Analyzing Motion

Scalar & Vector

Scalar

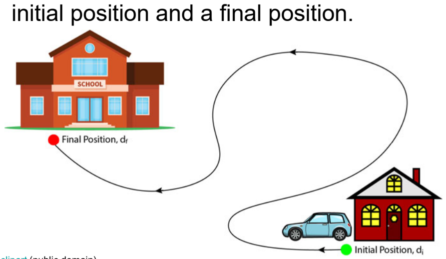
- A quantity that has magnitude (how big or how much) but does not take into account direction
  - mass
    - 70 kg

Vector

- A quantity that has both magnitude and direction
  - velocity
    - 30 m/s, North
- Note: we place an arrow above the symbol for the quantity to indicate it is a vector ($\vec{d}$).

Position

- Where an object is.
  - A car driving from home to school has an initial position and a final position.



Images: Openclipart (public domain)

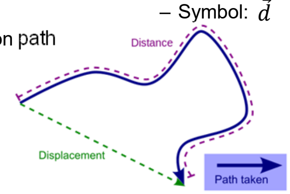
Distance & Displacement

Distance

- The length of the path between its initial position and its final position.
  - Depends on path taken
  - Symbol: d

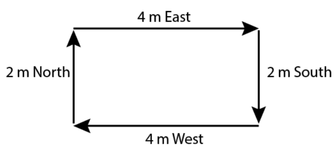
Displacement

- The net change in position of an object.
  - Includes the direction
  - Symbol: $\vec{d}$



Example

- A boy walks 4 m East, 2 m South, 4 m West and finally 2 m, North.



What distance does he travel?
12 m

What is his displacement?
0 m

Speed & Velocity

Speed

- The rate at which an object changes its location.
- The average speed is the total distance traveled divided by time

$$v_{av} = \frac{distance}{time} = \frac{d}{t}$$

Velocity

- The speed and direction of an object.
  - Includes direction
- The average velocity is the displacement divided by time

$$\vec{v}_{av} = \frac{displacement}{time} = \frac{\Delta \vec{d}}{\Delta t}$$

- Instantaneous speed or velocity
  - As an object travels from position A to position B, the speed or velocity will not necessarily remain the same.
  - Average speed or velocity does not take into account what happens between positions A and B.
  - The speed or velocity at a specific point in time is the instantaneous speed or velocity.
  - The speedometer on a car, for example, measures the instantaneous speed of the car.

Example

- A turtle leaves his house and moves 30 m North followed by 10 m South. The trip takes 20 s to complete. Calculate the average speed and velocity of the turtle.

Average Speed

$$v_{avg} = \frac{d}{t} = \frac{30 + 10\ m}{20\ s}$$

$$= 2\ m/s$$

Average Velocity

$$\vec{v}_{avg} = \frac{\Delta\vec{d}}{\Delta t} = \frac{30 - 10\ m}{20\ s}$$

$$= 1\ m/s, \text{North}$$

Acceleration

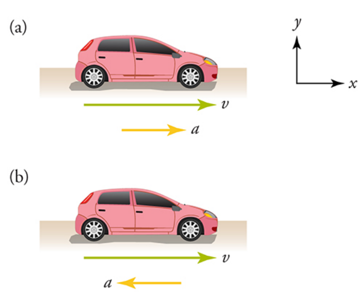
- The change in velocity divided by a period of time during which the change occurs.
  - Acceleration is a vector (includes direction)

$$\vec{a}_{av} = \frac{\Delta\vec{v}}{\Delta t}$$

- Since velocity is speed plus direction, the velocity will change if the speed changes or the direction changes.
- Therefore, an object will accelerate if its speed changes or its direction changes.

- The direction of the acceleration depends on
  - what direction the object is moving
  - how the speed is changing
- The general principle for determining the direction of acceleration is
  - **If an object is slowing down, then its acceleration is in the opposite direction of its motion**

(a) Car is speeding up



(b) Car is slowing down

Examples

- Which direction is the acceleration?
  - A car is speeding up while traveling North
    - North
  - A truck going forwards is slowing down
    - Backwards
  - A car is slowing down while traveling East
    - West
  - A truck is speed up while going backwards
    - backwards

Uniform Motion

- The object is moving with a **constant** velocity

Summary

- Distance d
- Displacement $\vec{d}$
- Average speed $v_{av} = \frac{distance}{time}$
- Average velocity $\vec{v}_{av} = \frac{\Delta\vec{d}}{\Delta t}$
- Average acceleration $\vec{a}_{av} = \frac{\Delta\vec{v}}{\Delta t}$

