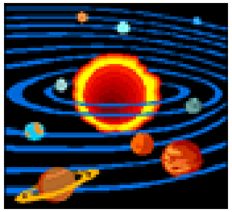
Ch 2: One-dimensional Motion

- How do we measure the velocity of something?
- Sampling rate
- Coordinate system
- Position vs time: $\{t_i , x_i(t_i)\}$ – Table/Graph
- Displacement in time interval: Δx in Δt
  depends only on end points, not path
- Average velocity: $\bar{v} = \dfrac{\Delta x}{\Delta t}$
- Example: Schenectady to NYC (150 mi) in 2.5 h
- Total distance traveled
- Average speed vs average velocity

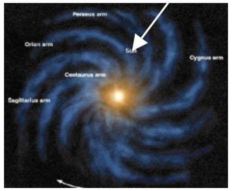
Am I moving?

- What’s my speed?
  - Earth is rotating:
    - v_1 ~ 500 m/s or ~ 1000 miles/h

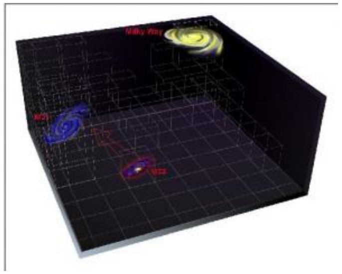
  - Earth orbits the sun:
    - v_2 ~ 5 km/s or ~ 3 miles/s or 11,000 miles/h



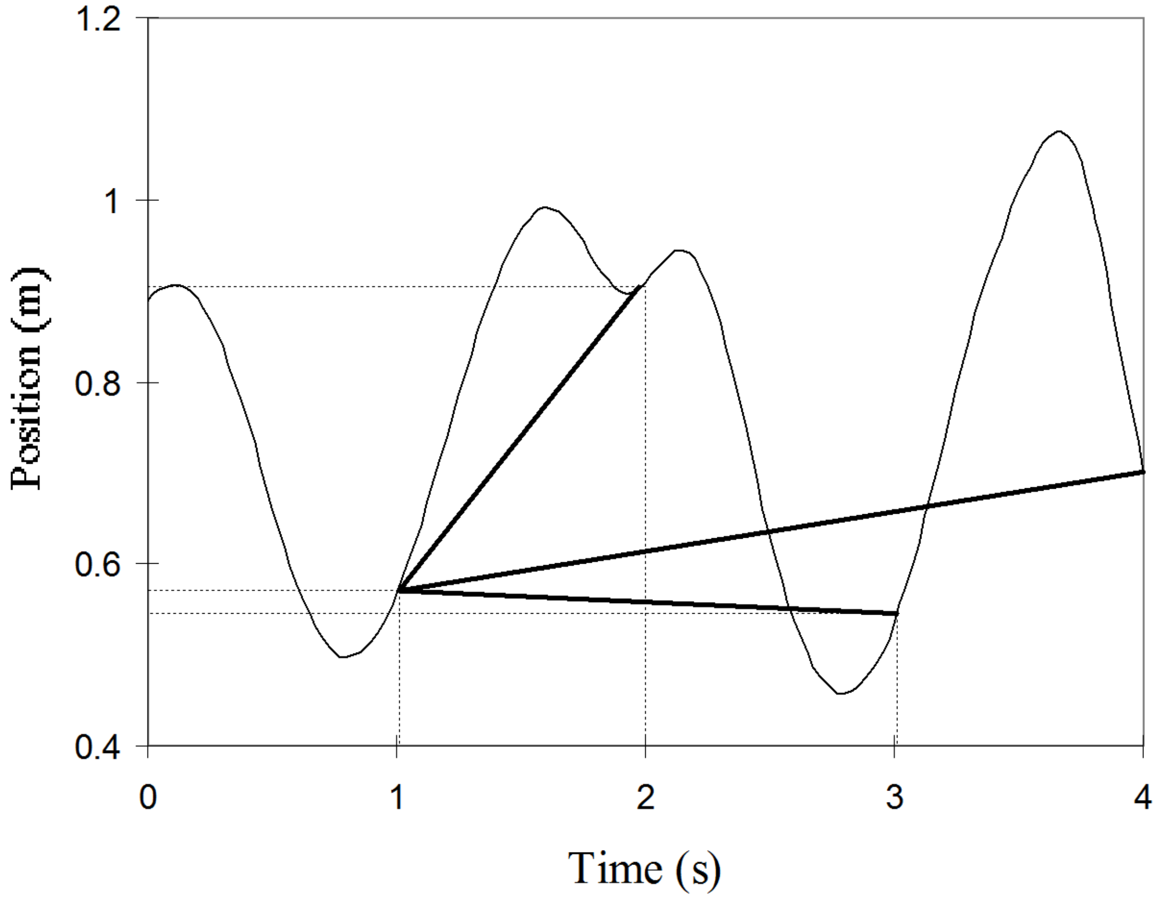
  - Earth rotates around Milky Way Galaxy:
    - v_3 ~ 200 km/s or ~ 120 miles/s or 400,000 miles/h



