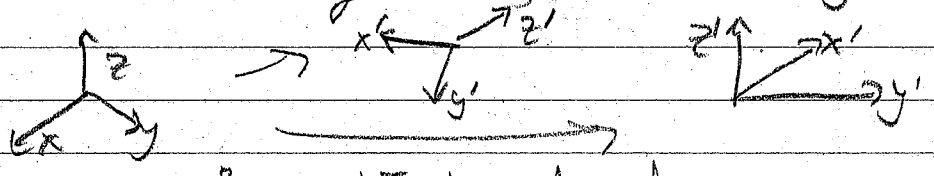
Intro + Newton's Laws

- Hints for learning the material (from textbook)
  - Practice! • HW is worth a lot, and it is the only way to learn the material well.
    - Find more practice problems if you need them
  - Reading: assignments give you another point of view.
  - IDEA method for problems
    - Identify what it's asking and what is relevant
    - Develop: organize information, figure out the laws + math to use
    - Evaluate: solve it
    - Assess: check units, limits as variables change

- Space + Time
  - Fundamental assumptions in Newtonian mech
    - Continuous in nature
    - There is a standard scale for the universe
    - There is an absolute time } vs relativity
    - Geometry is Euclidean }
    - No limits to accuracy } vs quantum

  - Positions
    - Time t: all observers agree up to choice of $t=0$
    - Spatial position (x,y,z) is given by coords. w.r.t 3 ⊥ axes
      + Choose location of origin $(x,y,z) = (0,0,0)$
      + Choose orientation by rotating or reflecting



Always use the right-hand rule

- Positions are vectors
  + Can write as components $r_i = (x,y,z)$ $(i=1,2,3)$ or sum over basis vectors $\vec{r} = x\hat{i} + y\hat{j} + z\hat{k}$

(we may use $\hat{x}, \hat{y}, \hat{z}$ as basis vectors)

+ The vector $\vec{F}$ is a mathematical object independent of choice of axis. The components are not. The basis vectors tell us the axes

Newton's 1st Law

"An object remains in the same state of motion unless acted on by an external force"

- Defines inertial reference frames : in these frames, objects do not accelerate on their own
  - Inertial frames move at constant velocity wrt each other
- Relativity principle: physics is the same in all inertial frames
  - Only relative velocities + positions matter : forces between objects depend on $\vec{r}_i - \vec{r}_j$ or $\vec{v}_i - \vec{v}_j$
  - We can work in a convenient reference frame.

Newton's 3rd Law

"Any action has an equal but opposite reaction"

- By the relativity principle, any force on object i is due to some other object j
  - For example $\vec{F}_{grav} = m_i \vec{g}$ (gravitational force) is really the force on i by the earth
  - Define the force on i by j as $\vec{F}_{ij}$ ($\vec{F}_{grav} = \vec{F}_{i\oplus}$)
- The 3rd law states $\vec{F}_{ij} = -\vec{F}_{ji}$ (note about electrodynamics)
- Consider an object made of particles i, j. Forces are
  - $\vec{F}_i = \vec{F}_{i\,ext} + \sum_j \vec{F}_{ij}$
  - So the total force on all constituents is

$$\vec{F} = \sum_i \left(\vec{F}_{i\,ext} + \sum_j \vec{F}_{ij}\right) = \vec{F}_{ext} + \frac{1}{2}\sum_{ij}\left(\vec{F}_{ij} + \vec{F}_{ji}\right)$$

$$= \vec{F}_{ext}$$

  - Internal forces all cancel; only external forces change the motion of an object

Newton's 2nd Law

$\vec{F}_i = m_i \vec{a}_i$ where $\vec{F}_i$ = total force on object i

- This gives the equations of motion (EOM)

- Definitions
  - m_i = inertial mass of i
  - The position $\vec{r}_i(t)$ has velocity $\vec{v}_i = \frac{d\vec{r}_i}{dt}$ + acceleration $\vec{a}_i = \frac{d\vec{v}_i}{dt}$

    We will also use dot notation for derivatives

    $\vec{v}_i = \dot{\vec{r}}_i$, $\vec{a}_i = \dot{\vec{v}}_i = \ddot{\vec{r}}_i$

- The momentum is $\vec{p} = m\vec{v}$, so the 2nd law is $\vec{F} = d\vec{p}/dt$

  The 3rd law means momentum of a closed system is conserved

- More about mass
  - This is an intrinsic property of an object. Constancy is necessary for momentum conservation to work in collisions of isolated objects
  - If 2 objects join, their masses add (consider a collision of 3 objects w/ 2 together)
  - The equivalence principle says that inertial mass (as described above) equals gravitational mass (found in Newton's law of gravity)

- The EOM from Newton's Law is generally a differential eqn. We will see techniques for solving ordinary differential equations