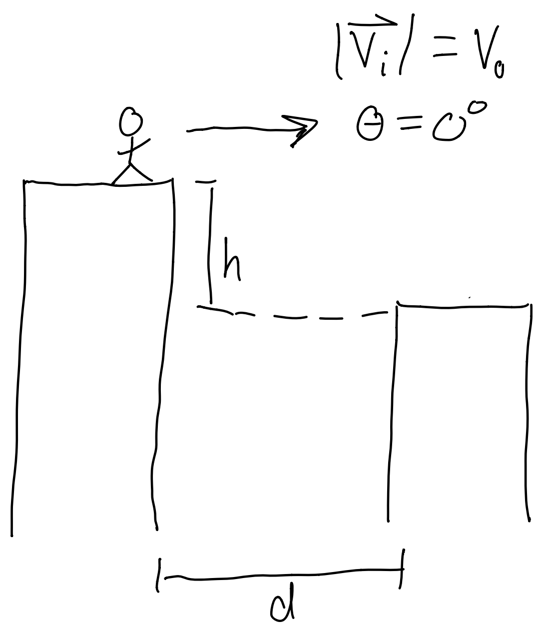


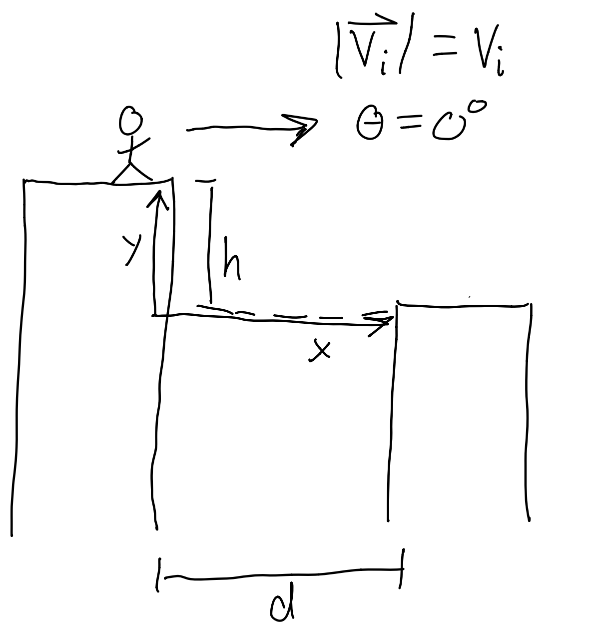
- Will they make it to the other building?