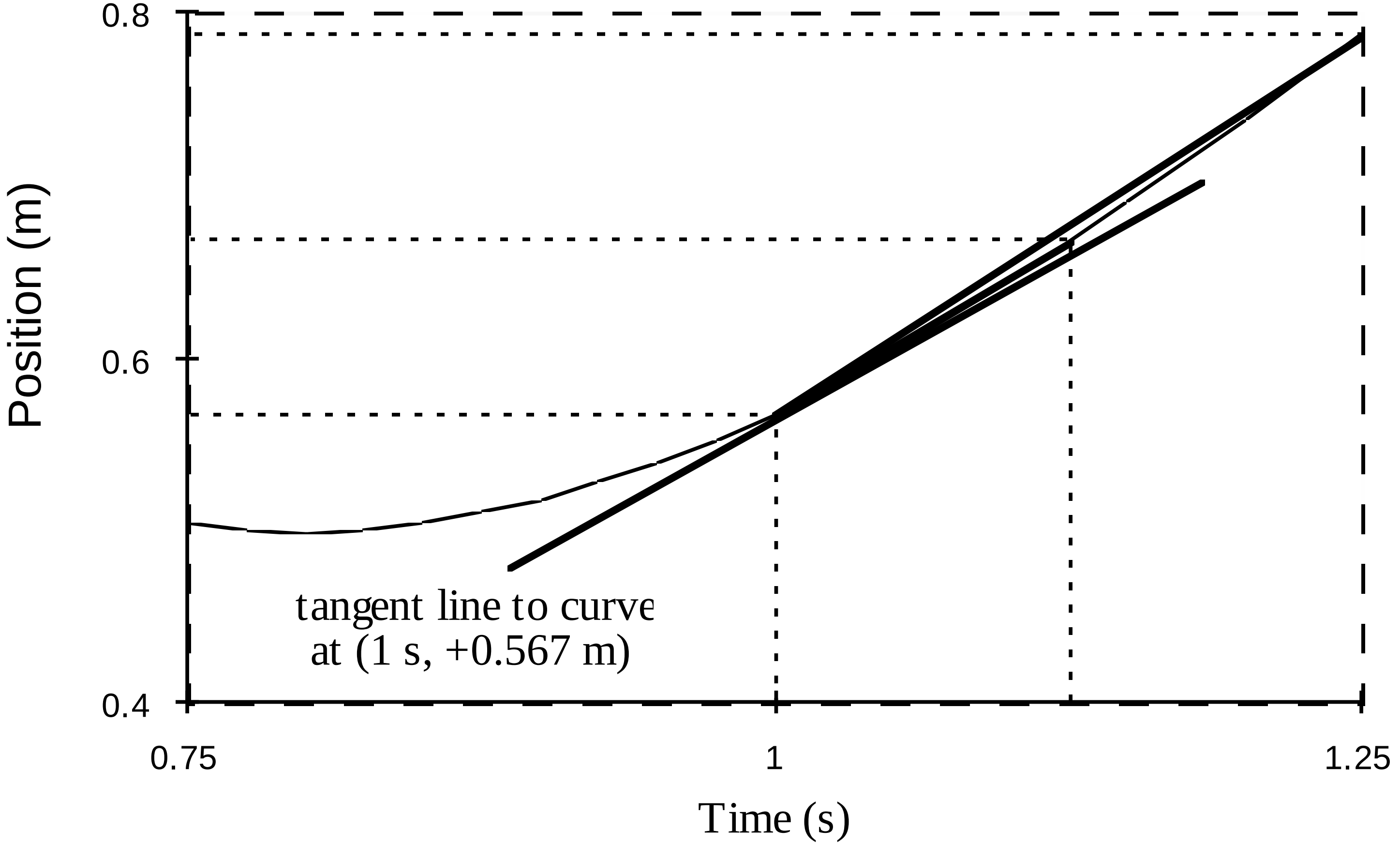
  - Milky Way Galaxy itself moving:
    - v_4 ~ 600 km/s or ~360 miles/s or 1,200,000 miles/h
    - This is about 0.2% of $c = 3 \times 10^8$ m/s



