Announcements

- WebWorK 6 will be posted after class
  - Will require some Glowscript work
  - Make sure you do the work in your Public folder so that you can share the url
- Tests *may* get returned Wednesday, for sure by Friday
  - Some people still need to take, so please no discussion yet
- Finishing up Ch 3 content today
- Polling `rembold-class.ddns.net`

Review Question

The code to the left seeks to automate the iteration method for a ball thrown from the surface of the Earth with some initial velocity. What important step is missing?

A) Net force is not defined

B) Ball momentum is never updated

C) Ball position is never updated

D) Δt is never defined

```
ground = box(size=vec(30,0.1,30), color=color.green)
ball = sphere(pos=vec(0,0,0), radius=1, color=color.red)

ball.m = 5 # kg
ball.vel = vec(30,50,20)
ball.p = ball.m*ball.vel

while ball.pos.y > -0.1:
        rate(100)
        fnet = ball.m*vec(0,-9.8,0)
        ball.p = ball.p + fnet*dt
        ball.pos = ball.pos + ball.p/ball.m*dt
```

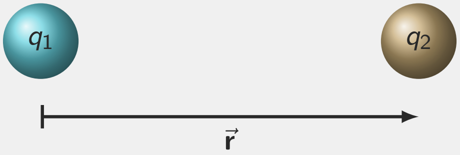
Solution: Δt is never defined

Upcoming:

Fundamental Force 2: The Electric Force

- Technically, the electromagnetic force is comprised of both electric and magnetic bits
- We'll look at the electric bit here and save the magnetic bit till next semester
- Electric Force takes on a form *very* similar to gravity's!
- For two charged particles:

$$\vec{\mathbf{F}}_{\text{elec 1 on 2}} = \frac{1}{4\pi\epsilon_0}\frac{q_1 q_2}{\left|\vec{\mathbf{r}}\right|^2}\hat{\mathbf{r}}$$



Comparing Forces

$$\vec{\mathbf{F}}_g = -G\frac{m_1 m_2}{|\vec{\mathbf{r}}|^2}\hat{\mathbf{r}}, \quad \vec{\mathbf{F}}_e = \frac{1}{4\pi\epsilon_0}\frac{q_1 q_2}{|r|^2}\hat{\mathbf{r}}$$

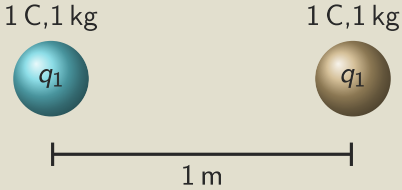
- G and $\frac{1}{4\pi\epsilon_0}$ are both constants giving the strength of the force

$$\frac{1}{4\pi\epsilon_0} = 9\times 10^9\,\mathrm{Nm}^2/\mathrm{C}^2$$

- q and m are the properties of the objects (charge or mass)
  - Mass m is always positive and measured in kilograms (kg)
  - Charge q can either be positive or negative and is measured in coulombs (C)
- In both cases, $\vec{\mathbf{r}}$ points from the surrounding object to the system object

How much is a Coulomb?

Given the image below, compare the magnitude and direction of the electric force and the gravitational force.



Strong Side, Weak Side

- The Strong Force
  - Responsible for holding the nucleus of atoms together against extreme electric repulsion forces
  - Balance of strong and electric forces dictates atomic stability
  - Only effective over extremely short distances (diameter of proton)
- The Weak Force
  - Responsible for atomic decay
  - Causes neutrons to decay to a proton + electron + neutrino if left untended
  - Can also cause electron capture in the opposite direction
- Both have important roles in fusion

Upcoming:

Momentum Conservation

The Flow of Momentum

- Imagine a truck collides with a stationary car
- We measure the change in momentum of the car
  - Car is system, truck is surroundings
- Could also measure the change in momentum of the truck
  - Truck is system, car is surroundings
- Observe that momentum lost by the truck is gained by the car!

$$\Delta\vec{\mathbf{p}}_{sys} + \Delta\vec{\mathbf{p}}_{surr} = \vec{\mathbf{0}}$$

- Thus if we choose our system so that the surroundings exert no force on the system:

$$\Delta\vec{\mathbf{p}}_{sys} = 0$$

$\neq$Lifting

A 20 kg curling stone is sliding down some frictionless ice at $\vec{\mathbf{v}} = \langle -10, 0, 5 \rangle$ m/s when it strikes another stationary stone. After the collision, the stationary stone is moving at $\vec{\mathbf{v}}_2 = \langle -4, 0, 3 \rangle$ m/s. What was the delivered impulse and what in the final velocity of the original moving stone?

