MOTION

- **Motion** is described as **change in position** of an object relative to a **frame of reference**.

- **Frame of reference** is a coordinate system that is assumed to be **stationary**.

- **Kinematics** is the scientific description of motion **without** regard to its **cause**.
- Motion can be:

Uniform: Car cruising down a highway.

Non-uniform: Skier sliding down the slope.

Linear: Sprinter running along a straight line.

Non-linear: Golf ball flying in a trajectory.

VECTORS

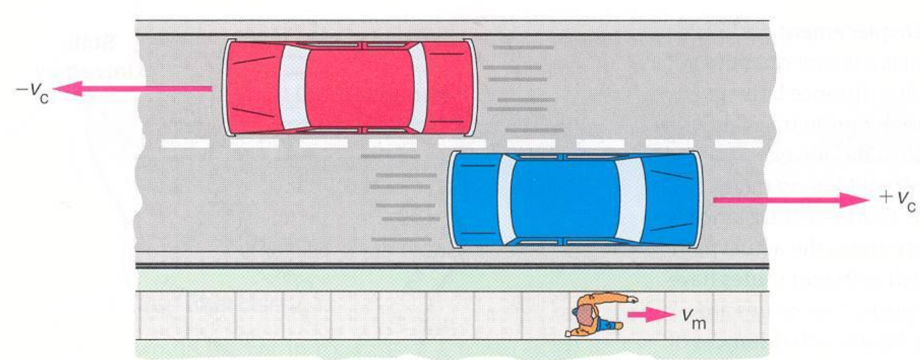
Two types of quantities exist in science:

- **Scalar**: those expressed only with a **magnitude**.
  Examples: mass, time, length, speed.

- **Vector**: those expressed with a **magnitude** and **direction**.
  Examples: velocity, acceleration, force.

- **Vectors** are represented by **arrows**, where the **length** represents the **magnitude**, and the **arrowhead** represents the **direction** of the vector.

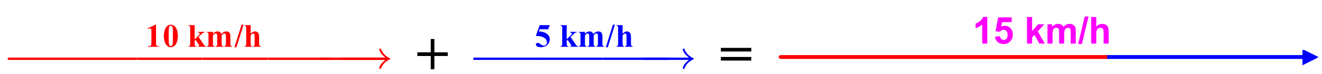
3 mi East →   ← **4 mi West**   **1 mi North** ↑



ADDITION OF VECTORS

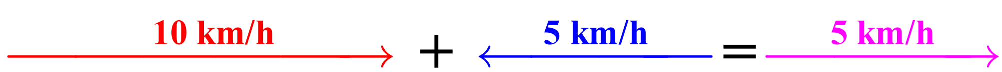
- When two vectors are **parallel** and in the **same direction**, their **resultant** is their **sum**.

Example:
A motor boat travels 10 km/h relative to the water. If the water flow is 5.0 km/h, what is the boat's speed relative to the shore, if the boat is heading directly downstream?



- When two vectors are **parallel** and **opposite in direction**, their **resultant** is their **difference**.

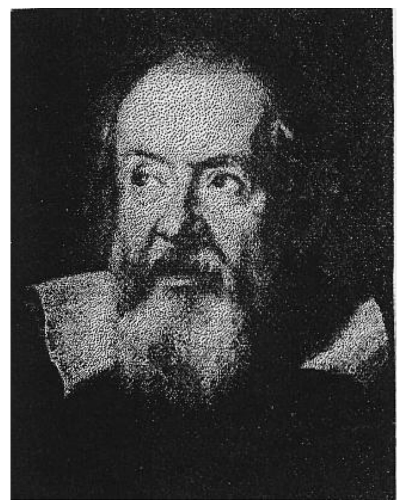
Example:
In the above problem, what is the boat's speed if it is heading upstream?



HISTORY OF MOTION

Study of motion goes back to the time of **Aristotle** (384-322 B.C.). In his view, two classes of motion existed: natural and violent. In **natural** motion, every object had a proper place, determined by its "nature". An object that was not in its proper place would "strive" to get there. Based on this view, Aristotle reasoned that an unsupported lump of clay, being of earth, would properly fall to the ground; and a puff of smoke, being of the air, properly rose to the sky. According to Aristotle's description of motion, the **distance** of an object from its natural place was the determining factor in its **motion**.

