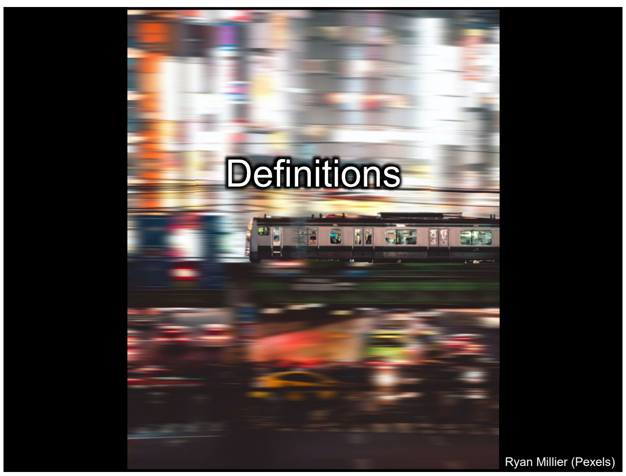
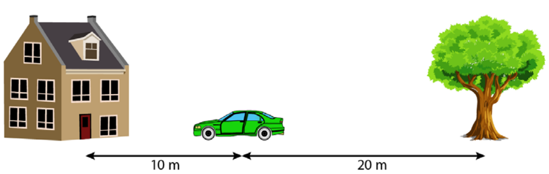


Position

- Where an object is at a particular time with respect to a reference frame.
  - Earth is often used as a reference frame.



- The car is 10 m to the right of the house.
- The car is 20 m to the left of the tree.

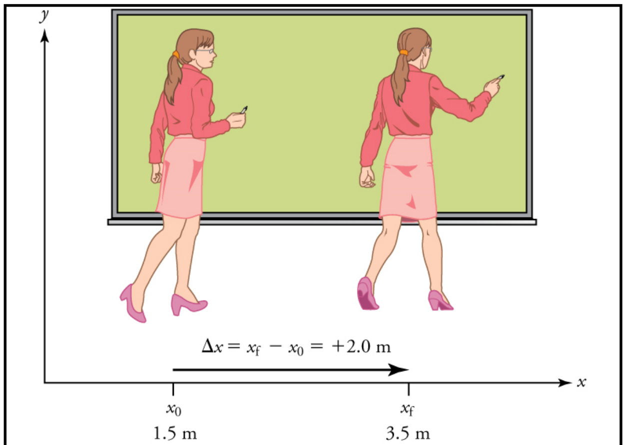
House – rdevries (public domain)
Car – Machovka (public domain)
Tree – GDJ (public domain)

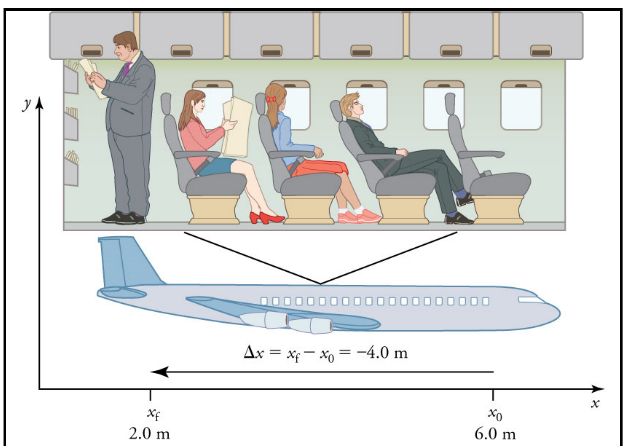
Displacement

- The change in position of an object.

$$\Delta x = x_f - x_0$$

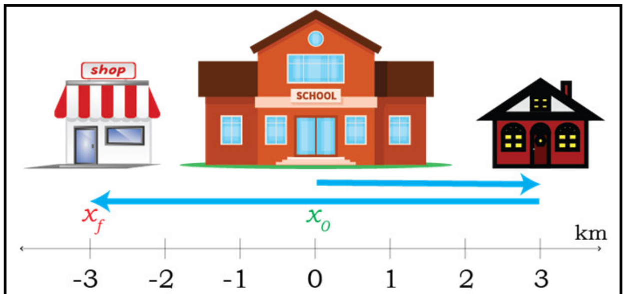
where:
Δx is the displacement
x_f is the final position
x_0 is the initial position





Distance

- Displacement is described in terms of direction, distance is not.
- Distance is defined to be the magnitude or size of displacement between two positions.
- Note that the distance between two positions is not the same as the distance traveled between them. Distance traveled is the total length of the path traveled between two positions.