Procedure

1) Find time for them to move $\Delta y = h$

2) Find Δx for that time

Let's call the height of the lower building $y = 0$



$x_i = 0$

$y_i = h$

$\vec{F}_{net} = \langle 0, -mg \rangle$

$$y(t) = y_i + |\vec{v}_i| \sin\theta\, t - \frac{1}{2} g t^2$$

$$= h + v_i \sin(0) t - \frac{1}{2} g t^2$$

$$y(t) = h - \frac{1}{2} g t^2$$

$0 = h - \frac{1}{2} g t^2$, $t = \pm\sqrt{\frac{2h}{g}}$, we want the +

$$t_{land} = \sqrt{\frac{2h}{g}}$$

$$x(t) = x_i + |\vec{v}_i| \cos\theta \, t$$

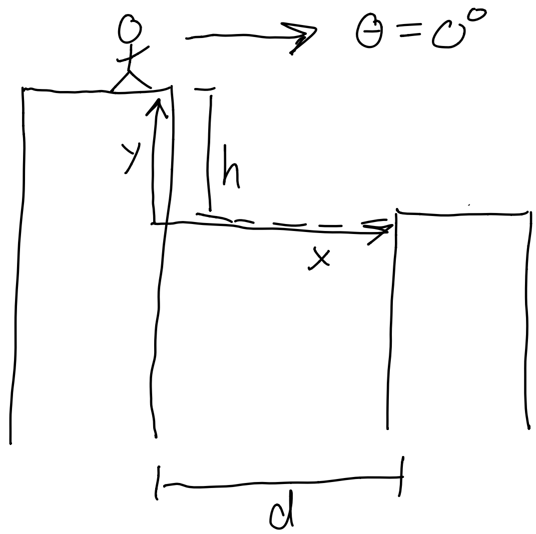
$$= v_i \cos(0) \, t$$

$$x(t) = v_i t$$

$$x(t_{land}) = (v_i)\left(\sqrt{\frac{2h}{g}}\right)$$

$$|\vec{V}_i| = V_i$$

$$\theta = 0^\circ$$



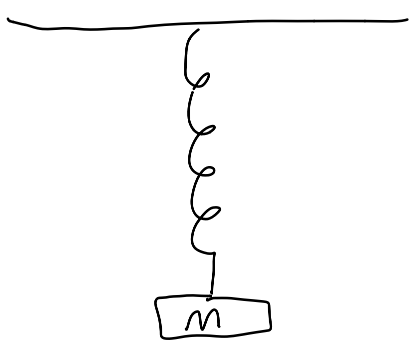
Say: $h = 10\ m$

$d = 15\ m$

$v_i = 12\ \frac{m}{s}$

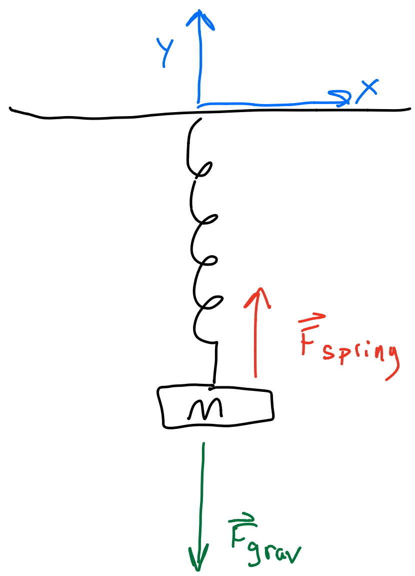
$$x(t_{land}) = (12)\sqrt{\frac{2(10)}{9.8}} \approx 17.1\ m$$

A more interesting system...



If I pull down + release, what happens?

Not constant Force anymore!



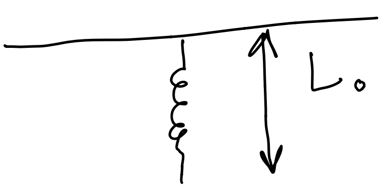
$$|\vec{F}_{grav}| = mg \quad = \text{const}$$

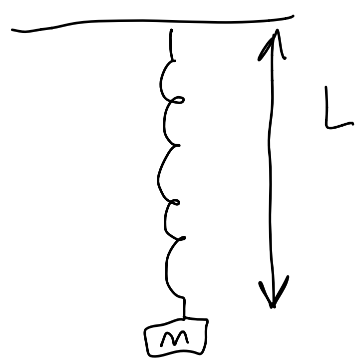
$$\hat{F}_{grav} = \langle 0, -1, 0 \rangle \qquad -(\hat{y})$$

$$\vec{F}_{grav} = mg\langle 0, -1, 0 \rangle = -mg\,\hat{y}$$

Spring?