Violent motion resulted from pushing or pulling **forces**. Provided that a body was in its proper place, it would not move unless subjected to a force. Based on this view, the **normal state** of objects was **rest**.



Galileo Galilei (1564-1642), the pioneer scientist in moving physics into the modern era, broke rank with the traditional concepts of thinking. Galileo, an experimentalist, performed many experiments with falling objects from the Leaning Tower of Pisa. Through these experiments, he conclusively refuted Aristotle's concept of motion. Galileo realized that **time** was an important factor in describing motion. He studied change of various quantities with time, and introduced concept of **rate** to the study of motion.

SPEED

- **Speed** is the **rate** of change of **distance** with time.

$$\textbf{speed}=\frac{\textbf{distance}}{\textbf{time}} \qquad \textbf{s}=\frac{\textbf{d}}{\textbf{t}}$$

$$\textbf{Average speed } (\bar{s})=\frac{\textbf{Total distance}}{\textbf{Total time}}$$

- **Instantaneous speed** is speed at a given time.

Examples:

1. Determine the speed (km/h) of a biker who travels 10 km in 12 minutes.

$$s = \frac{d}{t} = \frac{10\text{ km}}{12\ \cancel{\text{min}}} \text{x} \frac{60\ \cancel{\text{min}}}{1\text{ h}} = 50\text{ km/h}$$

2. Sound travels at about 340 m/s. 5.0 seconds after seeing the lightning in a cloud, you hear thunder. How far away is the cloud?

$$d = s \text{ x } t = 340\frac{\text{m}}{\cancel{\text{s}}} \text{x } 5.0\ \cancel{\text{s}} = 1700\text{ m} \text{ or } 1.7\text{ km}$$

3. Mary jogs 1.5 miles from her home to the track in 20 min, and returns home in 25 min. What is Mary's average speed (mi/h) for the entire distance?

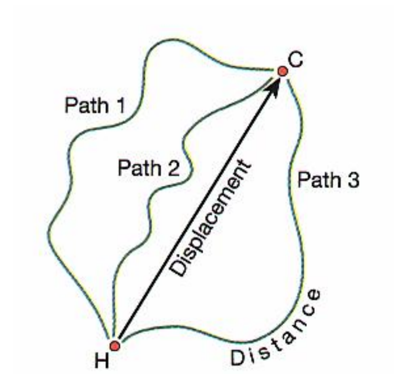
$$\bar{s} = \frac{\text{total distance}}{\text{total time}} = \frac{1.5\text{ mi}+1.5\text{ mi}}{20\ \cancel{\text{min}}+25\ \cancel{\text{min}}} \text{x} \frac{60\ \cancel{\text{min}}}{1\text{ h}} = 4.0\text{ mi/h}$$

4. A racecar travels 180 km in 72 minutes. What is the speed of the racecar in km/h?

VELOCITY

- **Velocity** is **speed** in a particular **direction** (**vector** quantity).

Distance vs. Displacement:



- **Displacement** is the **shortest** straight-line **distance** between two points. **Displacement** is a **vector** quantity.

- Velocity is the **rate** of change of **displacement** with **time**.

$$\textbf{velocity} = \frac{\textbf{displacement}}{\textbf{time}} \qquad v = \frac{\vec{d}}{\textbf{t}}$$

$$\textbf{Average velocity } (\bar{v}) = \frac{\textbf{Total displacement}}{\textbf{Total time}}$$

- **Instantaneous velocity** is velocity at a given time.

