Today 13.1, 13.2

$\boxed{L35}$

Today 13.1, 13.2

$\boxed{L35}$

Newton's law of gravitation

ASU

Today 13.1, 13.2

$\underbrace{13.1}_{\text{Newton's law of gravitation}}$, $\underbrace{13.2}_{\text{Weight}}$

L35

$\boxed{L35}$

Today 13.1, 13.2

Monday 13.3, 13.4

L35

Today 13.1, 13.2

Monday 13.3, 13.4

Gravitational potential energy

Today 13.1, 13.2

Monday 13.3, 13.4

Gravitational potential energy

Motion of satalites

$\boxed{L35}$

<u>Today</u> 13.1, 13.2

<u>Monday</u> 13.3, 13.4

<u>Wednesday</u> 13.5, 13.8

ASU

L35

Today 13.1, 13.2

Monday 13.3, 13.4

Wednesday 13.5, 13.8

Kepler's laws

L35

Today 13.1, 13.2

Monday 13.3, 13.4

Wednesday $\underbrace{13.5}_{\text{Kepler's laws}}$, $\underbrace{13.8}_{\text{Black holes}}$

$\boxed{L35}$

Today 13.1, 13.2

Monday 13.3, 13.4

Wednesday 13.5, 13.8

Friday Nov. 27th Holiday

L35

Today 13.1, 13.2

Monday 13.3, 13.4

Wednesday 13.5, 13.8

Friday Nov. 27th Holiday

Monday Nov. 30th Exam #4

L35

Today 13.1, 13.2

Monday 13.3, 13.4

Wednesday 13.5, 13.8

Friday Nov. 27th Holiday

Monday Nov. 30th Exam #4

Wednesday Dec. 2nd Day of Reckoning

L35

Today 13.1, 13.2

Monday 13.3, 13.4

Wednesday 13.5, 13.8

Friday Nov. 27th Holiday

Monday Nov. 30th Exam #4

Wednesday Dec. 2nd Day of Reckoning

Friday Dec 4th Final exam

Newtons Law of gravitation

Newtons Law of gravitation

$$F_g = \frac{Gm_1 m_2}{r^2}$$

Newtons Law of gravitation

Newton's **law of gravitation:**
Magnitude of attractive gravitational force between any two particles

$$F_g = \frac{Gm_1m_2}{r^2}$$

Newtons Law of gravitation

Gravitational constant (same for any two particles)

Newton's **law of gravitation:** Magnitude of attractive gravitational force between any two particles

$$F_g = \frac{Gm_1m_2}{r^2}$$

ASU

Newtons Law of gravitation

Newton's **law of gravitation:**
Magnitude of attractive gravitational force between any two particles

Gravitational constant (same for any two particles)

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

Masses of particles

Newtons Law of gravitation

Gravitational constant (same for any two particles)

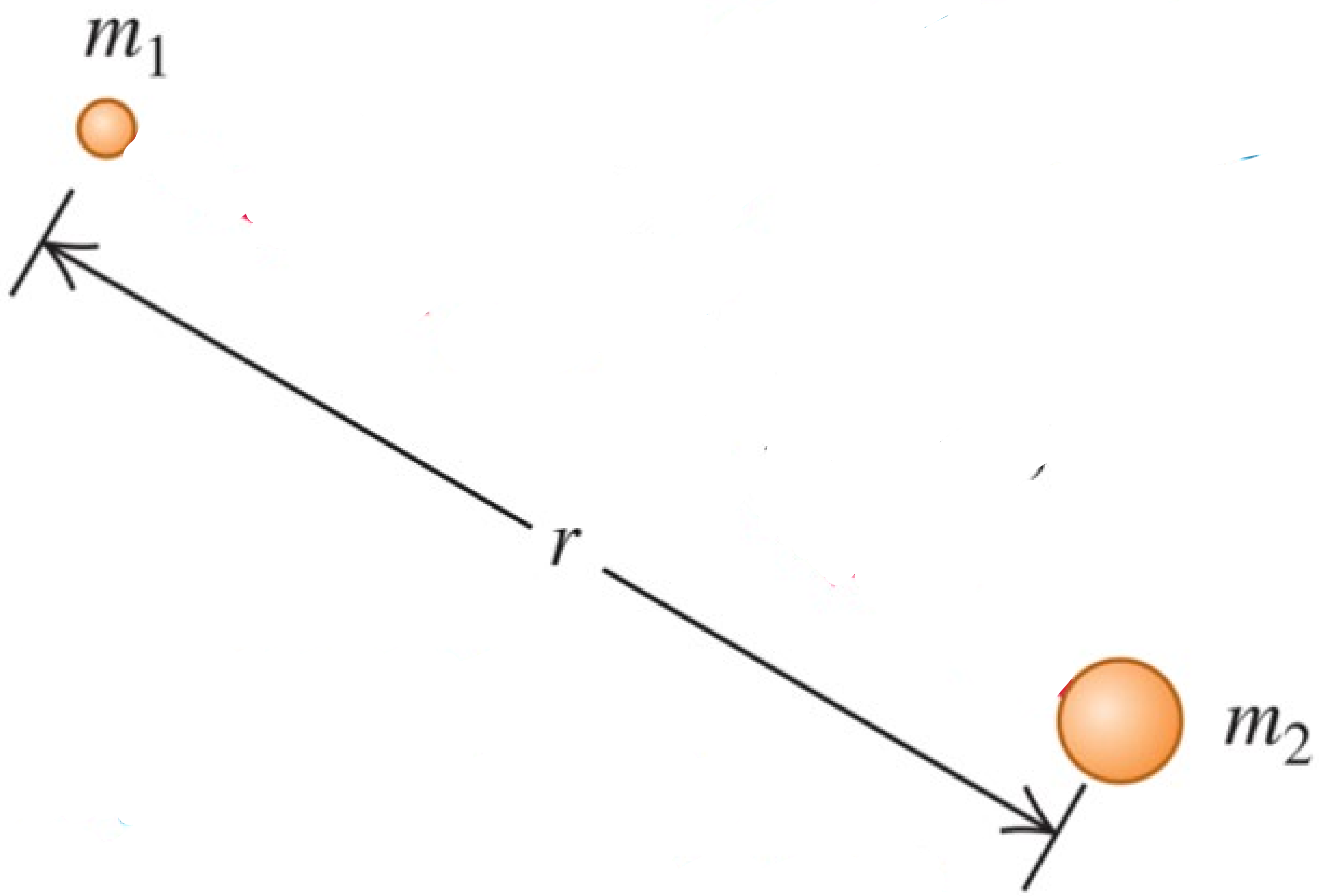
Newton's **law of gravitation:** Magnitude of attractive gravitational force between any two particles