Motion of glider



Zoom-in of motion



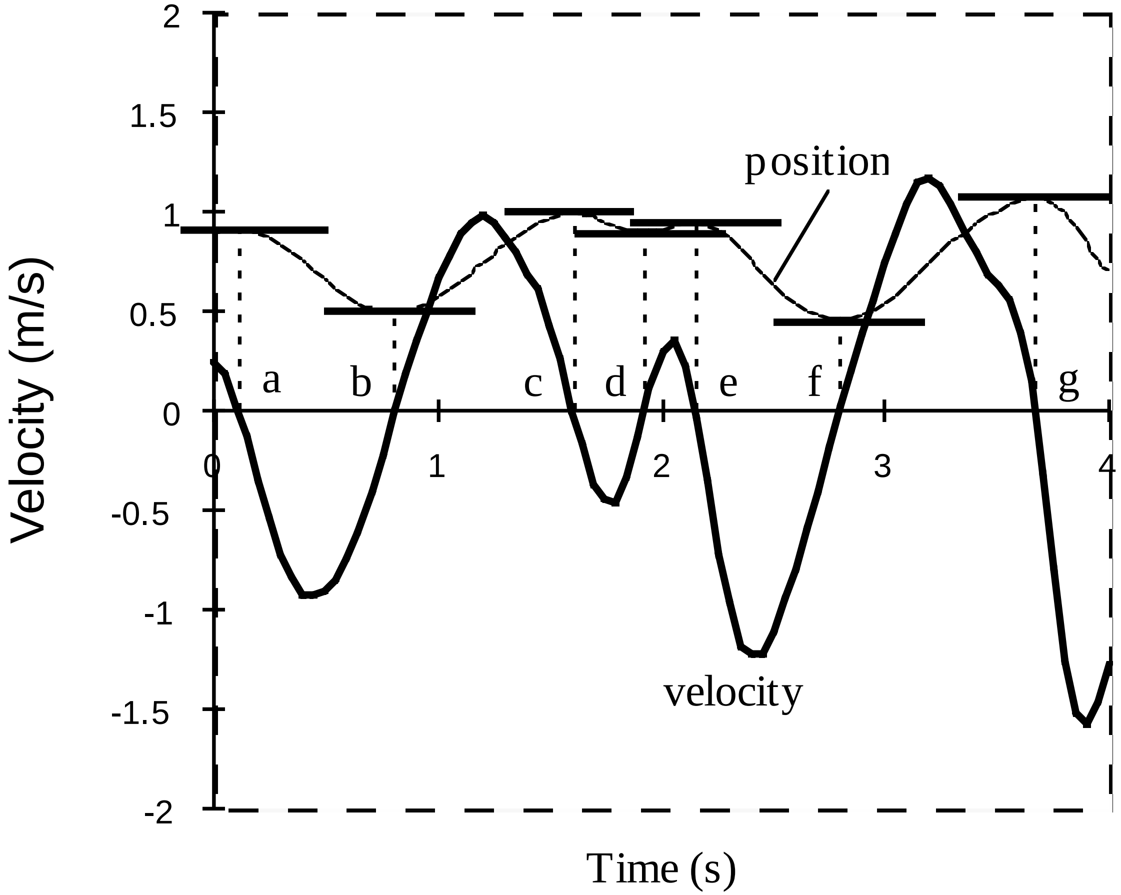
Instantaneous velocity

- As Δt approaches zero, Δx also does, but the ratio approaches a finite value:

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

- On a graph of x(t) vs t, dx/dt is the slope at a point on the graph
- Larger slope → faster
- Smaller slope → slower
- Positive slope → moving toward +x
- Negative slope → moving toward –x
- “slopemeter” can be used to move along the curve and measure velocity