$|\vec{F}_s| = k_s |s|$ ← depends on distance stretched or compressed





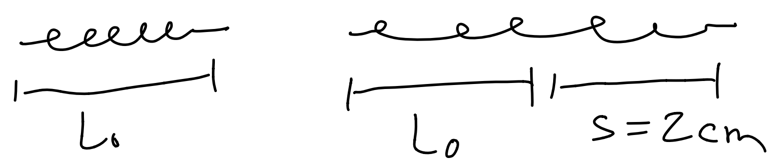
k_s = spring constant

always positive

$$s = L - L_0$$

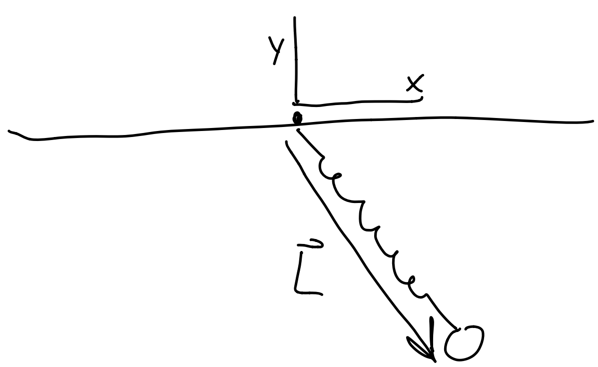
If I know k_s, I can use s to measure force

Ex: You pull on a spring ($k_s = 500 \frac{N}{m}$)
and find it stretches 2 cm. What is
the magnitude of the force you applied?



$$|\vec{F}_s| = k_s\,|s| = \left(500\,\frac{N}{m}\right)(0.02\,m) = 10\,N$$

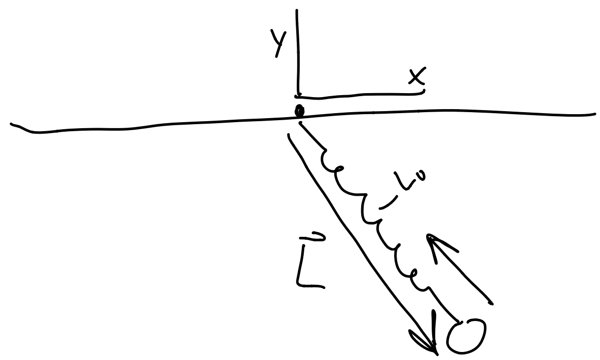
That's magnitude, what about direction?



$\vec{L}$ points from point of attachment to end of spring

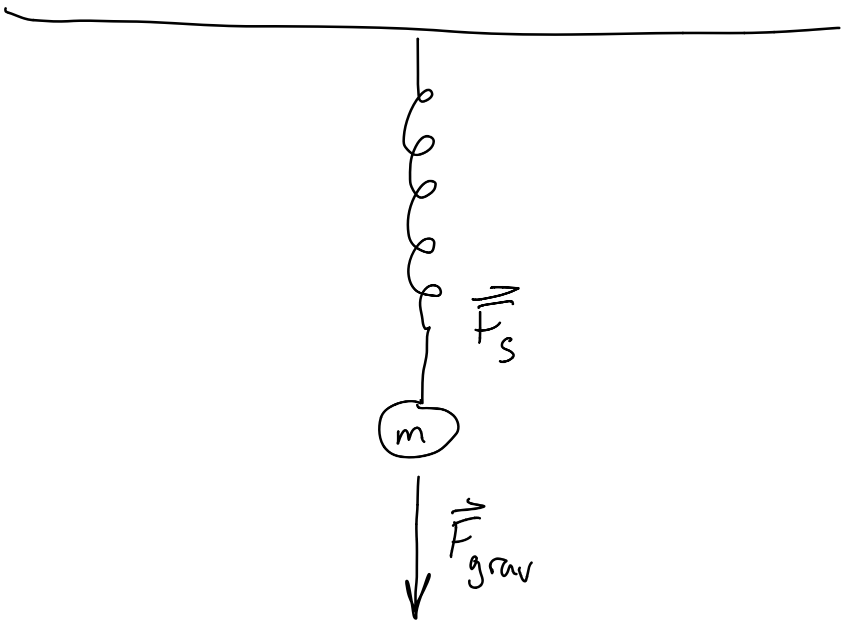
$$|\vec{F}_s| = k_s|s| = k_s\,\left|\,|\vec{L}| - L_0\right|$$