$$F_g = \frac{Gm_1m_2}{r^2}$$

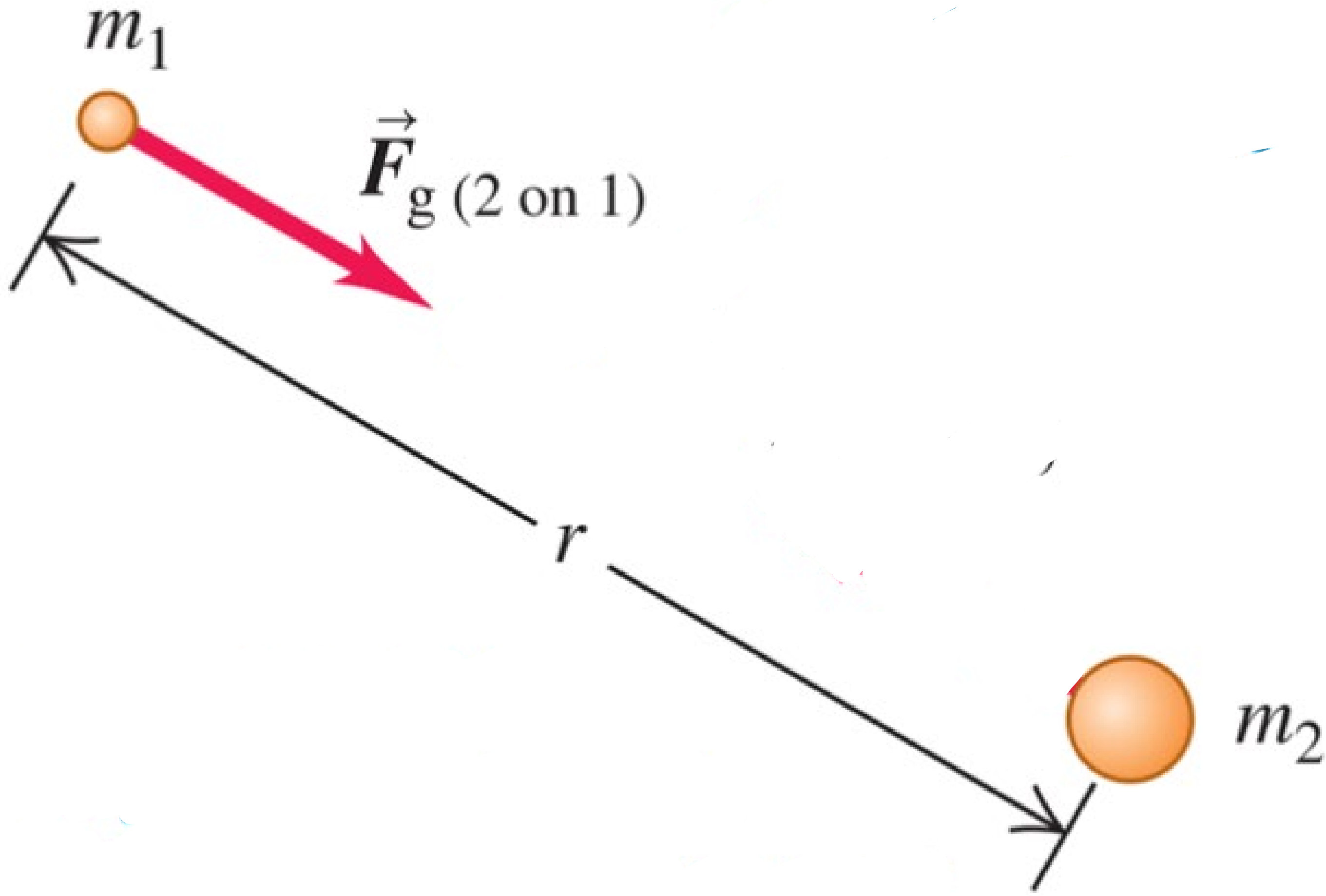
Masses of particles

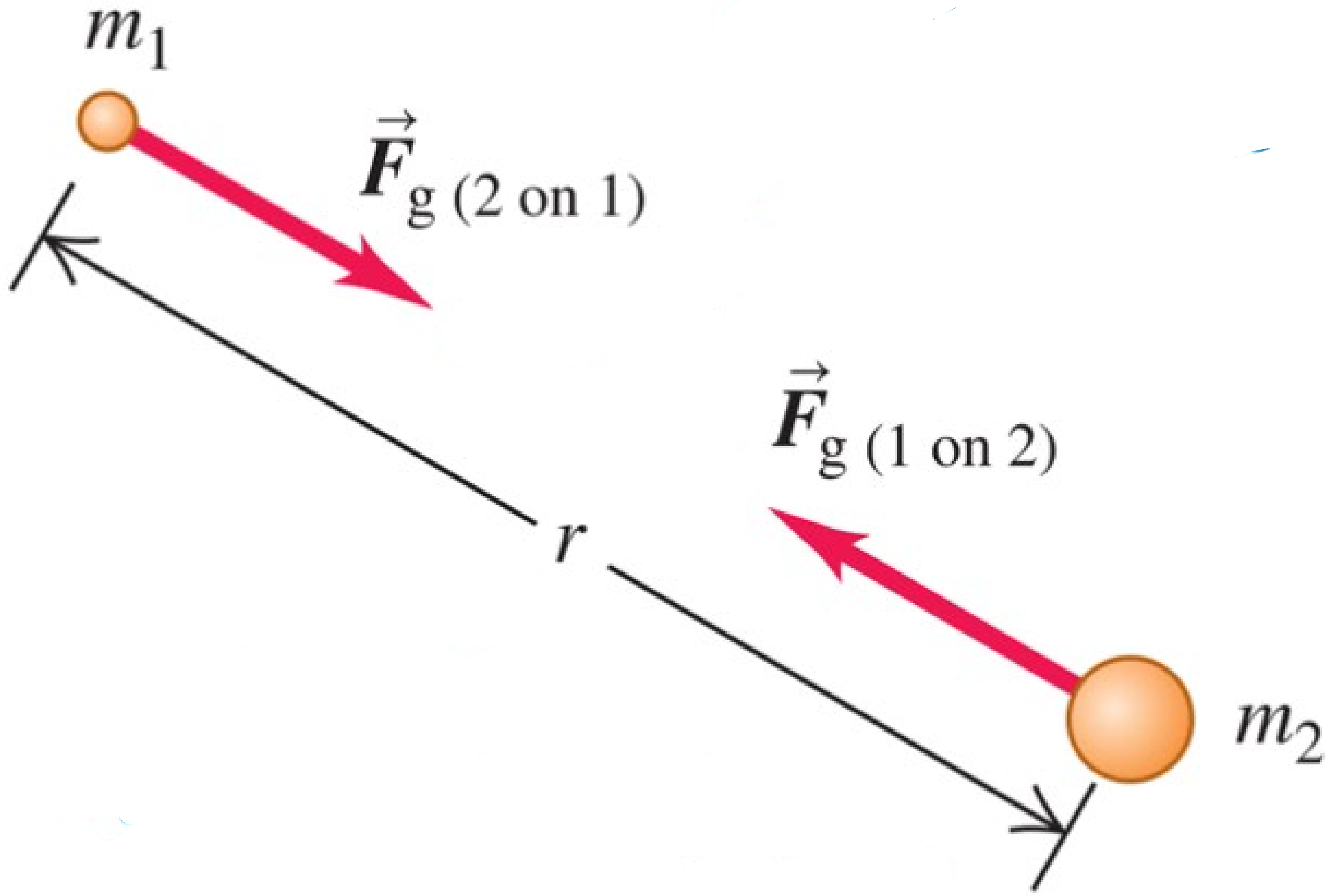
