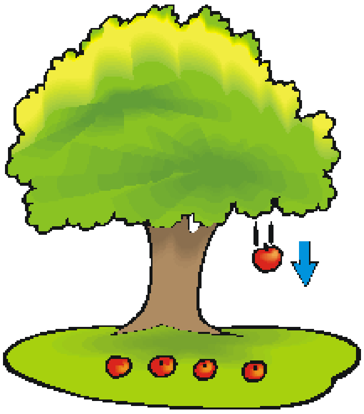
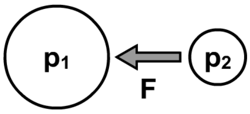
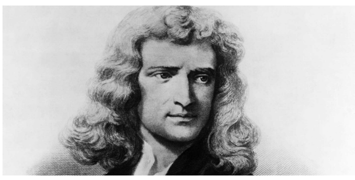
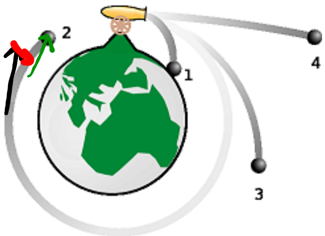
# L01 - Gravitational Force

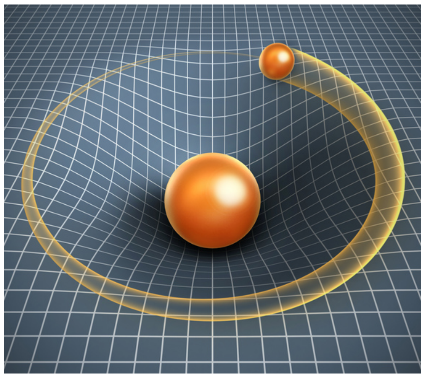





$$F = \frac{G*m_1*m_2}{r^2}$$





## Gravitational Forces are Vectors

Unicron and the Autobot Moon Base (Start to 0:02:35)

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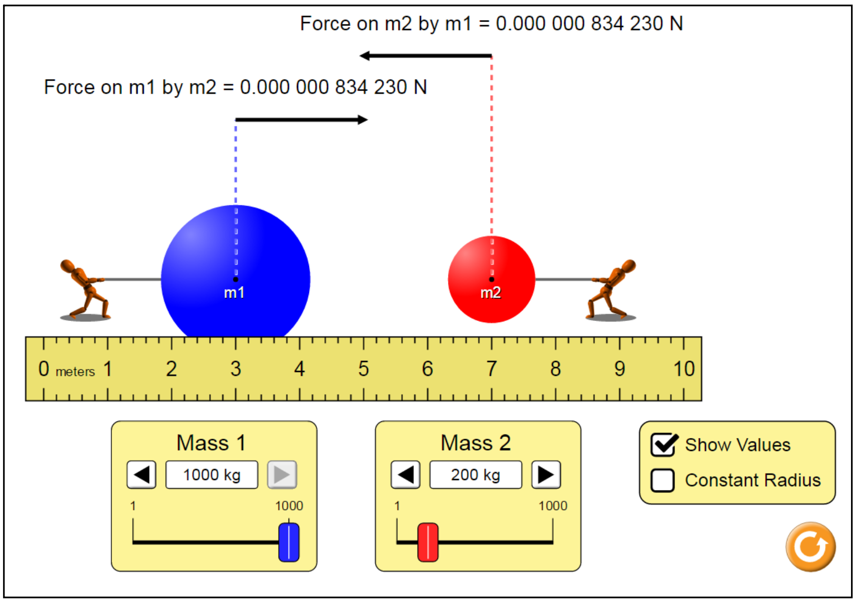
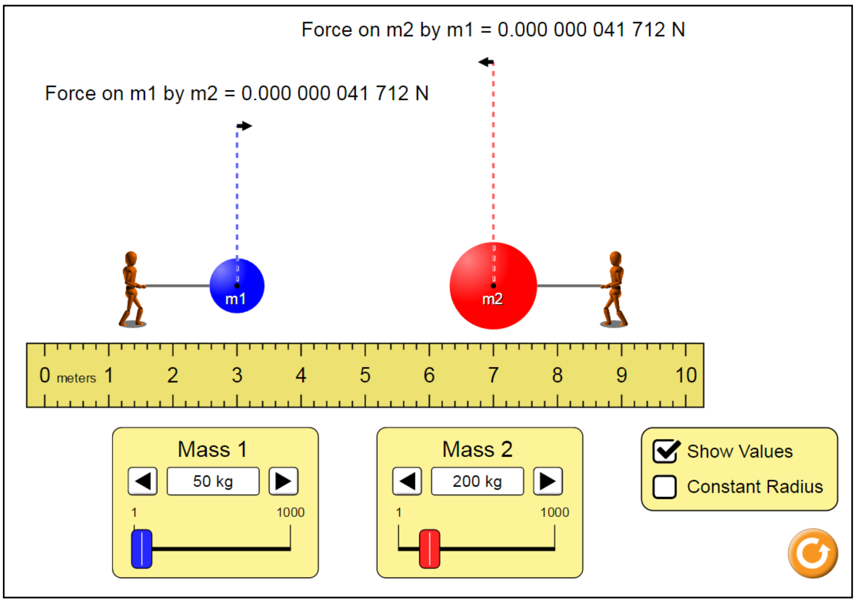
Colorado PheT: Gravity