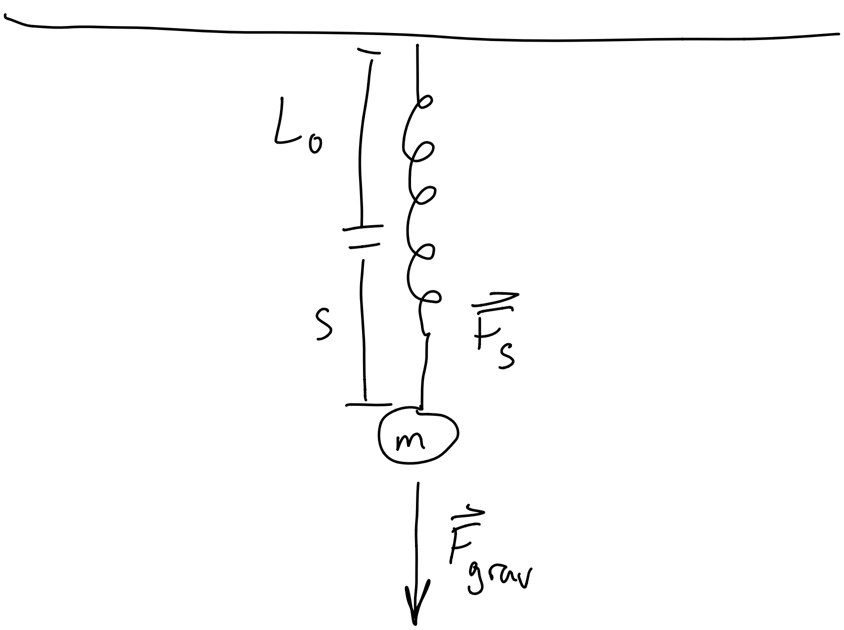
- if $|\vec{L}|$ is longer than L_0, Force is in the $-\hat{L}$ direction



- if $|\vec{L}|$ is shorter than L_0, Force is in $\hat{L}$ direction

in general: $\vec{F} = -k_s s \hat{L}$





$$\vec{F}_s = -k_s s \hat{L} \,, \quad \hat{L} = \langle 0, -1, 0 \rangle$$

$$= \langle 0, k_s s, 0 \rangle$$

$\vec{F}_g = \langle 0, -mg, 0 \rangle$

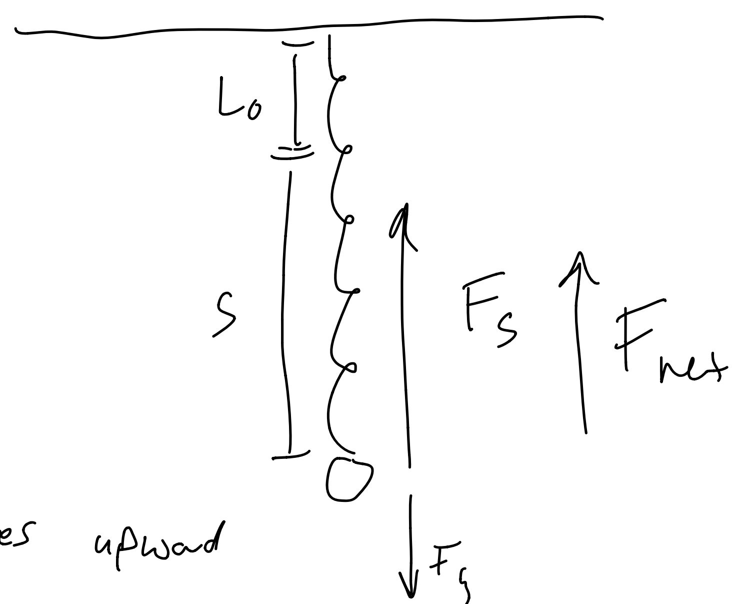
$\vec{F}_{net} = \langle 0, K_s s - mg, 0 \rangle$