Distance between particles


m_1
m_2

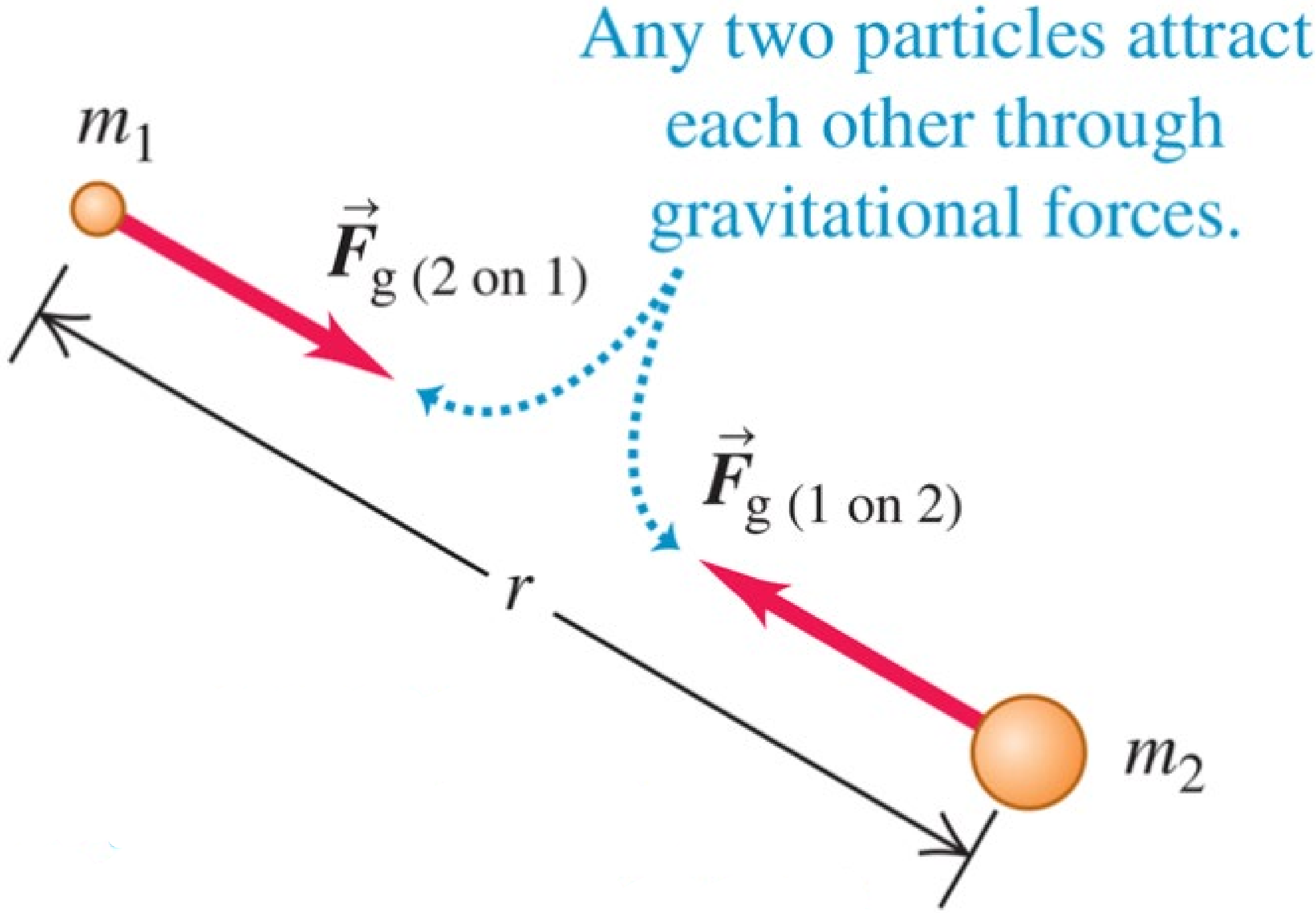


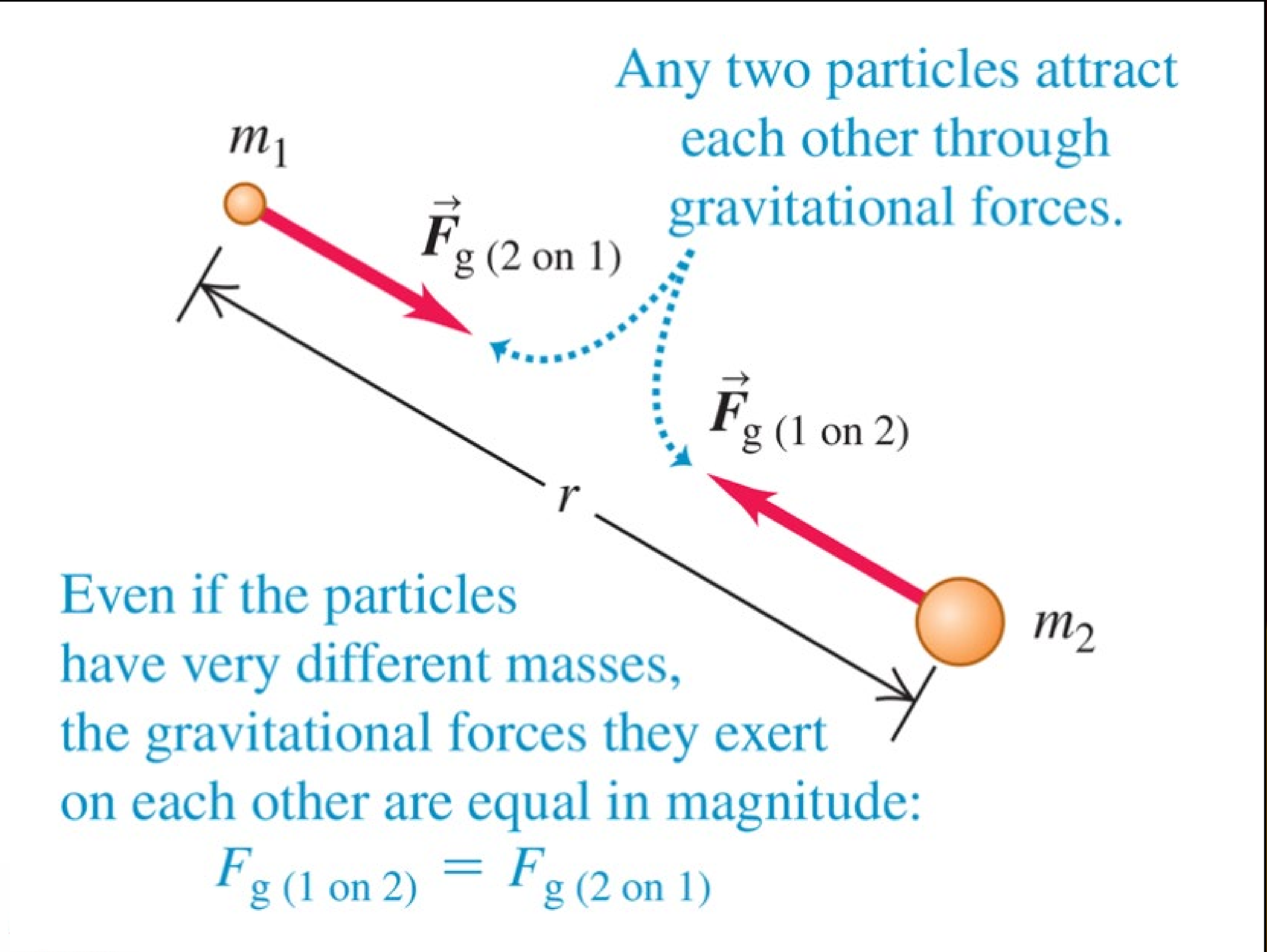
m_1
r
m_2


m_1