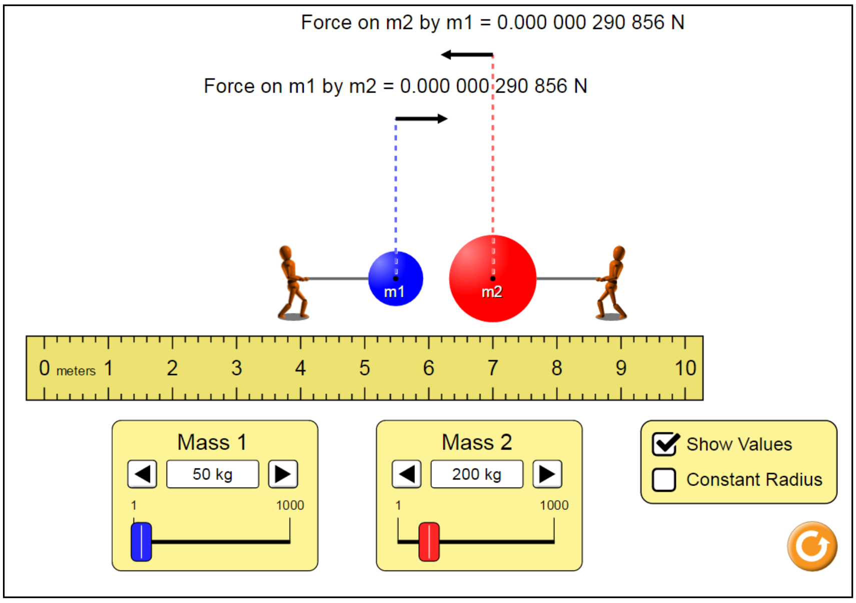



Increase Mass

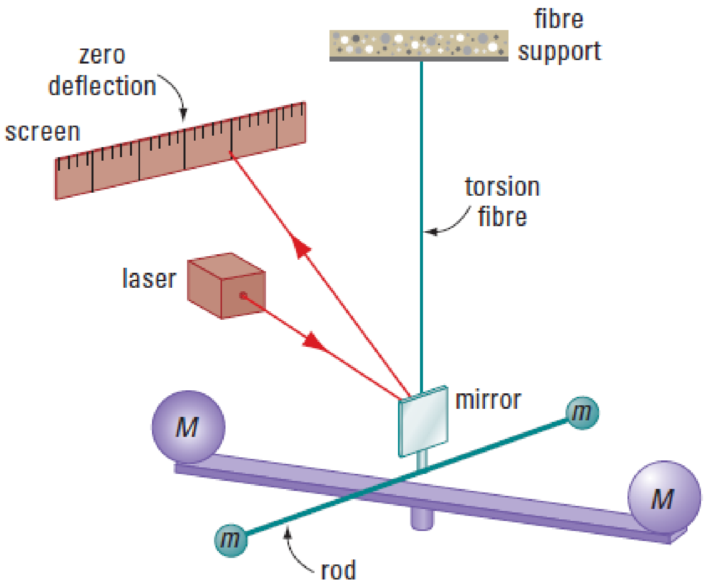


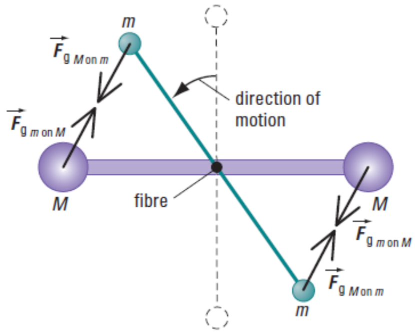

Original Condition

Decrease Distance



## Cavendish Experiment - Calculate G




The current accepted value of $G$ to three significant digits is $6.67 \times 10^{-11}\ \text{N}\cdot\text{m}^2/\text{kg}^2$.