Understanding Check

I throw a 500 g apple up into the air. You fire a 50 g arrow at the apple. At the moment of contact, the arrow has a velocity given by $\langle 10, 10, 0 \rangle$ m/s and the apple is traveling straight up with a speed of 5 m/s. If the arrow sticks into the apple and they move off together, what is their final velocity?

A) $\langle 0.5, 3, 0 \rangle$ m/s

B) $\langle 0.91, 5.45, 0 \rangle$ m/s

C) $\langle 5.5, 27.27, 0 \rangle$ m/s

D) $\langle 10, 5, 0 \rangle$ m/s

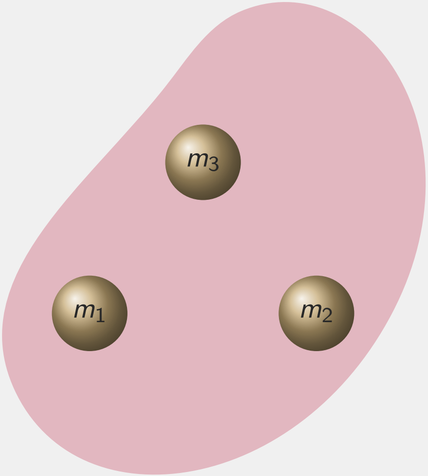
Solution: $\langle 0.91, 5.45, 0 \rangle$ m/s

Upcoming:

Dealing with the Many

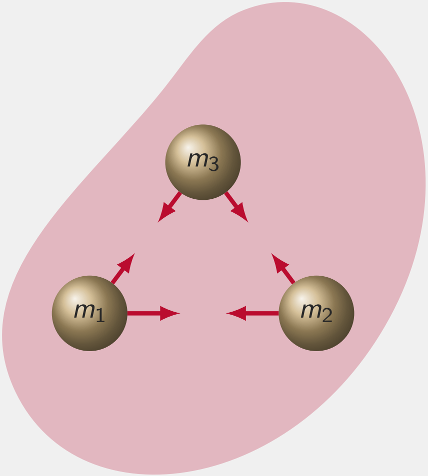
Multiparticle Systems

- Can break forces in a multiparticle system up



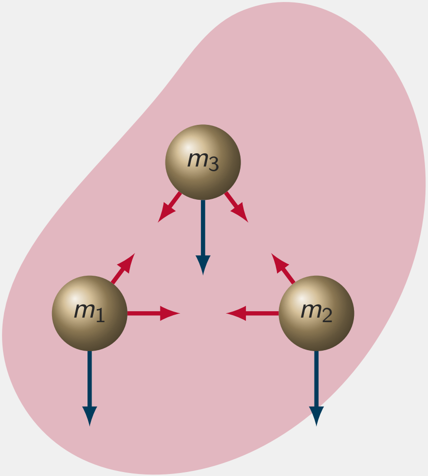
Multiparticle Systems

- Can break forces in a multiparticle system up
  - Internal Forces



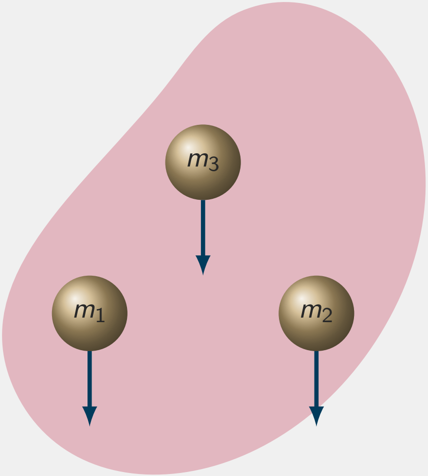
Multiparticle Systems

- Can break forces in a multiparticle system up
  - Internal Forces
  - External Forces