Unit Conversions

$$\frac{km}{h} \times \frac{1000}{3600} = \frac{m}{s}$$

Example:

$$50\ \frac{km}{h} \times \frac{1000}{3600} = 13.9\ \frac{m}{s}$$

Example

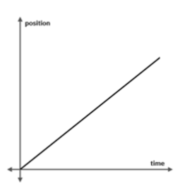
- A car starting from rest reaches a velocity of 100 km/h North in 5 s. What is the acceleration of the car?
  - First convert km/h to m/s

$$100\frac{km}{h} \times \left(\frac{1000}{3600}\right) = 27.78\ \mathrm{m/s}$$

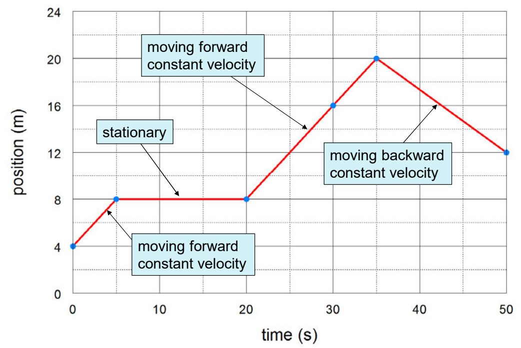
$$\vec{a}_{av} = \frac{\vec{v}_2 - \vec{v}_1}{\Delta t} = \frac{(27.78-0)}{5} = 5.6 \text{ m/s North}$$

Graphing

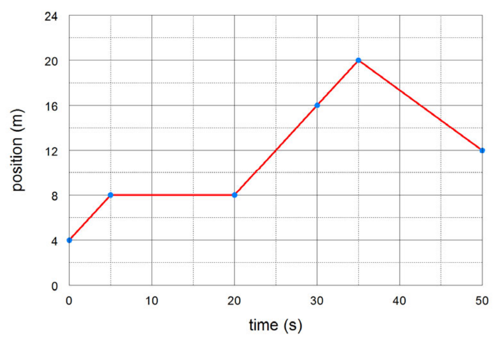
- If an object is moving at a constant velocity, then its position will be constantly increasing.
- A graph of its position vs time would look like this



- Describe the motion as shown in the following position-time graph.



- We can also use the graph to calculate the average velocity from 20 to 35 s.



- The slope of a position-time is average velocity

$$\vec{v}_{av} = slope = \frac{rise}{run}$$

$$= \frac{20 - 8}{35 - 20}$$

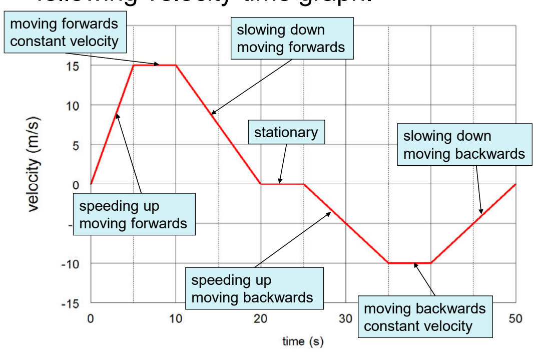
$$= \frac{12}{15}$$

$$\vec{v}_{av} = 0.8 \text{ m/s}$$

- If an object travels with a constant velocity, then a graph of velocity vs time would be a flat line.

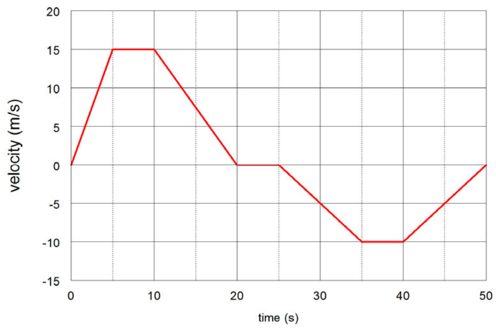
- If the object speeds up at a constant rate, then a graph of the velocity vs time would look like this

- Describe the motion as shown by the following velocity-time graph.



- A velocity-time graph can be used to calculate both displacement and acceleration.
  - The area under the curve is the displacement.
  - The slope is the acceleration

- Calculate the displacement and average acceleration from 10 - 20 s.



- Displacement

$$\Delta\vec{d} = \text{area} = \frac{\text{base} \times \text{height}}{2} = \frac{(20-10)(15-0)}{2}$$

$$\Delta\vec{d} = 75 \text{ m}$$

- Acceleration

$$\vec{a} = \text{slope} = \frac{\text{rise}}{\text{run}} = \frac{0-15}{20-10}$$

$$\vec{a} = -1.5 \text{ m/s}^2$$

- When an object is accelerating, the position-time graph is curved.