{\Delta t} = \frac{-5.0\ \text{m/s} - (-15.0\ \text{m/s})}{5.0\ \text{s}}$$

$$= \frac{-5.0\ \text{m/s} + 15.0\ \text{m/s}}{5.0\ \text{s}} = +2.0\ \text{m/s}.$$

- **"Deceleration":** A word which means "slowing down". We try to avoid using it in physics. Instead (in one dimension), we talk about ***positive & negative acceleration***.
- This is because (for one dimensional motion) deceleration does not necessarily mean the acceleration is negative!

Conceptual Question

Velocity & Acceleration are both vectors.

Is it possible for an object to have a zero acceleration and a non-zero velocity?

Conceptual Question

Velocity & Acceleration are both vectors.

Is it possible for an object to have a zero acceleration and a non-zero velocity?

YES!!

If the object is ***moving at a constant velocity***, the acceleration vector is zero!

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Velocity & acceleration are both vectors.

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YES!!

If the object is ***instantaneously at rest*** **(v = 0)** ***but is either on the verge of starting to move or is turning around & changing direction***, the velocity is zero, but the acceleration is not!