Ch 3 : Fundamental Forces

- We know how objects respond to forces
  ($\bar{p}$ principle)

- But what <u>causes</u> a force?
  (+ how can we predict?)

- Every interaction
  leaf blowing in wind
  chemical rxn
  boiling water
  planets orbiting
  etc..

Focus

s

i due to a combination of just 4 Fundamental

Four Forces

- gravitational force
- electromagnetic force
- strong force

  (holds nuclei together)
- weak force

  (responsible for radioactivity)

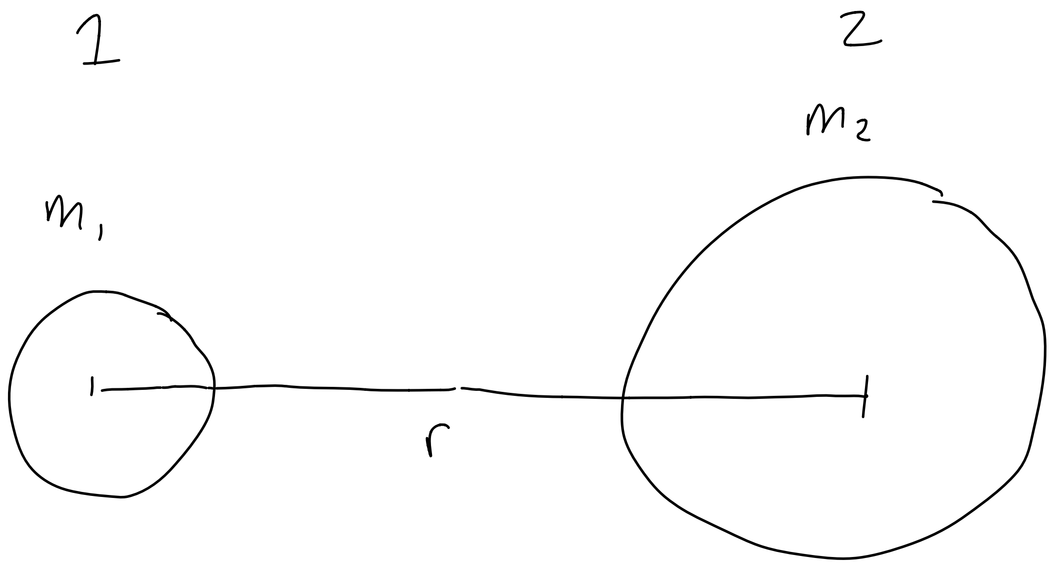
Any interaction you can imagine, one (or more) of these four interactions is responsible

- Standard model?

Gravitational Force

- we've been using mg but that's just an approximation on Earth

Two objects (planets, people, protons, etc)