$\vec{F}_{g\,(2\text{ on }1)}$
r
m_2



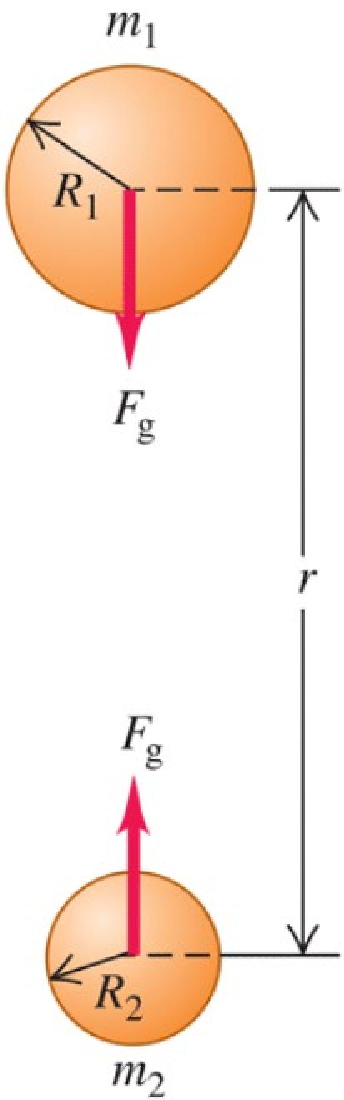
m_1
$\vec{F}_{g\,(2\text{ on }1)}$
r
$\vec{F}_{g\,(1\text{ on }2)}$
m_2

