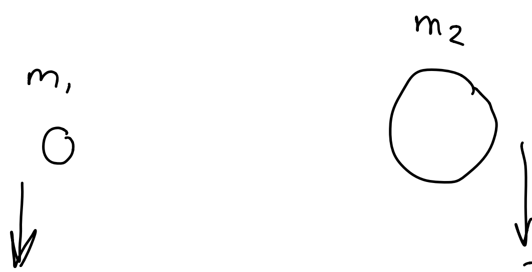
Start w/ demo:

2 objects of <u>different</u> mass

Q: which one will hit the ground first?

Do it a few times

- Measure the masses



$\vec{F}_{grav} = \langle 0, -m_1 g, 0 \rangle$ $\qquad$ $\vec{F}_{grav} = \langle 0, -m_2 g, 0 \rangle$

So the force is greater on the heavier mass.

Why do they fall at the same rate?

$$\Delta p_y = F_y \Delta t$$

$$m a_y = -mg$$

$$\boxed{a_y = -g}$$

All objects fall at same rate!

Why does a feather take so long to fall?

Ex: If someone weighs 150 lbs on Earth, how much will they weigh on Mars?

$1 \text{ lb} = 4.5 \text{ N}$

$|\vec{F}_g| = 150 \text{ lb} \times \frac{4.5 \text{ N}}{1 \text{ lb}} = 675 \text{ N}$

$|\vec{F}_g| = m\, g_{earth} = m(9.81 \text{ m/s}^2) = 675 \text{ N}$

$m = \frac{675 \text{ N}}{9.81 \text{ m/s}^2} = \frac{675 \text{ N}}{9.81 \text{ N/kg}} = 68.8 \text{ kg}$

$m = 68.8 \text{ kg}$

What is m on mars?
still 68.8 kg

$|\vec{F}_{g,mars}| = m\, g_{mars}$

$g = \frac{G M_{mars}}{R_{mars}^2}$

$M = 6.4 \times 10^{23} \text{ kg}$ (about 1/10 of Earth)

$R_{mars} = 3.4 \times 10^{6} \text{ m}$ (about 1/2 of Earth)

$$g_m = \frac{\left(6.7\times10^{-11}\,\frac{N\,m^2}{kg^2}\right)\left(6.4\times10^{23}\ kg\right)}{\left(3.4\times10^{6}\ m\right)^2} = 3.7\ N/kg$$

$$|\vec{F}_g| = m g_{mars} = (68.8\ kg)\left(3.7\,\frac{N}{kg}\right) = 255\ N$$

$$255\ N \times \frac{1\ lb}{4.5\ N} = 57\ lb$$

150 lb on Earth $\longrightarrow$ 57 lb on Mars

Briefly: how do orbits work?

Scenario

Sun

Earth (not moving)

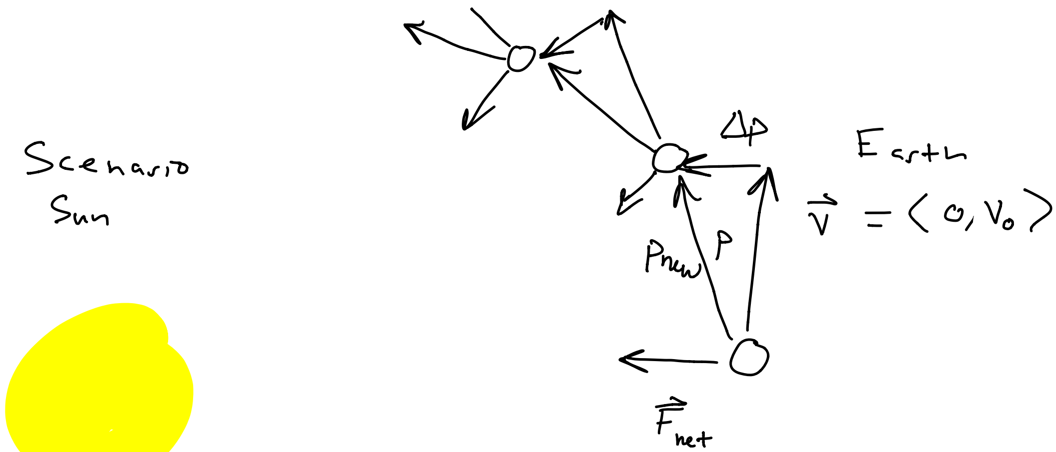
$\vec{v} = \langle 0, 0 \rangle$

$\vec{F}_{net}$

$\Delta \vec{p} = \vec{F}_{net} \Delta t$

- gains velocity toward sun
- moves toward sun
- boom

Scenario



$$\Delta \vec{p} = \vec{F}_{net}\, \Delta t$$

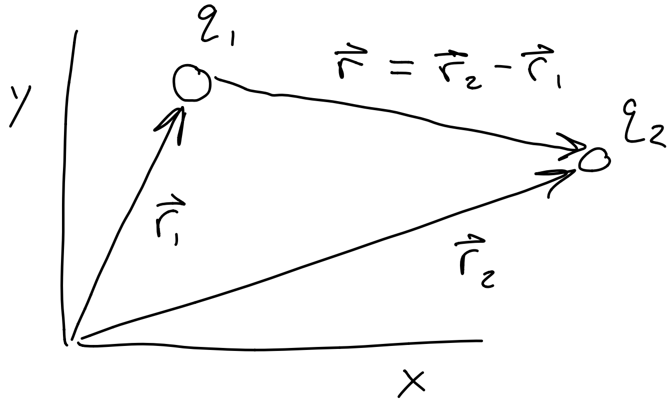
Let's look at EM force

mass interacts with mass via gravity

another property of matter is charge

Charge interacts w/ charge via electromagnetism

→ Equations are very similar!