$$\left|\vec{F}_{\text{on 2 by 1}}\right| = \frac{G m_1 m_2}{r^2}$$

Direction: toward m_2 $G = 6.7 \times 10^{-11} \frac{Nm^2}{kg^2}$

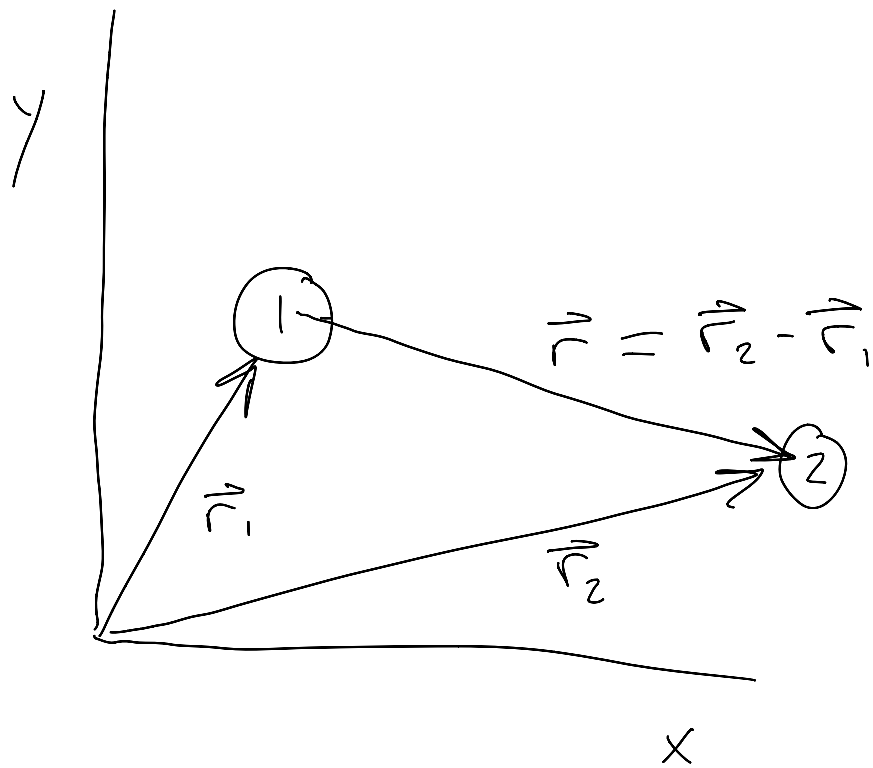
r: center 2 center

Doube r, $\frac{1}{4}$ F

Double m, 2x F

Combine magnitude & direction

R points from cause of force to object experiencing force



$$\vec{F}_{on\,2\,by\,1} = \frac{-G\, m_1 m_2}{|\vec{r}|^2}\,\hat{r}$$

Ex:

Star at $\vec{r}_{star} = \langle 2\times10^{11}, 1\times10^{11}, 1.5\times10^{11} \rangle$ m

mass $= 4\times10^{30}$ kg

Planet at $\vec{r}_{planet} = \langle 3\times10^{11}, 3.5\times10^{11}, -0.5\times10^{11} \rangle$,

mass $= 3\times10^{24}$ kg

What is

$\vec{F}_{\text{on planet by star}}$?

Object 1 is causing the force

object 2 is expiriencing the force

Step1: Find $\vec{r}$

$$\vec{r} = \vec{r}_2 - \vec{r}_1 = \vec{r}_{planet} - \vec{r}_{star}$$

$$= \langle 3\times10^{11}, 3.5\times10^{11}, -0.5\times10^{11} \rangle \text{ m}$$
$$- \langle 2\times10^{11}, 1\times10^{11}, 1.5\times10^{11} \rangle \text{ m}$$

$$\vec{r} = (1\times10^{11}, 2.5\times10^{11}, -2\times10^{11})\ m$$

Step 2:

Find $|\vec{r}|$

$$|\vec{r}| = \sqrt{(1\times10^{11})^2 + (2.5\times10^{11})^2 + (-2\times10^{11})^2}$$

$$|\vec{r}| = 3.35\times10^{11}\ m$$

Step 3:

Calculate $|\vec{F}| = G\dfrac{m_1 m_2}{|\vec{r}|^2}$

$$|\vec{F}| = \left(6.7\times10^{-11}\ \frac{Nm^2}{kg^2}\right) \times \frac{(3\times10^{24}\ kg)(4\times10^{30}\ kg)}{(3.35\times10^{11}\ m)^2}$$

$$|\vec{F}| = 7.15\times10^{21}\ N$$

Step 4:

Find $-\hat{r}$

$$\hat{r} = \frac{\vec{r}}{|\vec{r}|}$$

$$-\hat{r} = \frac{-\vec{r}}{|\vec{r}|}$$

$$= -\frac{\langle 1\times10^{11}, 2.5\times10^{11}, -2\times10^{11} \rangle \text{ m}}{3.35\times10^{11} \text{ m}}$$

$$-\hat{r} = \langle -0.298, -0.745, 0.596 \rangle$$

Step 5:

$$\vec{F} = |\vec{F}| \cdot (-\hat{r})$$

$$\vec{F} = 7.15\times10^{21} \text{ N} \langle -0.298, -0.745, 0.596 \rangle$$

$$\vec{F} = \langle -2.13\times10^{21}, -5.53\times10^{21}, 4.26\times10^{21} \rangle \text{ N}$$

$\vec{F}_{\text{on planet by star}}$

$= \langle -2.13\times10^{21}, -5.53\times10^{21}, 4.26\times10^{21} \rangle$ N

$\vec{F}_{\text{on star by planet}}$?