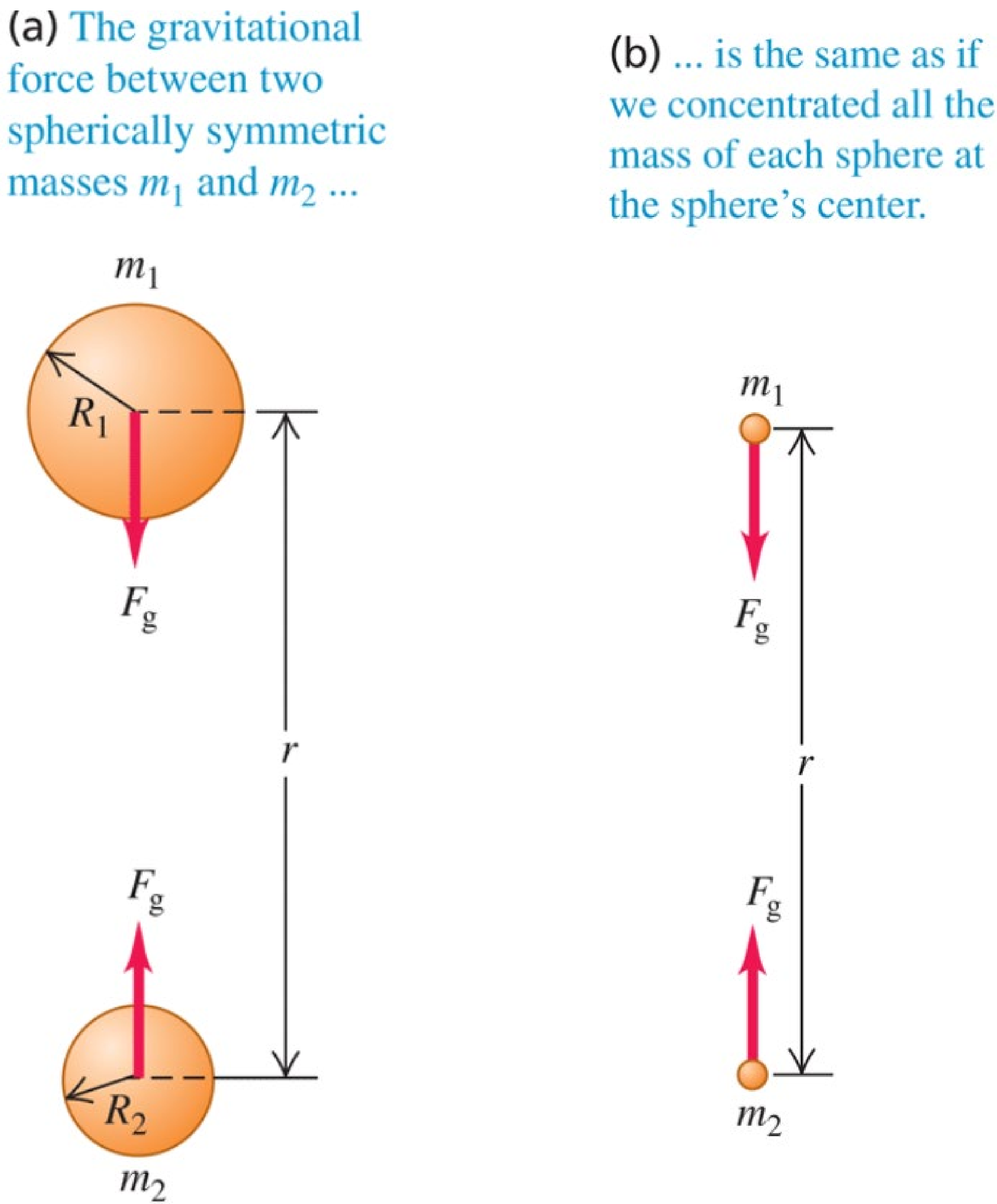

Any two particles attract each other through gravitational forces.
m_1
$\vec{F}_{g\,(2\text{ on }1)}$
$\vec{F}_{g\,(1\text{ on }2)}$
r
m_2

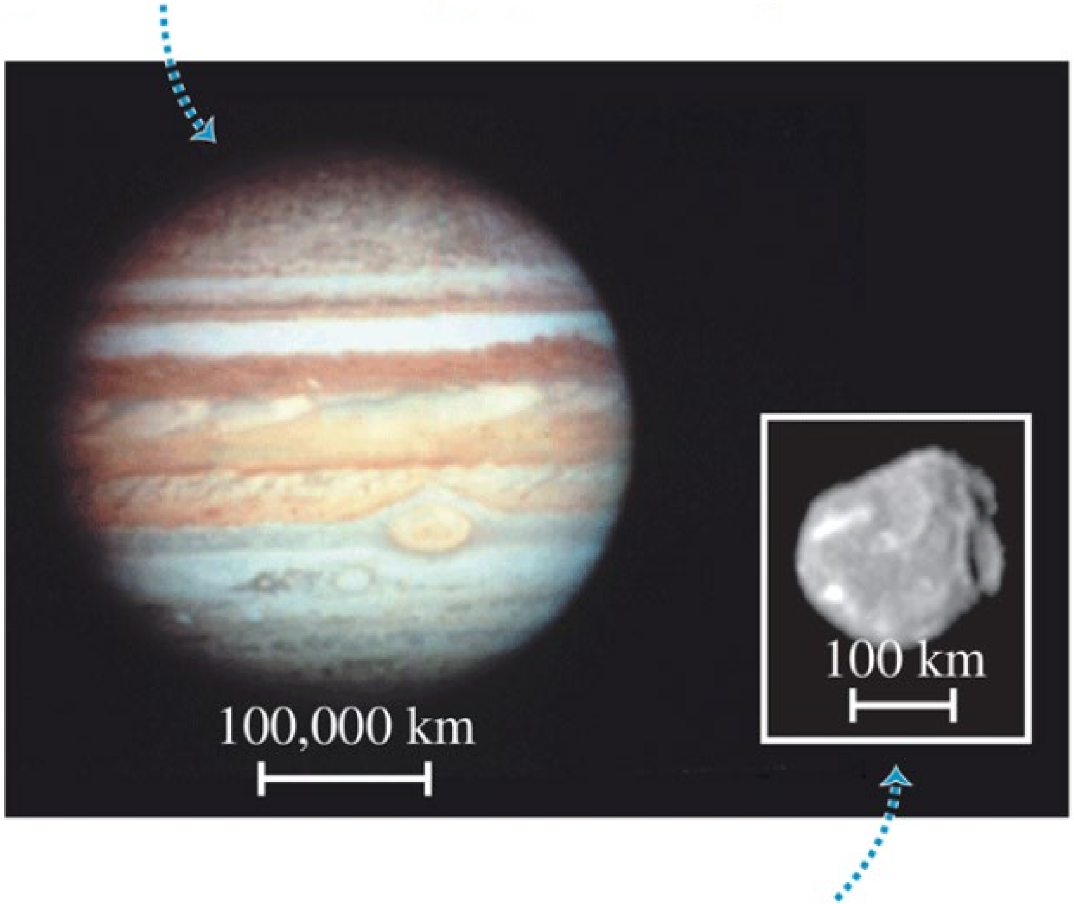


Any two particles attract each other through gravitational forces.
m_1
$\vec{F}_{g\ (2\ \mathrm{on}\ 1)}$
$\vec{F}_{g\ (1\ \mathrm{on}\ 2)}$
r
m_2
Even if the particles have very different masses, the gravitational forces they exert on each other are equal in magnitude:
$F_{g\ (1\ \mathrm{on}\ 2)} = F_{g\ (2\ \mathrm{on}\ 1)}$