initially, $K_s s > mg$

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

accelerates

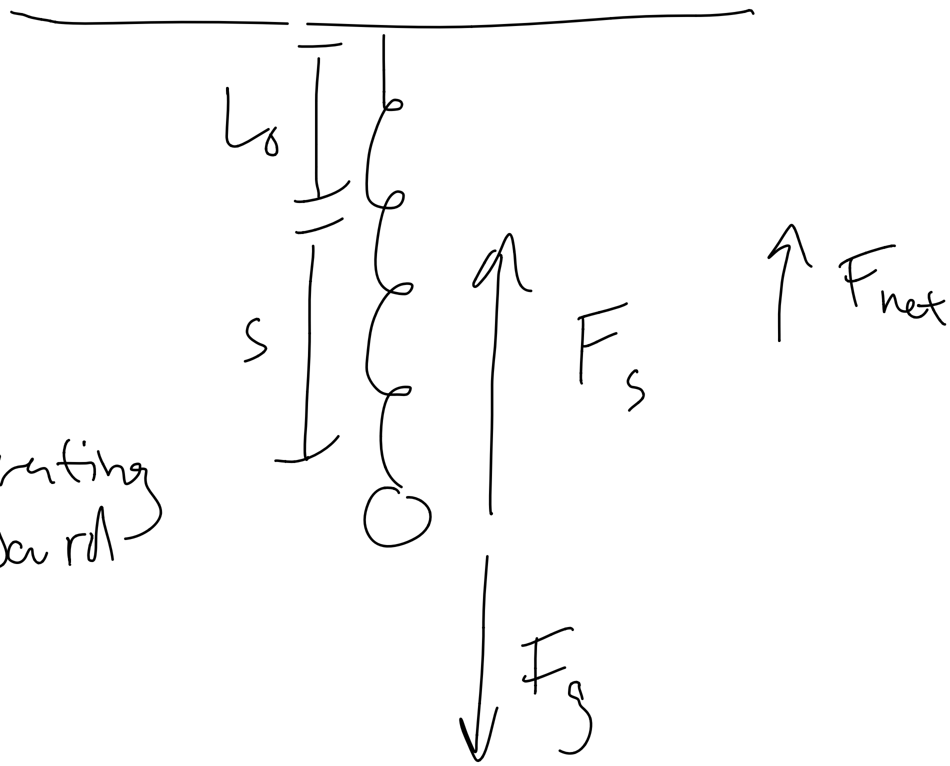
- spring gains momentum upward
- spring <u>moves</u> upward