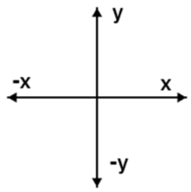
- A person travels from school to home and then to the store.
  - Displacement = -3 km
  - Distance = 3 km
  - Distance traveled = 9 km

Vectors and Scalars

- A **vector** is any quantity with both *magnitude* and *direction*.
  - Displacement (100 km North)
  - Velocity (110 km/h West)
- A **scalar** is any quantity that has a *magnitude*, but no direction.
  - Temperature (20°C)
  - Mass (70 kg)

Direction

- To describe the direction of a vector quantity, you must designate a coordinate system within the reference frame.



Note: It does not matter which direction is positive as long as the system is clear and consistent. Once you assign a positive direction and start solving a problem, you cannot change it.

Velocity

- **Average velocity** is displacement (change in position) divided by the time of travel.

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

Where:
$\bar{v}$ is the average velocity
x is the displacement
t is the time

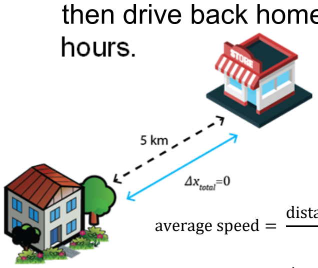
- The average velocity of an object does not tell us anything about what happens to it between the start and end points.
- The motion needs to be divided into smaller intervals to get more detailed information.
- **Instantaneous velocity**, v, is the average velocity at a specific instant in time (or over an infinitesimally small time interval).

Speed

- **Average speed** is the distance traveled divided by elapsed time.
- **Instantaneous speed** is the magnitude of instantaneous velocity.

Example

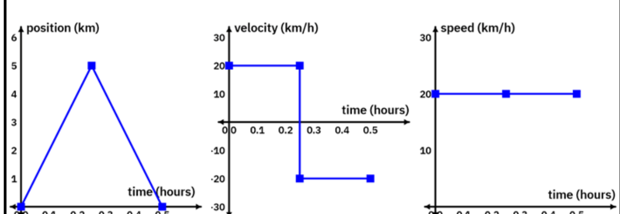
- You drive 5 km to school, turn around and then drive back home. The trip takes 0.5 hours.



$$\text{average speed} = \frac{\text{distance traveled}}{\text{time}} = 20\ \text{km/h}$$

$$\text{average velocity} = \frac{\Delta x}{t} = 0$$

- A graph can also be used to visualize the motion.



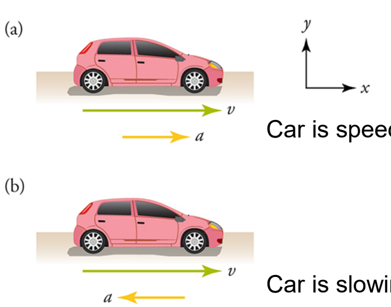
Acceleration

- **Average acceleration** is the rate at which velocity changes.

$$\bar{a} = \frac{\Delta v}{\Delta t} = \frac{v_f - v_0}{t_f - t_0}$$

Where:
$\bar{a}$ is the average acceleration
v is the velocity
t is the time

- Acceleration is a vector in the same direction as the change in velocity.
- Since velocity is a vector, it can change either in magnitude or in direction.
- Acceleration is therefore a change in either speed or direction, or both.
- When an object's acceleration is in the same direction of its motion, the object will speed up.
- When an object's acceleration is opposite to the direction of its motion, the object will slow down.



Car is speeding up

Car is slowing down

Image credit: Urone, Paul Peter, and Roger Hinrichs . "Defining Acceleration." In *Physics*. Houston, TX: OpenStax, 2020. https://openstax.org/books/physics/pages/3-1-acceleration (Creative Commons Attribution License 4.0)

Example

- A car with a velocity of 10 m/s accelerates to a velocity of 20 m/s in 20 seconds then drives at a constant velocity for 20 seconds. The car then slows down to 5.0 m/s in 20 seconds. Calculate the average acceleration for the first and last 20 seconds of the trip.

- First 20 seconds

$$\bar{a} = \frac{\Delta v}{\Delta t} = \frac{v_f - v_0}{t_f - t_0}$$

$$\bar{a} = \frac{20 - 10}{20} = 0.5 \text{ m/s}^2$$

- Last 20 seconds

$$\bar{a} = \frac{\Delta v}{\Delta t} = \frac{v_f - v_0}{t_f - t_0}$$

$$\bar{a} = \frac{5 - 20}{20} = -0.75 \text{ m/s}^2$$

- Graphing this motion gives...