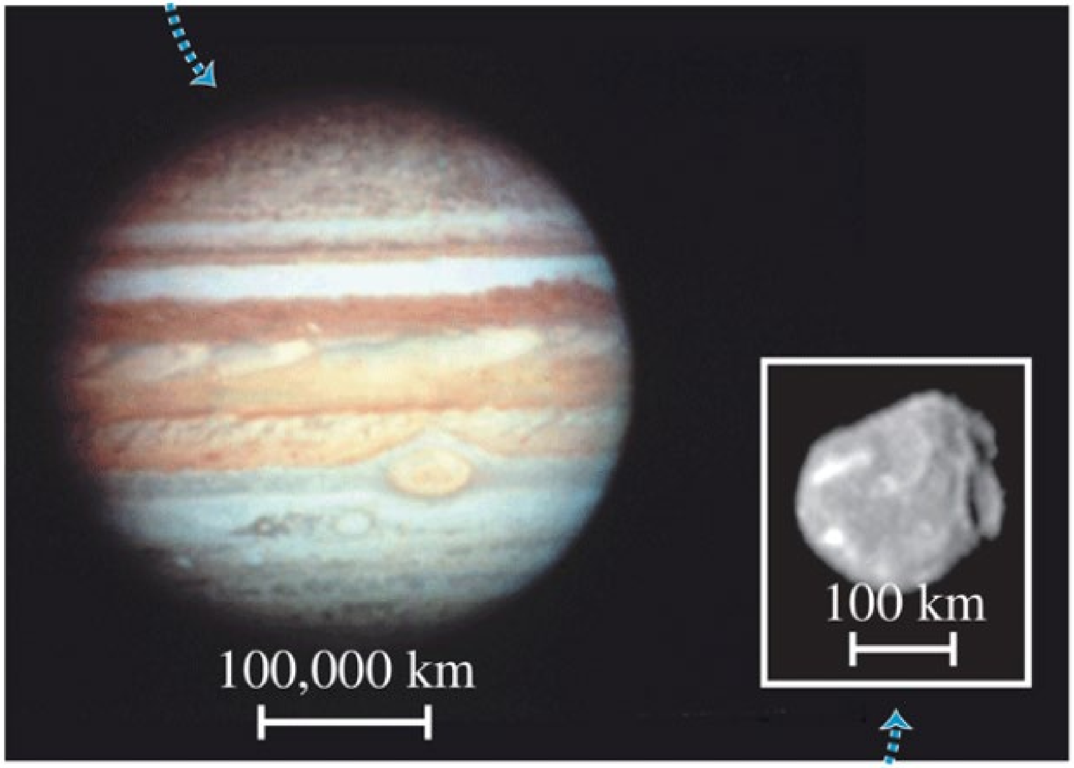
(a) The gravitational force between two spherically symmetric masses m_1 and m_2 ...



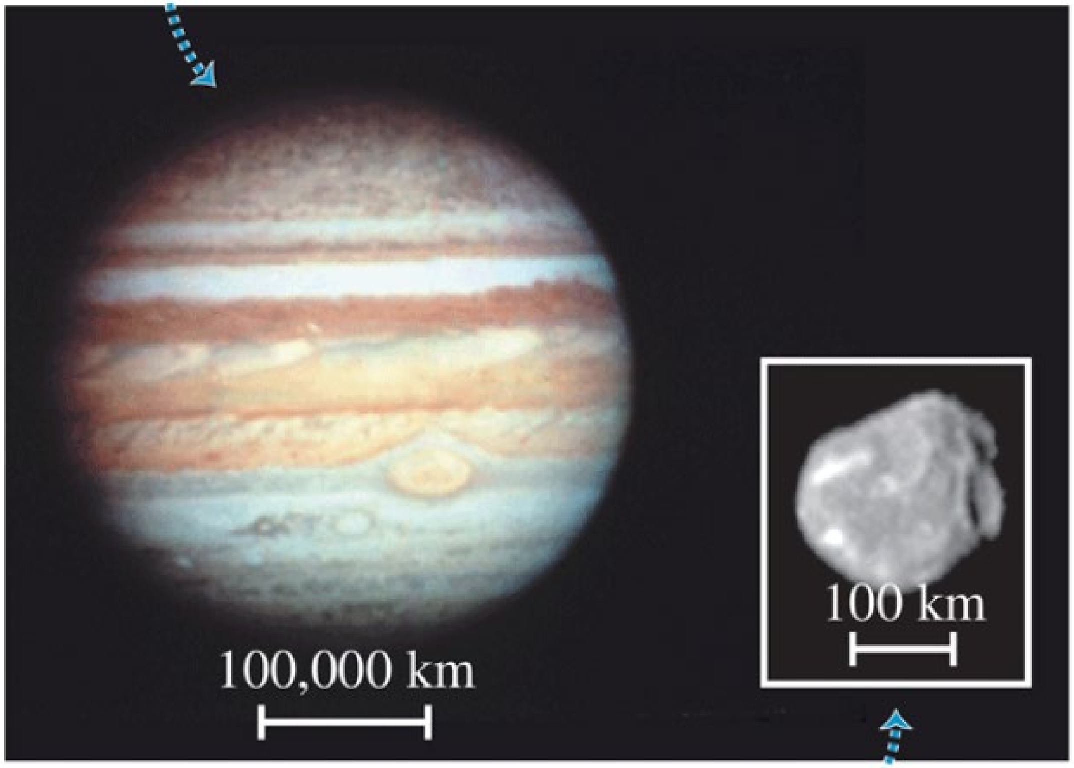

(a) The gravitational force between two spherically symmetric masses m_1 and m_2 ...
(b) ... is the same as if we concentrated all the mass of each sphere at the sphere's center.
m_1
R_1
F_g
r
F_g
R_2
m_2
m_1
F_g
r
F_g
m_2