Slopemeter velocity vs time



More on position/velocity vs time

- If v = constant, then v vs t is a horizontal line and x vs t is linear, with

  constant slope = v

- **In this case** we have that $v_x = \frac{dx}{dt} = \frac{\Delta x}{\Delta t}$

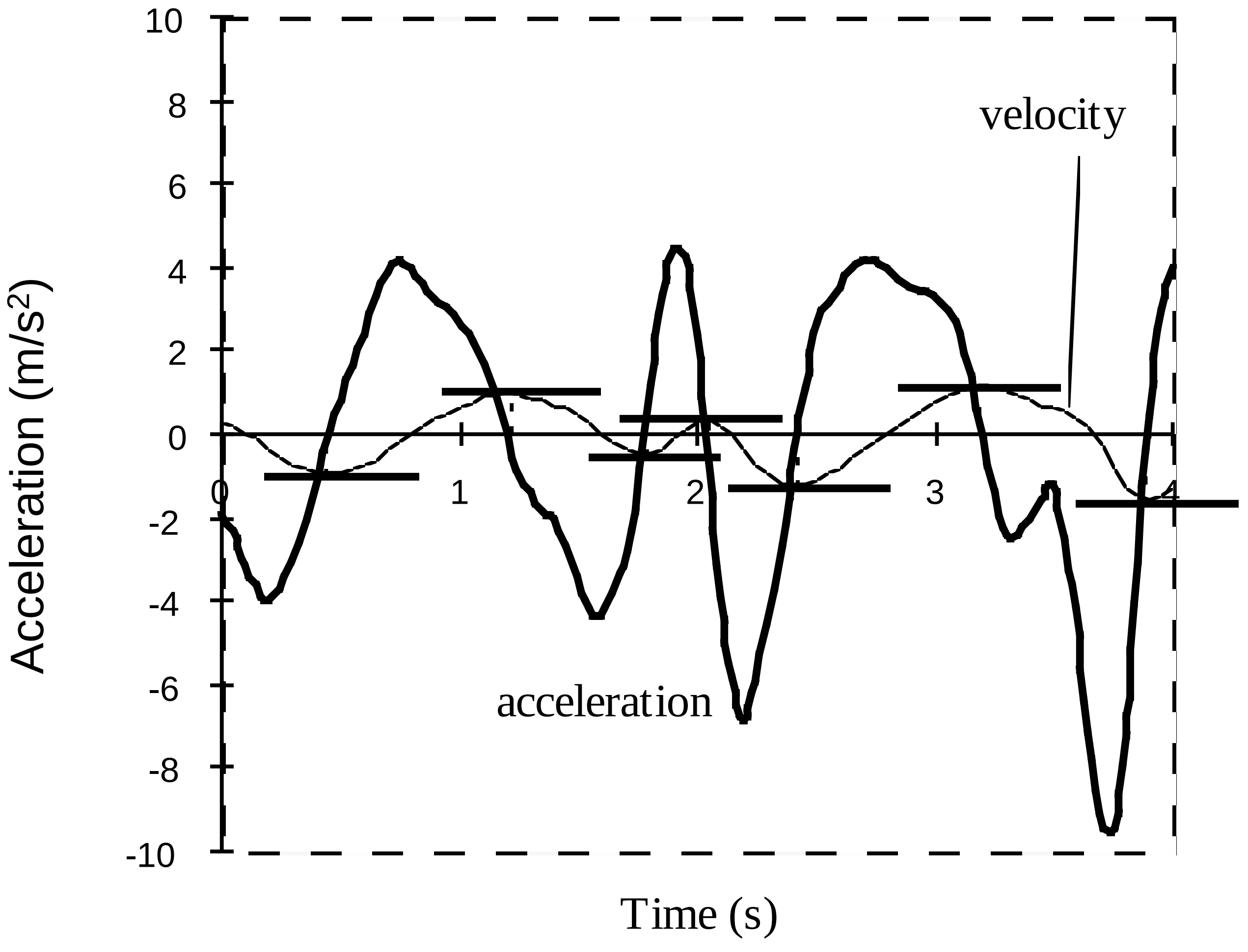
  so that $x_f = x_i + v_x \Delta t$

- Then the area under the v vs t graph is the displacement $Area = v_x \Delta t = x_f - x_i = \Delta x$
- If v is not constant then we need to introduce acceleration