Examples:

1. A man walks 3.0 mile north, then turns and walks back to his starting point. If it took him 2.5 hours to complete his walk, determine his average speed and average velocity.

$$\bar{\textbf{s}} = \frac{\textbf{d}}{\textbf{t}} = \frac{\textbf{3.0 mi+3.0 mi}}{\textbf{2.5 h}} = \textbf{2.4 mi/h}$$

$$\bar{v} = \frac{\vec{\textbf{d}}}{\textbf{t}} = \frac{\textbf{0 mi}}{\textbf{2.5 h}} = \textbf{0 mi/h}$$

2. A jogger runs 200 m around a circular track in 25 seconds. What are his average speed and velocity?

ACCELERATION

- Acceleration is the **rate** of change of **velocity** with time.

$$\textbf{acceleration} = \frac{\Delta\ \textbf{velocity}}{\textbf{time}} = \frac{\Delta\ \textbf{v}}{\textbf{t}}$$

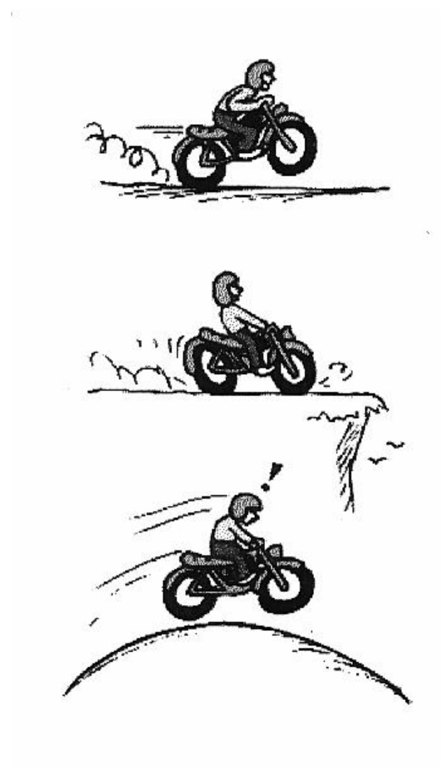
$$\textbf{a} = \frac{\textbf{final velocity-initial velocity}}{\textbf{time}} = \frac{\textbf{v}_f - \textbf{v}_0}{\textbf{t}}$$

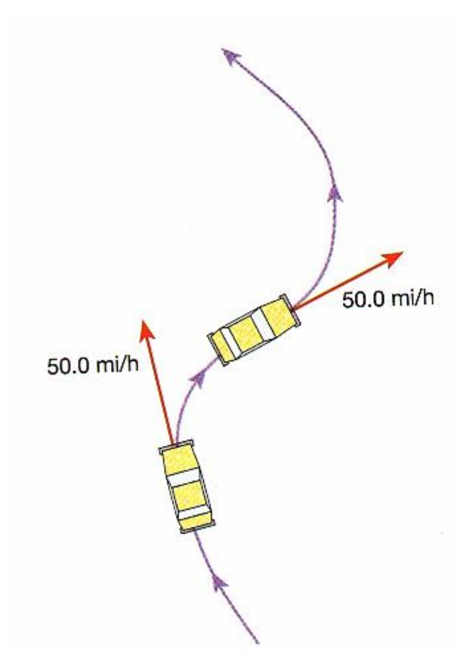
- **Acceleration** occurs whenever there is a **change in motion**:

Speeding up

Slowing down

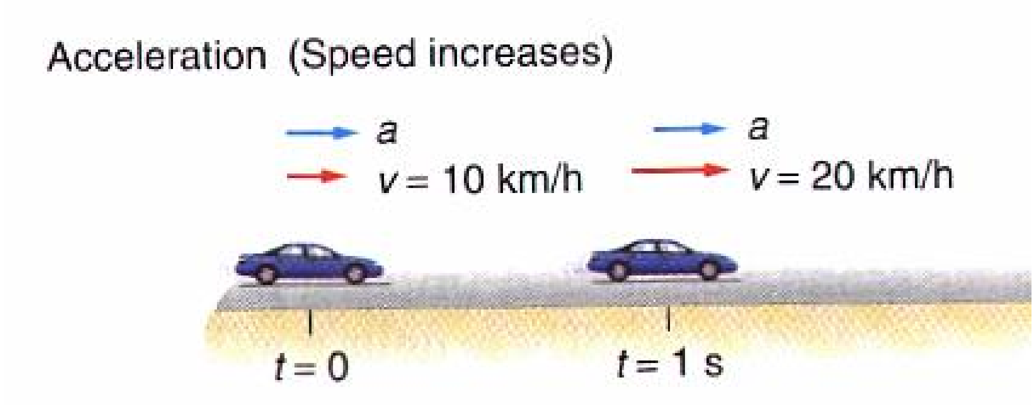
Turning



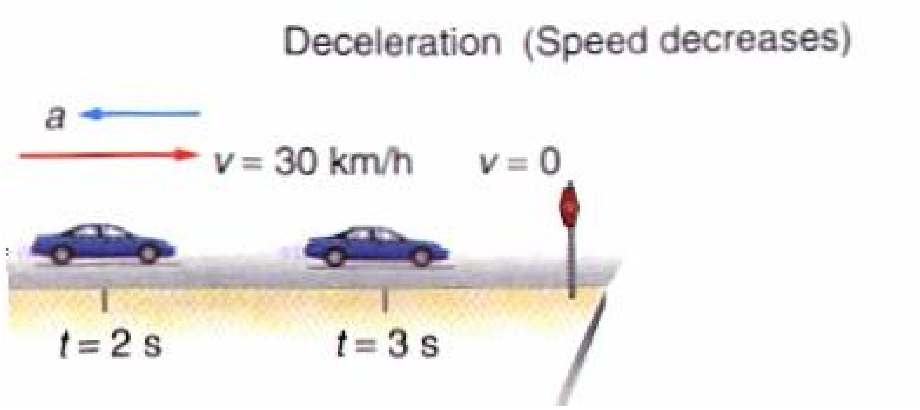


constant **speed**,
changing **velocity**

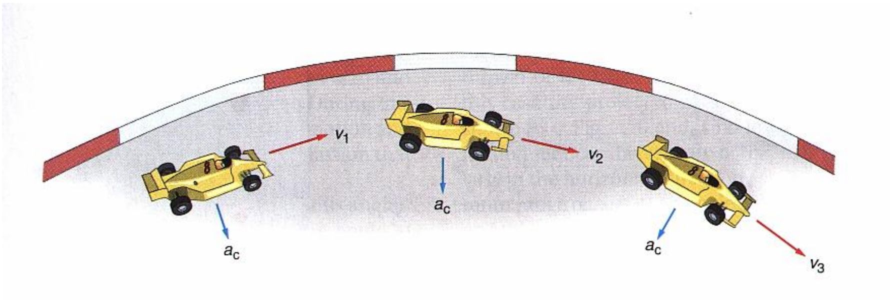
ACCELERATION vs. DECELERATION



- When **acceleration** and **velocity** are in the **same direction**, speed **increases**.



- When **acceleration** and **velocity** are in the **opposite direction**, speed **decreases**.



- When **acceleration** and **velocity** are **perpendicular** to each other, **turning** occurs.

Examples:

1. Starting from rest, an airliner achieves takeoff velocity of 100 m/s in 50 seconds. What is its acceleration?

$$\mathbf{a=\frac{v_f - v_0}{t}=\frac{(100\text{-}0)m/s}{50\ s}=2\ m/s^2}$$

2. A satellite's velocity is 15,000 m/s. After 30 seconds its velocity reaches 30,000 m/s. What is the satellite's acceleration?

$$\mathbf{a=\frac{v_f - v_0}{t}=\frac{(30000\text{-}15000)m/s}{30\ s}=\frac{15000\ m/s}{30\ s}=500\ m/s^2}$$

3. A car accelerates from rest and reaches a velocity of 25 m/s in 4.8 s. What is the car's acceleration?

- For an **accelerating** object, **velocity increases uniformly** with time:

$$\mathbf{v_f = v_0 + at}$$

$$\mathbf{v_f = at \quad (when\ initial\ velocity\ is\ zero)}$$

- For an **accelerating** object, **distance increases non-uniformly** with time:

$$\mathbf{d=\frac{1}{2}at^2}$$

Examples:

1. A rocket is given a constant acceleration of 2.0 m/s^2. What is its velocity 90 seconds after liftoff?

$$v_f = at = (2.0\ m/s^2)(90\ s) = 180\ m/s$$

2. The driver of a car traveling at a velocity of 30 m/s slams on the brakes and stops in 5.0 seconds.
   a) What is the car's acceleration?