100,000 km
100 km

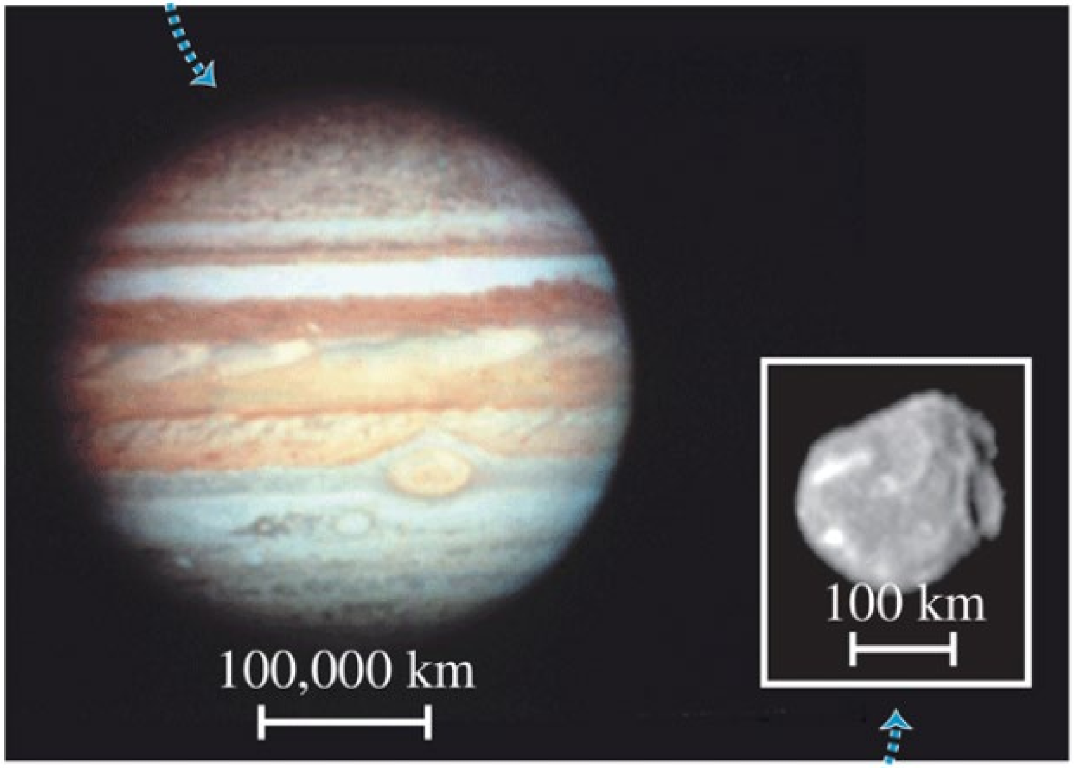
Jupiter's mass is very large (1.90×10^{27} kg),



Jupiter's mass is very large (1.90×10^{27} kg), so the mutual gravitational attraction of its parts has pulled it into a nearly spherical shape.

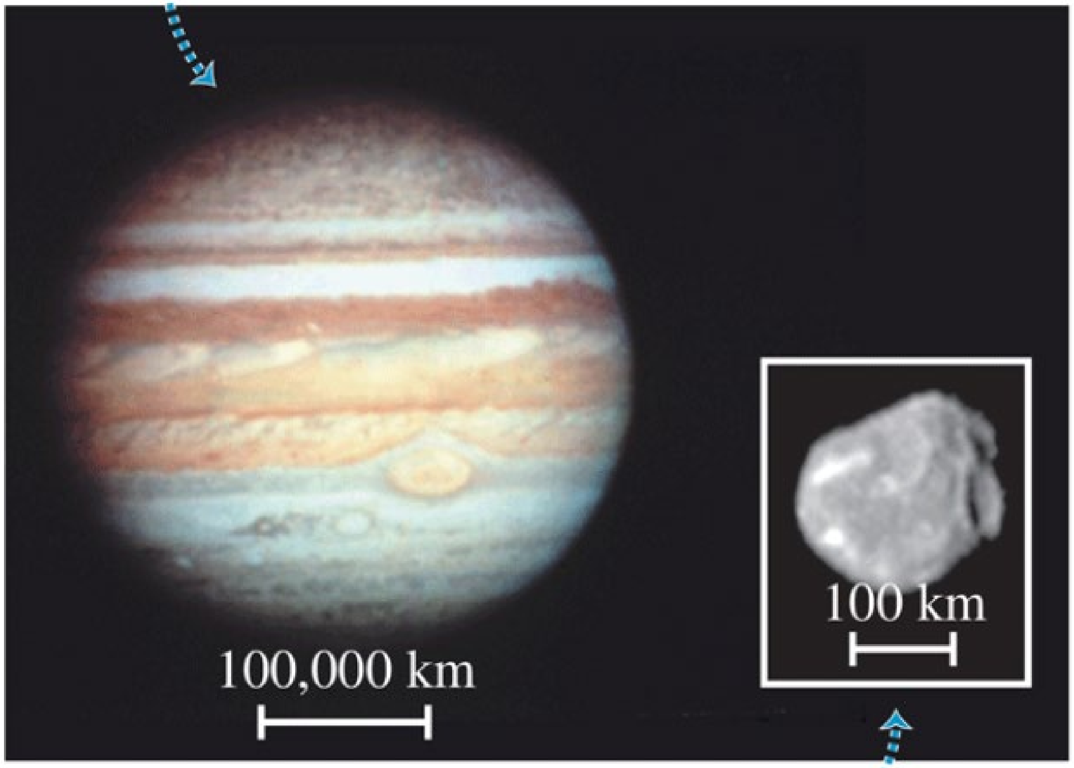


Jupiter's mass is very large (1.90×10^{27} kg), so the mutual gravitational attraction of its parts has pulled it into a nearly spherical shape.