$$F_g = \frac{G m_1 m_2}{r^2}$$

or

$$F_g = \frac{(6.67\times10^{-11}) m_1 m_2}{r^2}$$

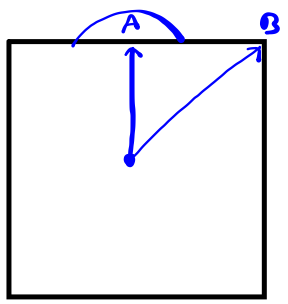
$$N = \frac{\left(\frac{Nm^2}{kg^2}\right)(kg)(kg)}{m^2}$$

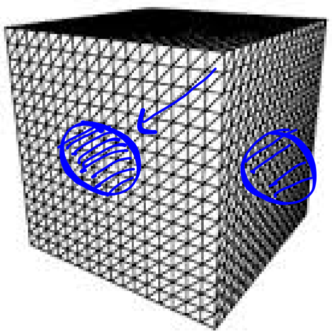
$G = 6.67\times10^{-11}\ \frac{Nm^2}{kg^2}$ EVERYWHERE

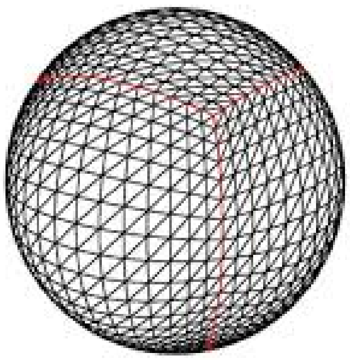
$g = 9.81\ m/s^2$ on surface of Earth

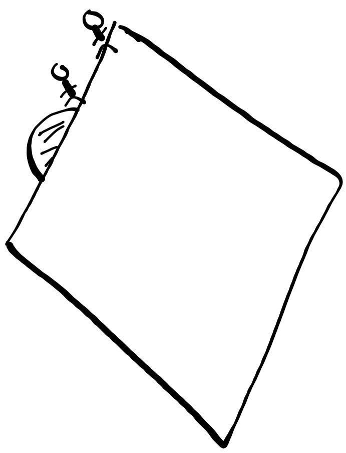
## What if the Earth were flat?


## What if the Earth were a cube?







## Mathy Stuff

$$\left|\vec{F}_g\right| = \frac{Gm_1m_2}{r^2}$$

Gravitational Constant ...... $G = 6.67 \times 10^{-11}$ N·m$^2$/kg$^2$

⇓

6.67E-11

$(2.0 \times 10^5)^2$

⇓

$(2.0E5)^2$

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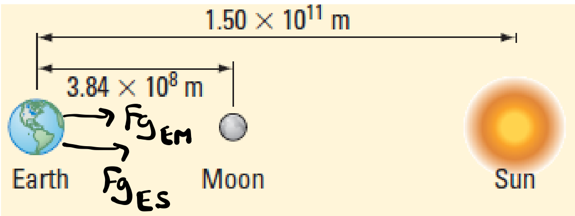
## Examples

**Q1:** During a solar eclipse, Earth, the Moon and the Sun are aligned on the same plane as shown below. Calculate the net gravitational force exerted by both the Moon and the Sun on Earth.




| Celestial Body | Mass* (kg) | Mean Separation Distance from Earth* (m) |
|---|---|---|
| Earth | $5.97 \times 10^{24}$ | — |
| Earth's Moon | $7.35 \times 10^{22}$ | $3.84 \times 10^{8}$ |
| Sun | $1.99 \times 10^{30}$ | $1.50 \times 10^{11}$ |

$$F_{g_{EM}} = \frac{G m_E m_M}{r^2} = \frac{(6.67\times10^{-11})(5.97\times10^{24})(7.35\times10^{22})}{(3.84\times10^{8})^2}$$

$$= \frac{2.92676...\times10^{37}}{1.47456\times10^{17}}$$

$$\boxed{= 1.9848\times10^{20}\ N}$$

$$F_{g_{ES}} = \frac{G m_E m_S}{r^2} = \frac{(6.67\times10^{-11})(5.97\times10^{24})(1.99\times10^{30})}{(1.50\times10^{11})^2}$$