$$\mathbf{a = \frac{v_f - v_0}{t} = \frac{(0 - 30) m/s}{5\ s} = -\ 6.0\ m/s^2}$$

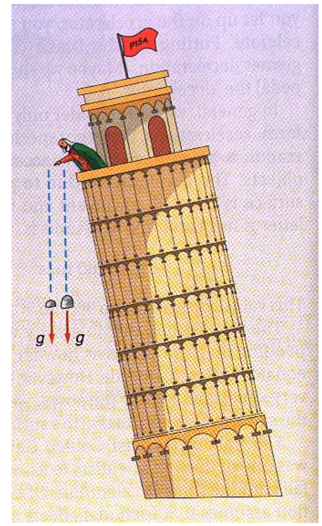
   b) How far does the car travel while braking?

$$\mathbf{d = \frac{1}{2} at^2 = \frac{1}{2}(6.0\ m/s^2)(5.0\ s)^2 = 75\ m}$$

3. A car accelerates from rest at a rate of 3.5 m/s^2 for 4.0 seconds.
   a) What is the car's velocity after 4.0 seconds?

   b) What distance does the car travel during this time period?

FREE FALL



- **Galileo** questioned Aristotle's view that objects fell because of their "earthiness". According to a popular story, he dropped stones of different masses from the tower of Pisa and determined experimentally how **mass** of objects affected their **rate of fall**.

- Galileo was the first person to correctly understand the motion of bodies **falling** under the force of **gravity** (**free fall**).

- In **free fall**, no **force** other than **gravity** acts on the object. (Air resistance is ignored for simplification).

- In **free fall**, all objects **fall** to the ground at the **same rate**, regardless of **mass**. They accelerate at the rate of 9.8 m/s^2 (**g**).

Velocity and distance of falling objects can be determined by using the following two equations:

$$v=gt \qquad d=\frac{1}{2}gt^2$$

where g = gravity ≈ 10 m/s^2

Examples:

1. A book falls from the balcony of a 12th-floor apartment and smashes to the ground 3.0 seconds later.
   a) How fast is it moving just before it hits the ground?

   $$v = gt = (10\ m/s^2)\ (3.0\ s) = 30\ m/s$$

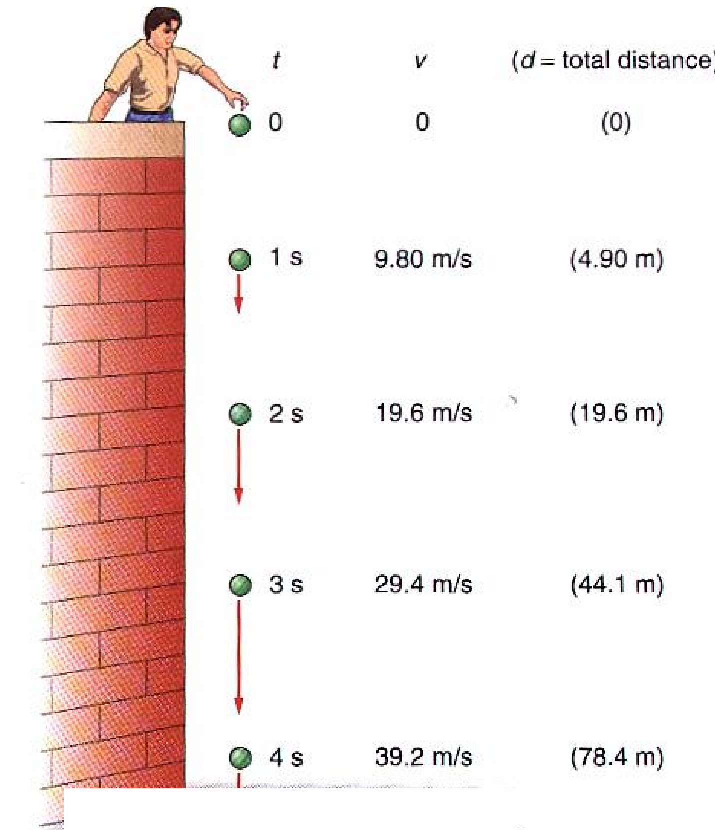
   b) What distance does the book fall?