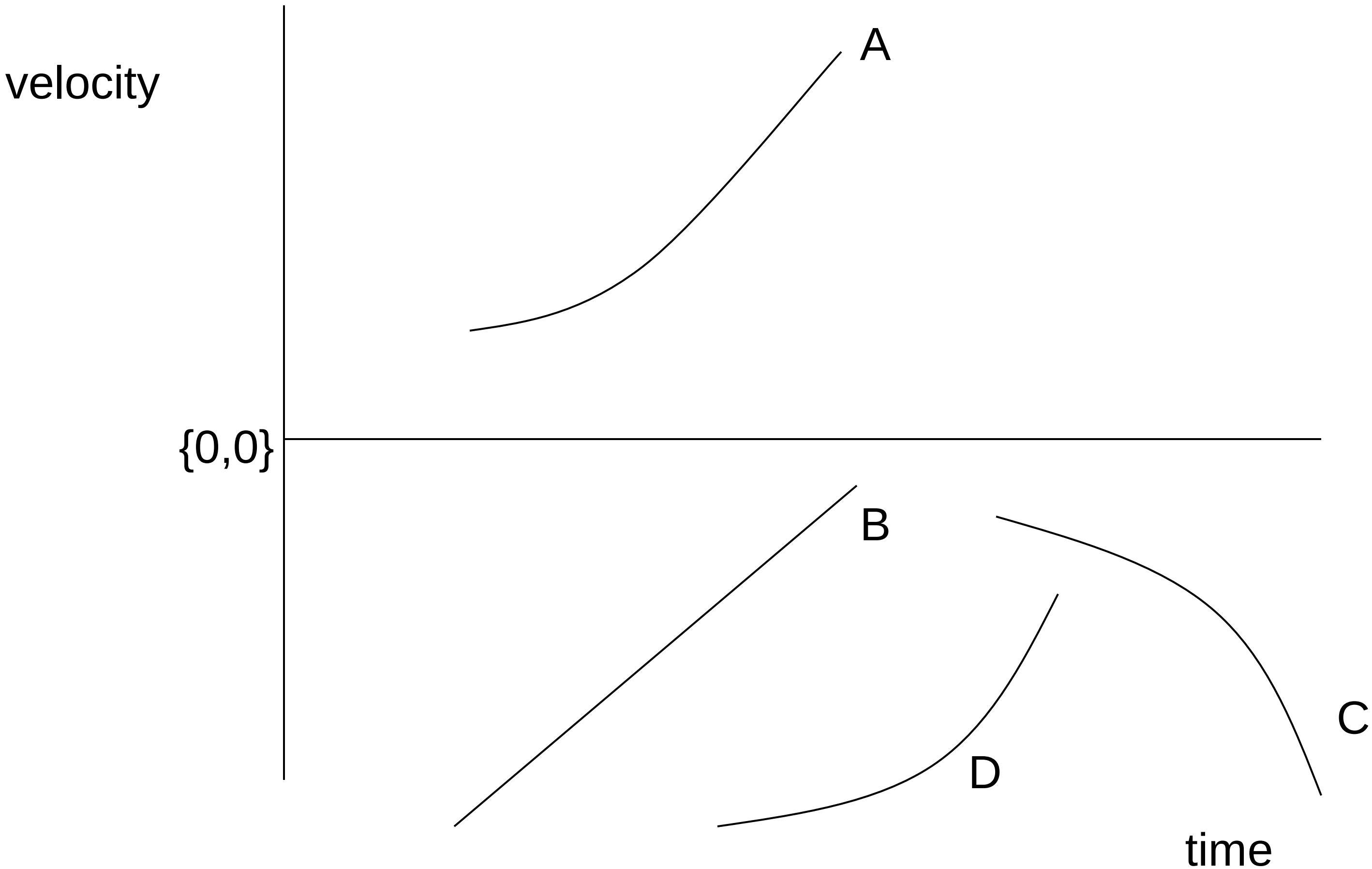
Changes in velocity – acceleration

- Average acceleration: $\bar{a} = \frac{\Delta \mathrm{v}}{\Delta t}$
- If v vs t graph is linear, then average acceleration is a constant
- If not, then use slopemeter idea to define instantaneous acceleration: $a = \lim_{\Delta t \to 0} \frac{\Delta \mathrm{v}}{\Delta t} = \frac{d\mathrm{v}}{dt}$
- Since $\mathrm{v}_\mathrm{x} = \frac{dx}{dt}$ we can write $a = \frac{d\mathrm{v}_\mathrm{x}}{dt} = \frac{d^2x}{dt^2}$
- So, *a* is the slope of a velocity vs time graph at a point
- Examples:
  - Draw possible v vs t graph for *a* = constant >0
  - Draw possible x vs t for that situation

Slopemeter to find accel. vs time



Are the velocity and acceleration greater, less than or = 0?