$$= \frac{7.9241601\times10^{44}}{2.25\times10^{22}}$$

$$\boxed{= 3.5218\times10^{22}\ N}$$

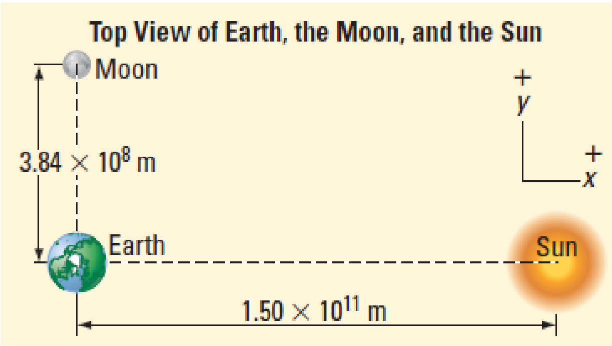
$0.019848..\times10^{22}$

$$\vec{F}_{net} = \vec{F}_{g_{EM}} + \vec{F}_{g_{ES}}$$

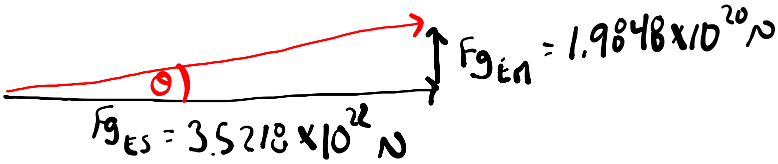
$$= 1.9848\times10^{20} + 3.5218\times10^{22}$$

$$\boxed{= 3.54\times10^{22}\ N}$$

**Q2:** During the first quarter phase of the Moon, Earth, the Moon, and the Sun are positioned as per the diagram below. Calculate the net gravitational force exerted by both the Moon and the Sun on Earth.




| Celestial Body | Mass* (kg) | Mean Separation Distance from Earth* (m) |
|---|---|---|
| Earth | $5.97 \times 10^{24}$ | — |
| Earth's Moon | $7.35 \times 10^{22}$ | $3.84 \times 10^{8}$ |
| Sun | $1.99 \times 10^{30}$ | $1.50 \times 10^{11}$ |




$a^2+b^2=c^2$

$c = 3.5219\times10^{22}$ N

$\theta = \tan^{-1}\left(\frac{o}{a}\right)$

$\theta = 0.3229^\circ$

$\vec{F}_{net} = 3.5219\times10^{22}$ N $[0.3229^\circ]$

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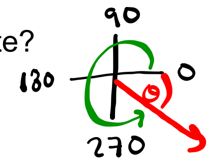
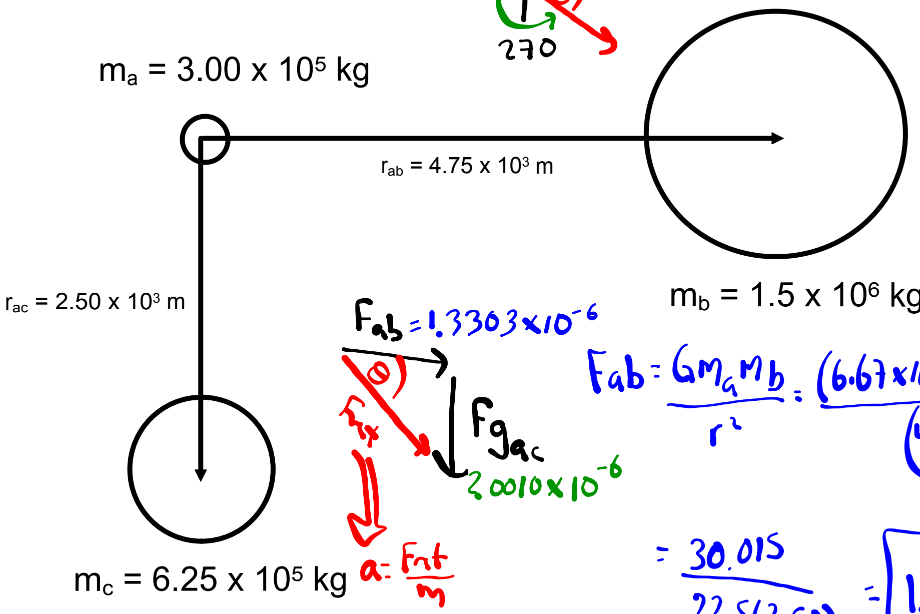
**Q3:** In what direction will $m_a$ accelerate?