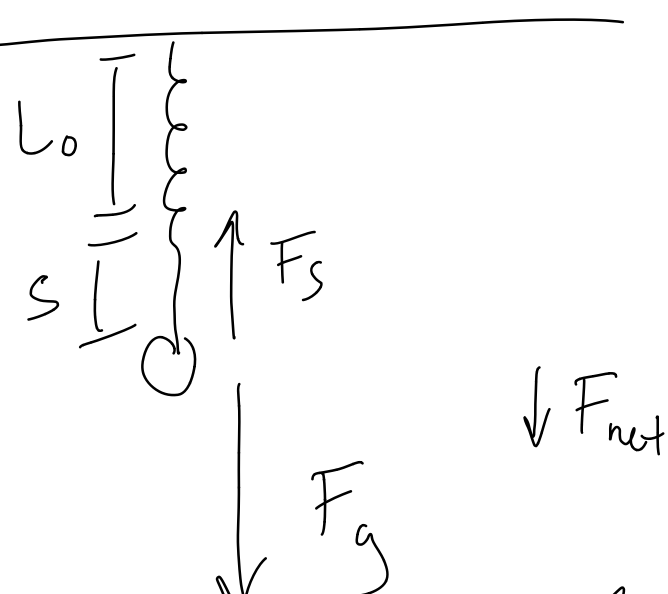
As spring moves upward

$|s|$ gets smaller, $|\vec{F}_s|$ gets smaller

- Still gaining momentum upward, but not as quickly



still accelerating upward

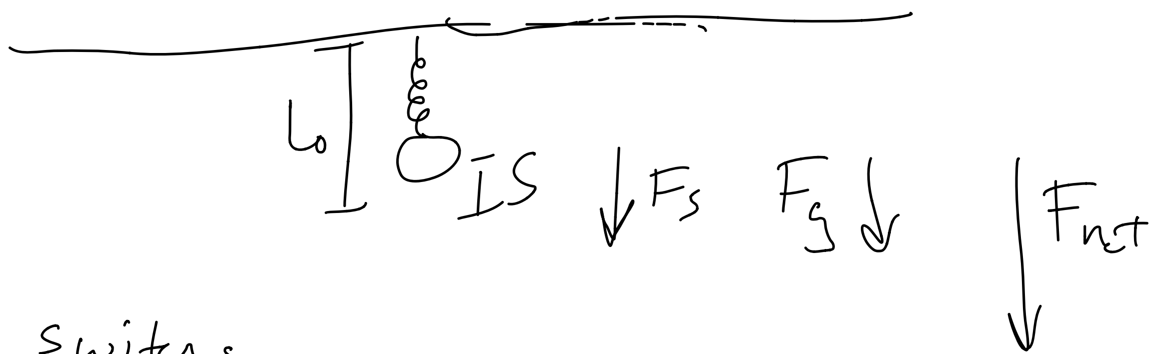


-move far enough up that

$k_s|s| < mg$

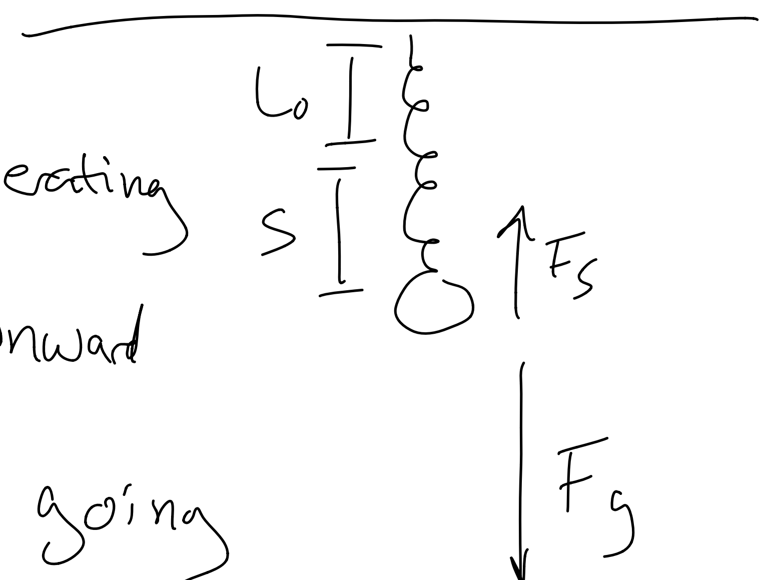
momentum starts to decrease

moving ↑ acc ↓



$\vec{P}$ switches directions

process starts anew



accelerating downward

keep going until $k_s|S| > mg$ again

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..

is due to a combination of just 4 fundamental Forces

Four Forces

- gravitational force
- electromagnetic force
- strong force
  (holds nuclei together)
- weak force
  (responsible for radioactivity)