   $$d=\frac{1}{2}gt^2=\frac{1}{2}(10m/s^2)(3.0s)^2=45m$$

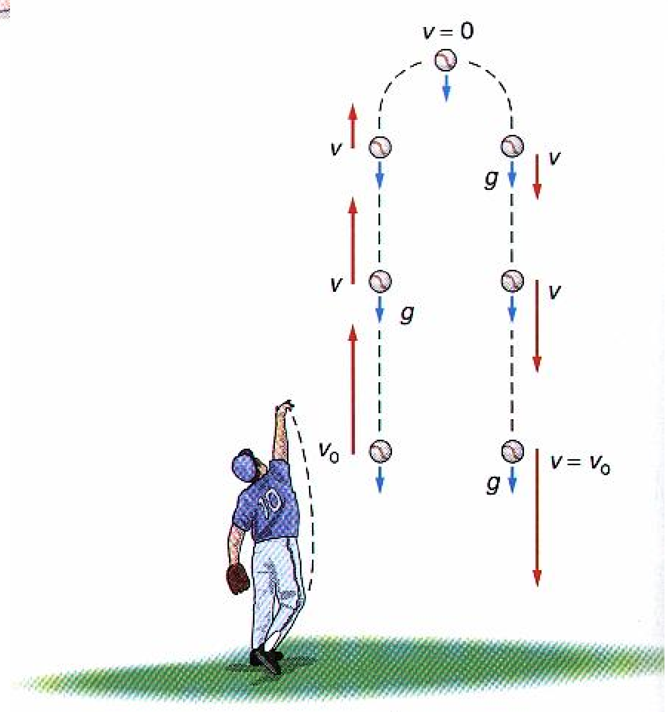
2. A rock is dropped in a well and hits the bottom in 6.0 seconds. How deep is the well?

FREE FALL

- In free fall, **velocity increases uniformly** with time, while **distance increases non-uniformly** with time.

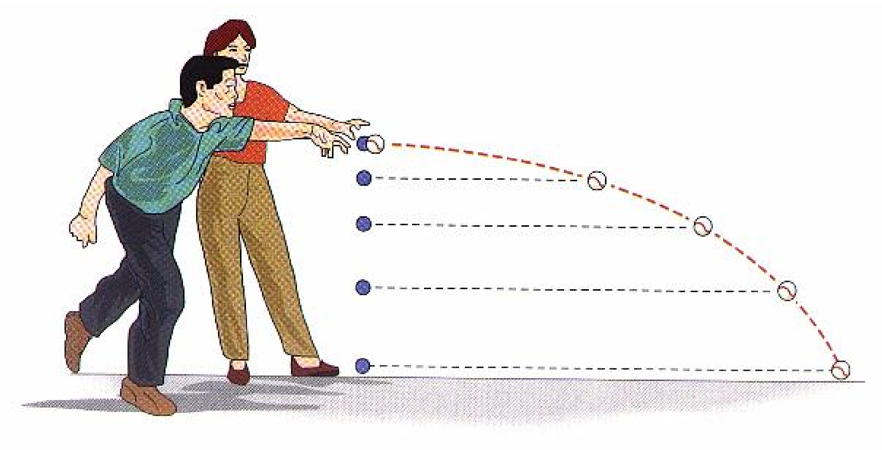


- An object thrown **straight upwards**, **slows** down because of gravity, **stops** at the top of its flight, and **accelerates** downwards to its starting point with a **velocity equal and opposite to the original velocity**.



PROJECTILES

- Motion in ***two dimensions*** can be analyzed by treating each dimension ***independently***.



- Distance traveled ***horizontally*** is only dependent on the horizontal ***velocity***.

- ***Height*** dropped depends only on gravity and can be treated as ***free fall***.

$$d_y=1/2\ gt^2$$

Example:

1. A rock thrown from a cliff with a horizontal velocity of 20 m/s reaches the bottom of the cliff in 5 seconds. A second rock is thrown from the same height with a horizontal velocity of 30 m/s.
   a) Which rock travels further? Explain why.

   b) Which rock strikes the ground first? Explain why.