$$F_{ab} = \frac{G m_a m_b}{r^2} = \frac{(6.67\times10^{-11})(3\times10^5)(1.5\times10^6)}{(4.75\times10^3)^2}$$

$$= \frac{30.015}{22{,}562{,}500} = \boxed{1.3303\times10^{-6}\,N}$$

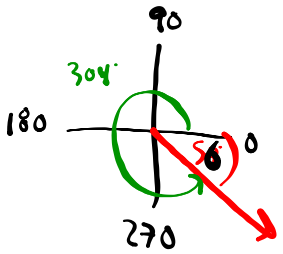
$$F_{ac} = \frac{G m_a m_c}{r^2} = \frac{(6.67\times10^{-11})(3\times10^5)(6.25\times10^5)}{(2.5\times10^3)^2}$$

$$= \frac{12.50625}{6{,}250{,}000} = \boxed{2.0010\times10^{-6}\,N}$$

$$\tan\theta = \left(\frac{2.001\times10^{-6}}{1.3303\times10^{-6}}\right)$$

$$\theta = 56.3832^\circ$$

$$\boxed{\theta = 304^\circ}$$



# The "Inverse $r^2$" Relationship

$F_g = \frac{Gm_A m_B}{r^2}$ $g = \frac{GM_{source}}{r^2}$ where $G = 6.67x10^{-11}\,\frac{Nm^2}{kg^2}$

**Q4:** What happens if we double our distance? Triple our distance?

$F_{g\,original} = \frac{Gm_1m_2}{r^2}$

$F_{new} = \frac{Gm_1m_2}{(2r)^2}$

$F_{new} = \frac{Gm_1m_2}{4r^2}$

$= \frac{1}{4}\left(\frac{Gm_1m_2}{r^2}\right)$

$= \frac{1}{4}\left(F_{g\,original}\right)$

Math 9, 10C

$(5x)^2 = 25x^2$

**Q5:** The force of gravity between two objects is 10N. The mass of the first object is doubled, and the distance between the objects is tripled. What is the new gravitational force?

*(Record your **three-digit** answer in the Numerical Response boxes below)*

| 2 | . | 2 | 2 |
|---|---|---|---|

$F_{g\,original} = \frac{Gm_1m_2}{r^2} = 10N$

$F_{new} = \frac{G(2m_1)m_2}{(3r)^2} = \frac{2Gm_1m_2}{9r^2} = \frac{2}{9}\left(\frac{Gm_1m_2}{r^2}\right)$

$= \frac{2}{9}(10\,N)$

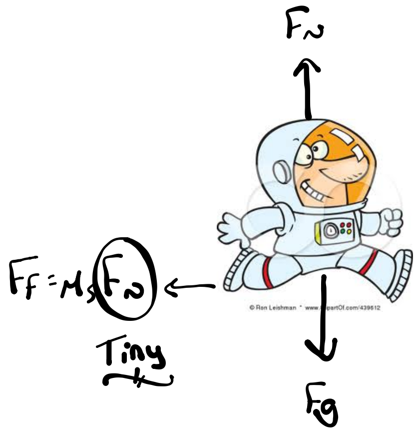
$= 2.2222\bar{2}\,N$

$\approx 2.22N$

# What is Happening?

Hint: Draw a Free-Body Diagram

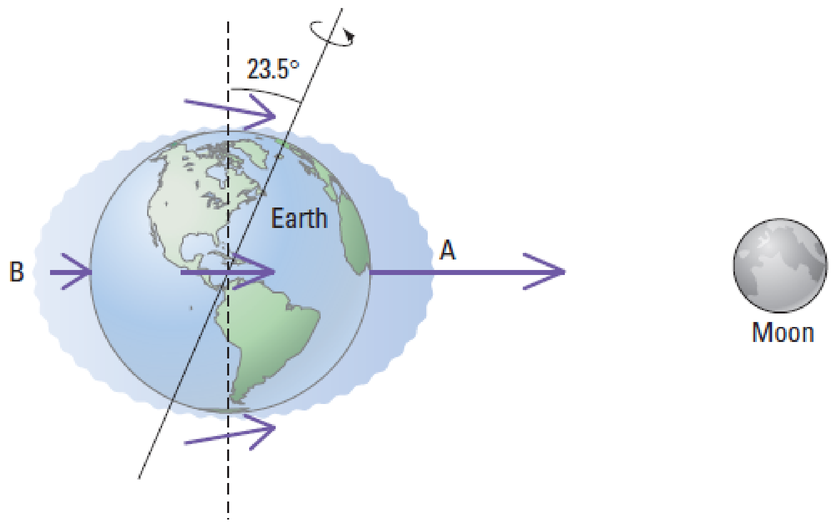
Astronauts on the Moon



## Textbook Practice

Pg. 215 #4, 5, 6

## What Causes Ocean Tides?

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