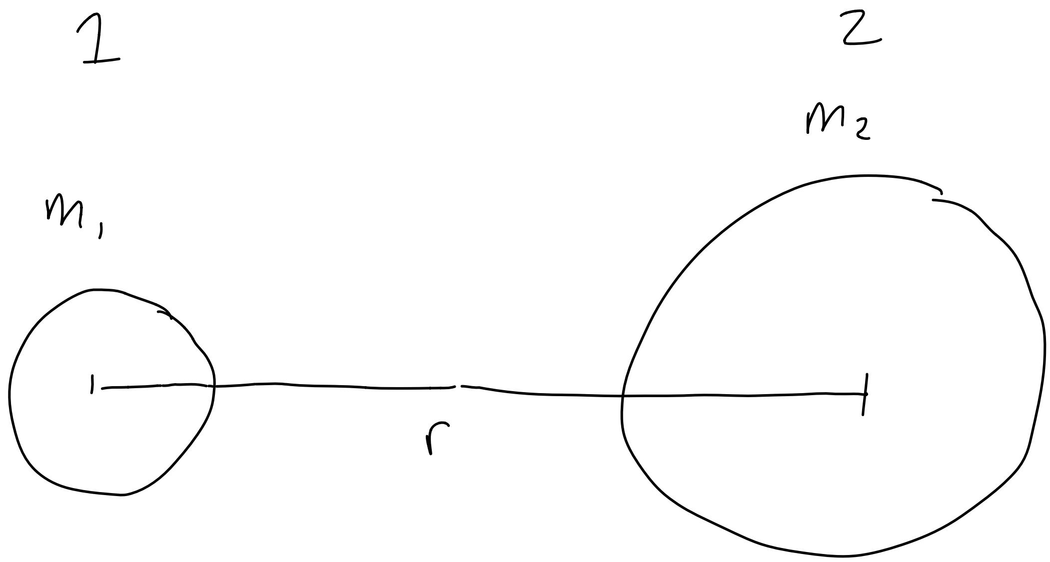
Any interaction you can imagine,
one (or more) of these four interactions
is responsible

- Standard model?

Gravitational Force

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

Two objects (planets, people, protons, etc)



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

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

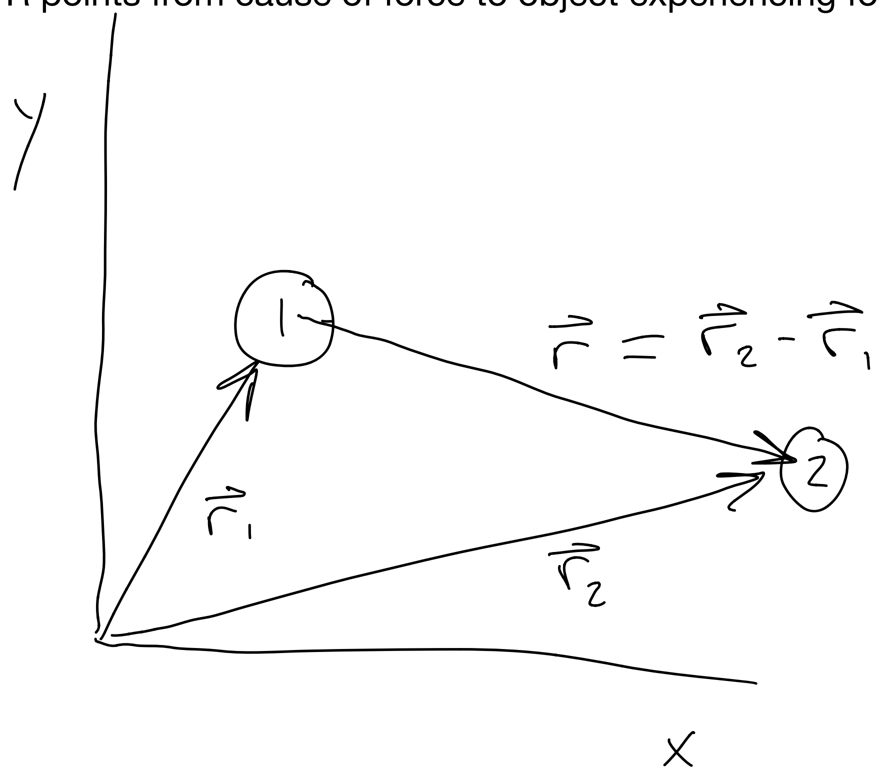
r: center 2 center

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

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 $\vec{r}$

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

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

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

Step 2:

Find $|\vec{r}|$

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

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

Step 3:

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

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

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

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:

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

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

$$\vec{F} = \langle -2.13\times10^{21}, -5.33\times10^{21}, 4.26\times10^{21}\rangle \text{ N}$$

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

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

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

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

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