Forces in Nature

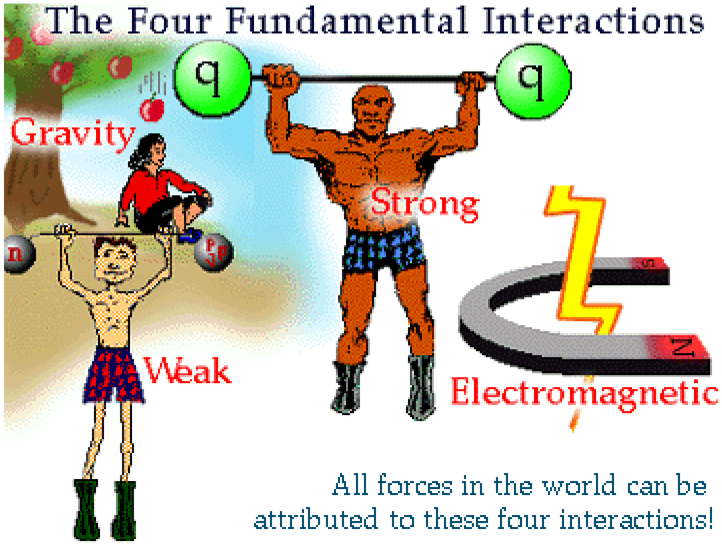
1. Gravity – near the earth's surface F = constant, but in general force between any two masses is:

   $$F = \frac{Gm_1m_2}{r^2}$$

   (don't worry about this now)

   where G = universal gravitational constant, m's are masses, and r is separation distance

2. Electromagnetic – all other forces that we experience including all pushes, pulls, friction, contact forces, electricity, magnetism, all of chemistry



1 and 2 are long-range forces – "action at a distance"

Nuclear forces:

3. Strong – holds nucleus together. Only acts within the nucleus.

4. Weak – responsible for radioactivity and the instability of larger nuclei.

How to understand action at a distance

- Two particles interact by exchanging “virtual” particles
- Each of the 4 basic forces (interactions) has its own “exchange” particle
- For electromagnetism it is the photon; for gravity, the graviton, for nuclear forces the gluon or the W and Z bosons; these travel at the speed of light and carry energy

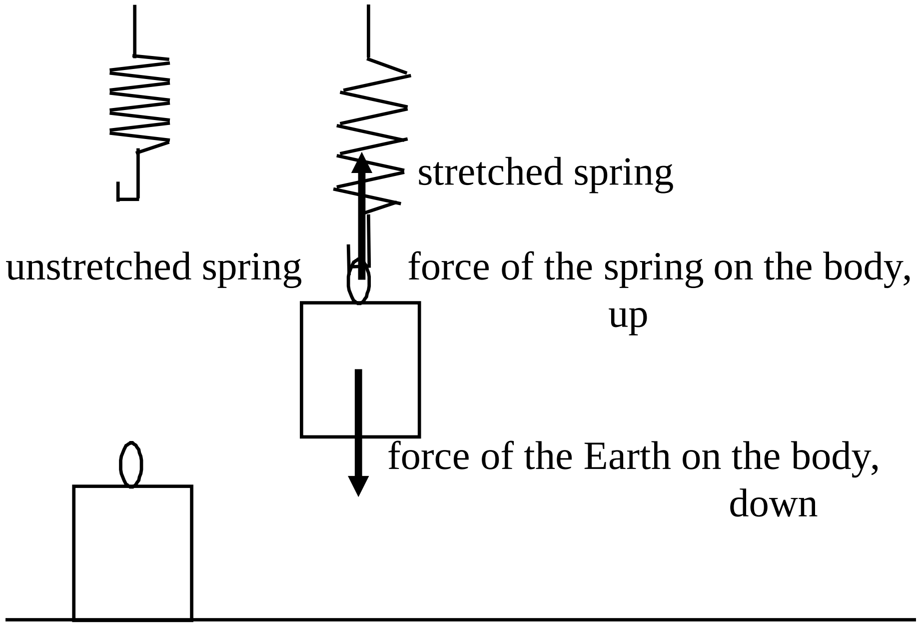
- Fields – each type of interaction establishes a field in space with an associated property; gravity has mass; electromagnetism has electric charge