Step 1

$\vec{r} = \vec{r}_2 - \vec{r}_1 = \vec{r}_{\text{star}} - \vec{r}_{\text{planet}}$

$\vec{r} = \langle -1\times10^{11}, -2.5\times10^{11}, +2\times10^{11} \rangle$ m

Step 2

$|\vec{r}|$ is same

$|\vec{r}| = 3.35\times10^{11}$ m

Step 3

$|\vec{F}|$ is same

7.15×10^{21} N

Step 4

$-\hat{r}$ is opposite of before

$$-\hat{r} = \langle 0.298, 0.745, 0.596 \rangle$$

Step 5:

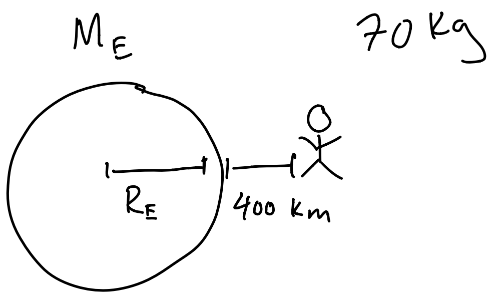
$$\vec{F}_{\text{on} * \text{by planet}} = 7.15 \times 10^{21}\,\text{N} \langle 0.298, 0.745, 0.596 \rangle$$

$$= \langle 2.13 \times 10^{21}, 5.53 \times 10^{21}, -4.26 \times 10^{21} \rangle \text{ N}$$

$$\vec{F}_{\text{on star by planet}} = -\vec{F}_{\text{on planet by star}}$$

This is not an accident!

Things to note about gravity:
-It is *Universal.*
    -Every object that has mass experience a gravitational attraction to every other object that has mass
    -Saturn is exerting a small force on me right now (and vice versa!)
    -This pen is exerting a small force on Jamie (and vice versa!)
-Gravity is *everywhere*
    -It is often said that there is no gravity in space, because astronauts float there
    Let's see if that's true:



$$|\vec{F}| = \frac{G M_E m_A}{(R_E + 400\,000)^2}$$

$$= \frac{(6.7\times10^{-11})(6\times10^{24})(70)}{(6.4\times10^{6} + 4\times10^{5})^2}$$

$$|\vec{F}| = 630 \text{ N}$$

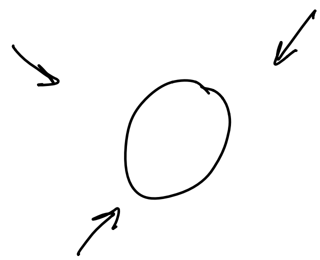
$$a = \frac{F}{m} = \frac{630}{70} = 9.0 \text{ m/s}^2 \qquad \left(g = 9.8 \frac{m}{s^2}\right)$$

What's happening?

Apparent weightlessness

- Falling inside an elevator
- Spaceships "falls" around the earth

- There is no "up" and "down"



If $F_{grav} = \frac{G m_1 m_2}{r^2}$, what is mg?

If we are close to the surface of Earth

$$|\vec{F}_g| = \frac{G M_E m}{(R_E + y)^2} \qquad R_E >> y$$

$R_E = 6.4 \times 10^6$ m

$y = 100$ m

if $y / R_E << 1$

$$|\vec{F}_g| \approx \left(\frac{G M_E}{R_E^2}\right) m = gm, \quad g = \frac{G M_E}{R_E^2} \approx 9.8 \text{ m/s}^2$$

We could do the same thing for the moon?

$$g_{moon} = \frac{GM_{moon}}{R_m^2} \simeq 1.7 \ \frac{m}{s^2}$$

$M = 7.3 \times 10^{22}$ kg

$R_m = 1.7 \times 10^{6}$ m

$F = ma = mg$

$a = g$