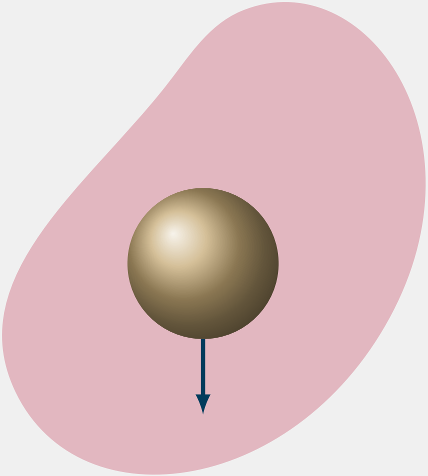
Multiparticle Systems

- Can break forces in a multiparticle system up
  - Internal Forces
  - External Forces
- Forces on the entire system only include external forces
  - Internal forces cancel



Multiparticle Systems

- Can break forces in a multiparticle system up
  - Internal Forces
  - External Forces
- Forces on the entire system only include external forces
  - Internal forces cancel
- Lets us consider extended objects as point masses
  - Mass the sum of all the particle masses
  - Location at the center of mass



Center of Mass

Since we can treat extended objects as points, would be useful to know the position of the point:

Center of Mass

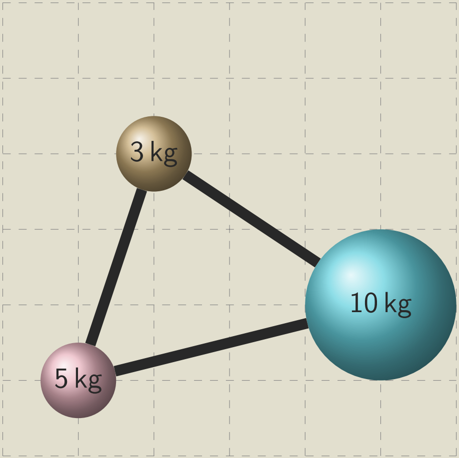
The center of mass for a multiparticle system is defined to be:

$$\vec{\mathbf{r}}_{CM} = \frac{m_1\vec{\mathbf{r}}_1 + m_2\vec{\mathbf{r}}_2 + m_3\vec{\mathbf{r}}_3 + \cdots}{M_{total}}$$

This is essentially a weighted-average of the position based on the masses.

Computing Centers of Mass

Determine the center of mass of the image to the right. You can assume the connecting bars are massless.



Momentum of the System

- If we take a change in the position of the center of mass:

$$\Delta\vec{\mathbf{r}}_{CM} = \frac{m_1\Delta\vec{\mathbf{r}}_1 + m_2\Delta\vec{\mathbf{r}}_2 + m_3\Delta\vec{\mathbf{r}}_3 + \cdots}{M_{total}}$$

  assuming that the mass isn't changing.

- Dividing by Δt then gives us:

$$\begin{aligned}
\frac{\Delta\vec{\mathbf{r}}_{CM}}{\Delta t} &= \frac{m_1\frac{\Delta\vec{\mathbf{r}}_1}{\Delta t} + m_2\frac{\Delta\vec{\mathbf{r}}_2}{\Delta t} + m_3\frac{\Delta\vec{\mathbf{r}}_3}{\Delta t} + \cdots}{M_{total}} \\
\vec{\mathbf{v}}_{CM} &= \frac{m_1\vec{\mathbf{v}}_1 + m_2\vec{\mathbf{v}}_2 + m_3\vec{\mathbf{v}}_3}{M_{total}} \\
M_{total}\vec{\mathbf{v}}_{CM} &= \vec{\mathbf{p}}_1 + \vec{\mathbf{p}}_2 + \vec{\mathbf{p}}_3 + \cdots \\
M_{total}\vec{\mathbf{v}}_{CM} &= \vec{\mathbf{p}}_{total}
\end{aligned}$$