Newton’s First Law

- *Constant velocity doesn't require an explanation (cause), but acceleration does*.
- Friction tricks our intuition here
- Newton’s First Law: in inertial reference frames, objects traveling at constant velocity will maintain that velocity unless acted upon by an outside force; as a special case, objects at rest will remain at rest unless an outside force acts. Inertia is tendency to stay at rest unless an outside force acts
- inertial reference frames: examples of inertial and non-inertial reference frames

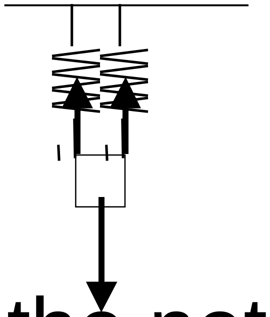
Forces I

- Contact vs field (action at a distance) forces
- How can we measure force?



Forces II

- Use springs to measure a push or pull force. Stretch of spring is proportional to force



- Can replace the net force on an object by a single calibrated stretched spring – a big stiff one for a large force, a small flexible one for a small force.

Mass and Acceleration

- Inertial mass m
- We can find the relative masses of two objects by exerting the same force on them (check with our springs) and measuring their accelerations:

$$\frac{m_2}{m_1} \equiv \frac{a_1}{a_2}$$

- This, with a 1 kg standard, defines inertial mass (different from weight, a force – later)

Newton's Second Law

- in an inertial frame of reference, the acceleration of a body of mass m, undergoing rigid translation, is given by

$$\vec{a} = \frac{\vec{F}_{\text{net on m}}}{m} \quad ,$$

where F_{net} is the **net external force acting on the body** (that is, the sum of all forces due to all bodies *other than the mass m* that push and pull on m).

- This is more usually written as F = m*a*
- *Units for mass (kilograms kg), force (newtons N)*
- Note that if $F_{net}=0$, then $a = 0$ and v = *constant*, giving Newton's First Law

Weight

- Weight is the force of gravity acting on a mass $F_g = mg$ where $g = GM_e/R_e^2$ (with numerical value $g = 9.8\ m/s^2$)- Note: the mass does not have to be accelerating to have weight !!
- Gravitational mass = inertial mass
- Mass and weight are different: on the moon you would have your same mass, but a weight that is much less, about 1/6 that on earth, due to the weaker pull of the moon
- Also, you weigh a bit less on a tall mountain since the earth pulls on you with a weaker force – this is responsible for the lower boiling point of water at high altitudes

Newton's Third Law

- An acceleration requires an external force – what is that for a runner or bicyclist or flying bird or swimming fish?
- What you push against is very important – forces are interactions between objects
- When one body exerts a force on a second body, the second exerts a force in the opposite direction and of equal magnitude on the first; that is,

$$\vec{F}_{2\,\mathrm{on}\,1} = -\vec{F}_{1\,\mathrm{on}\,2}$$

- These are sometimes called action-reaction pairs

Third Law Examples

- Identify the interaction pairs of forces. In each case draw a free-body diagram:
  - A book resting on a table
  - A book resting on a table with a second book on top of it
  - A cart being pulled by a horse along a level road
  - A heavy picture being pushed horizontally against the wall

Diffusion

- Why is diffusion important??
- Examples of diffusion = Brownian motion = thermal motion
- Random walk in one dimension
- Mean square displacement definition in 1 dim

$$< \Delta x^2 > = 2Dt$$

- In 2 or 3 dim: 2Dt $\rightarrow$ 4Dt $\rightarrow$ 6Dt

Diffusion Problem

- ***Example 2.9*** The diffusion coefficient for sucrose in blood at 37^{o}C is 9.6 x 10^{-11} m^2/s. a) Find the average (root mean square) distance that a typical sucrose molecule moves (in three-dimensions) in one hour. b) Now find how long it takes for a typical sucrose molecule to diffuse from the center to the outer edge of a blood capillary of diameter 8 μm.