$$\vec{F}_{\text{ON2 BY1}} = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{|\vec{r}|^2} \hat{r} \qquad \frac{1}{4\pi\epsilon_0} = 9 \times 10^9 \frac{N \cdot m^2}{C^2}$$

Charge measured in Coulombs

ELEC

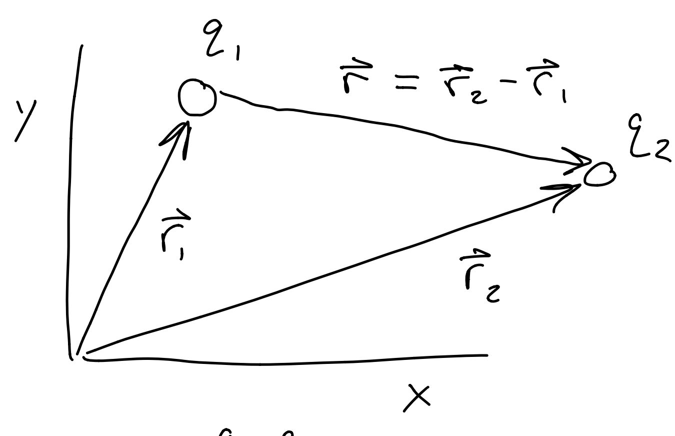
$$\vec{F}_{\text{ON 2 BY 1}} = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{|\vec{r}|^2} \hat{r}$$

GRAV

$$\vec{F}_{\text{ON 2 BY 1}} = G \frac{m_1 m_2}{|\vec{r}|^2} \hat{r}$$

$$(\text{constant}) \frac{(\text{property})(\text{property})}{|\vec{r}|^2} \hat{r}$$

Unlike grav, charge can be either positive or negative



$$\vec{F}_{\text{ON 2 BY 1}} = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{|\vec{r}|^2} \hat{r}$$

if $q_1 q_2$ is positive, $\hat{F} = \hat{r}$ (repel)

$q_1 q_2$ is negative, $\hat{F} = -\hat{r}$ (attract)

q_1	q_2	
+	+	Repel
−	−	Repel
+	−	attract
−	+	attract

Ex: Electron @ $\langle -3, 2, 0\rangle \times 10^{-9}$ m

α particle @ $\langle 6, -4, 0\rangle \times 10^{-9}$ m

$q_e = -1.6 \times 10^{-19}$ C

$q_\alpha = 3.2 \times 10^{-19}$ C

What is $\vec{F}_{\text{on e by } \alpha}$?

$$\vec{r} = \vec{r}_e - \vec{r}_\alpha = \langle -3, 2, 0\rangle \times 10^{-9}\,m - \langle 6, -4, 0\rangle \times 10^{-9}\,m$$

$$\vec{r} = \langle -9, 6, 0\rangle \times 10^{-9}\,m$$

$$|\vec{r}| = 1.08 \times 10^{-8}\,m$$

$$\hat{r} = \frac{\vec{r}}{|\vec{r}|} = \langle -0.832, 0.555, 0\rangle$$

$$\vec{F}_{ON2BY1} = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{|\vec{r}|^2} \hat{r}$$

$$= \left(9\times10^9 \frac{Nm^2}{C^2}\right) \frac{(-1.6\times10^{-19}C)(3.2\times10^{-19}C)}{(1.08\times10^{-8}\,m)^2} \langle -0.832, 0.555, 0 \rangle$$

$$\vec{F}_{ON2BY1} = \langle 3.28, -2.19, 0 \rangle \times 10^{-12}\ N$$

isn't 10^{-12} N small?

mass of electron is 9×10^{-31} kg

$$a = \frac{F}{m} = \frac{10^{-12}}{10^{-30}} = 10^{18}\ m/s^2 \quad (!)$$

Also note:

$$\vec{F}_{ON2BY1} = -\vec{F}_{ON1BY2}$$

Technically, this is not the entire net force

Both particles have mass, so they also interact gravitationally!

Ex:

$q_p = 1.6 \times 10^{-19}\ C$

$m_p = 1.7 \times 10^{-27}\ kg$

Grav Force

$$|\vec{F}_g| = \frac{G\, m_1 m_2}{|\vec{r}|^2} = \frac{\left(6.7 \times 10^{-11} \frac{Nm^2}{kg^2}\right)\left(1.7 \times 10^{-27} kg\right)\left(1.7 \times 10^{-27} kg\right)}{r^2}$$

$$|\vec{F}_g| = \frac{2 \times 10^{-64}}{r^2} N$$

Elec Force

$$|\vec{F}_e| = \frac{1}{4\pi\epsilon_0} \frac{|q_1 q_2|}{|\vec{r}|^2} = \frac{\left(9 \times 10^{9} \frac{Nm^2}{C^2}\right)\left(1.6 \times 10^{-19} C\right)\left(1.6 \times 10^{-19} C\right)}{r^2}$$

$$|\vec{F}_e| = \frac{2 \times 10^{-28}}{r^2} N$$

$$\frac{|\vec{F}_e|}{|\vec{F}_g|} \approx 10^{36} \qquad (!)$$

Electric Force is $\sim 10^{36} \times$ stronger

Takes alot of mass for gravity to be important