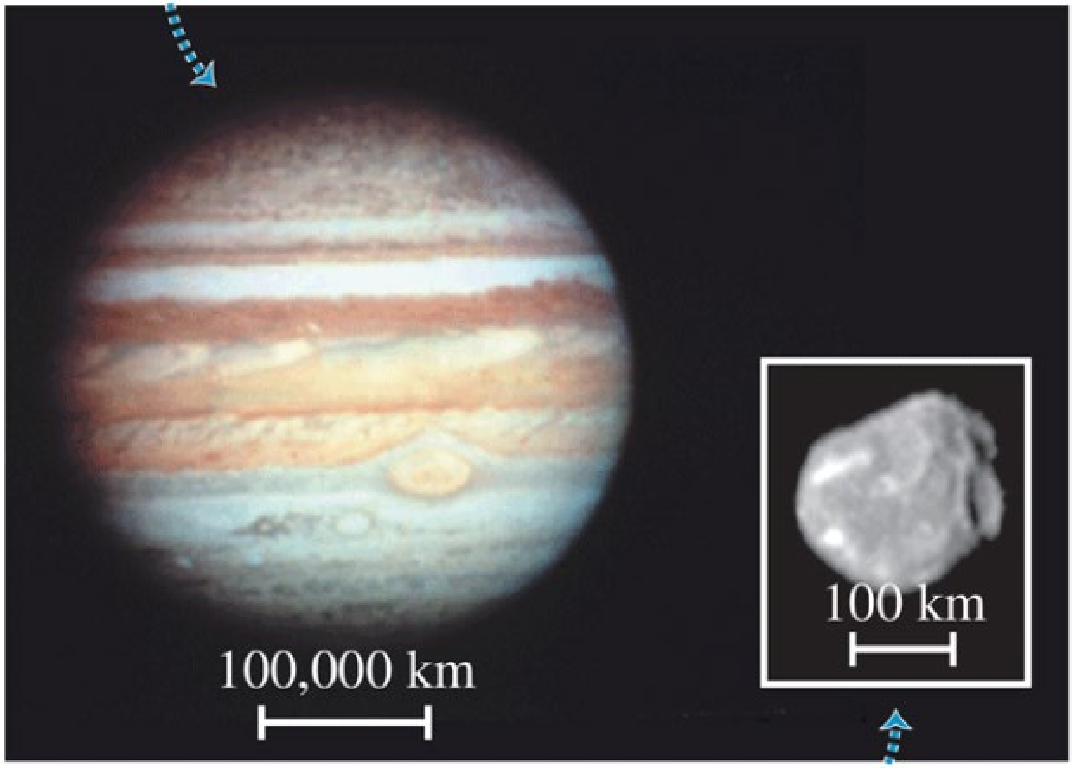
Amalthea, one of Jupiter's small moons, has a relatively tiny mass (7.17×10^{18} kg,

Jupiter's mass is very large (1.90×10^{27} kg), so the mutual gravitational attraction of its parts has pulled it into a nearly spherical shape.



Amalthea, one of Jupiter's small moons, has a relatively tiny mass (7.17×10^{18} kg, only about 3.8×10^{-9} the mass of Jupiter) and weak mutual gravitation,

Jupiter's mass is very large (1.90×10^{27} kg), so the mutual gravitational attraction of its parts has pulled it into a nearly spherical shape.



Amalthea, one of Jupiter's small moons, has a relatively tiny mass (7.17×10^{18} kg, only about 3.8×10^{-9} the mass of Jupiter) and weak mutual gravitation, so it has an irregular shape.

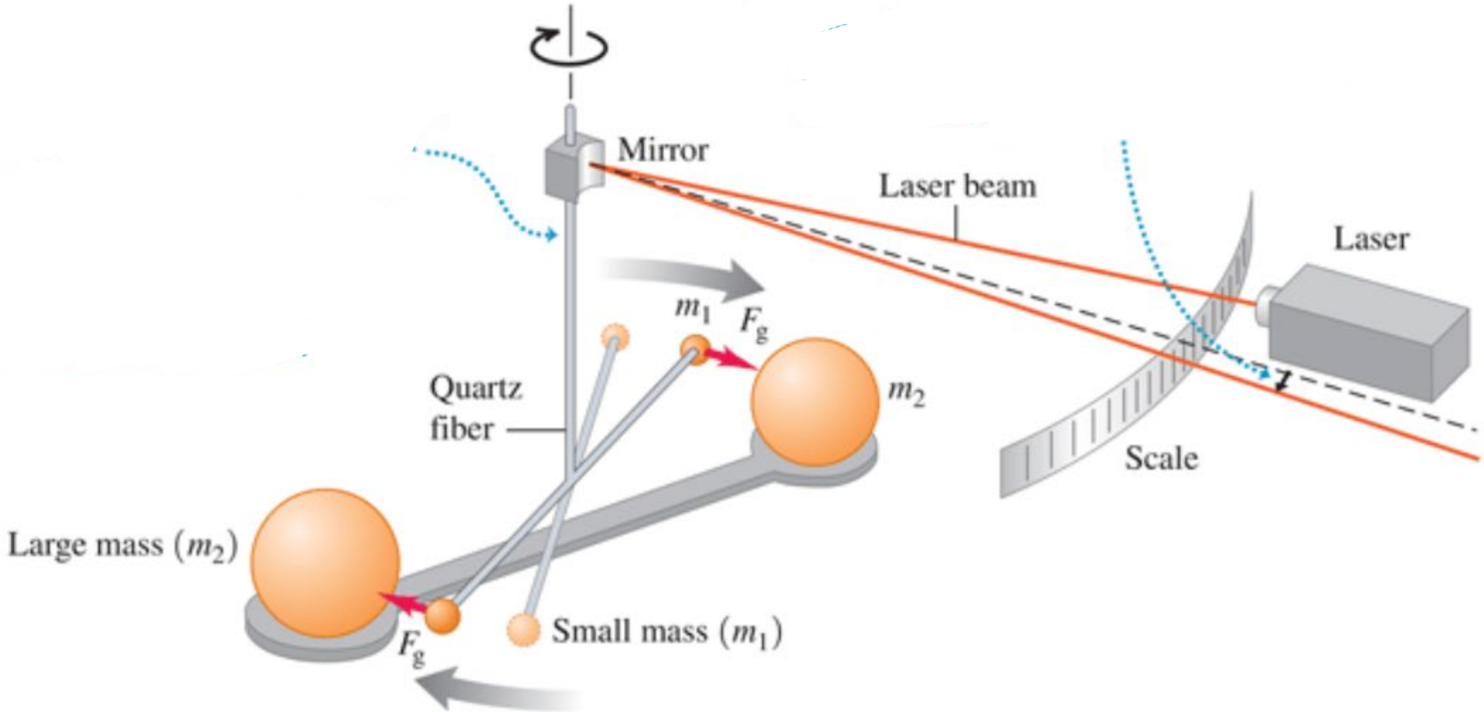
Determining the value of G

Determining the value of G

Cavendish torsion balance

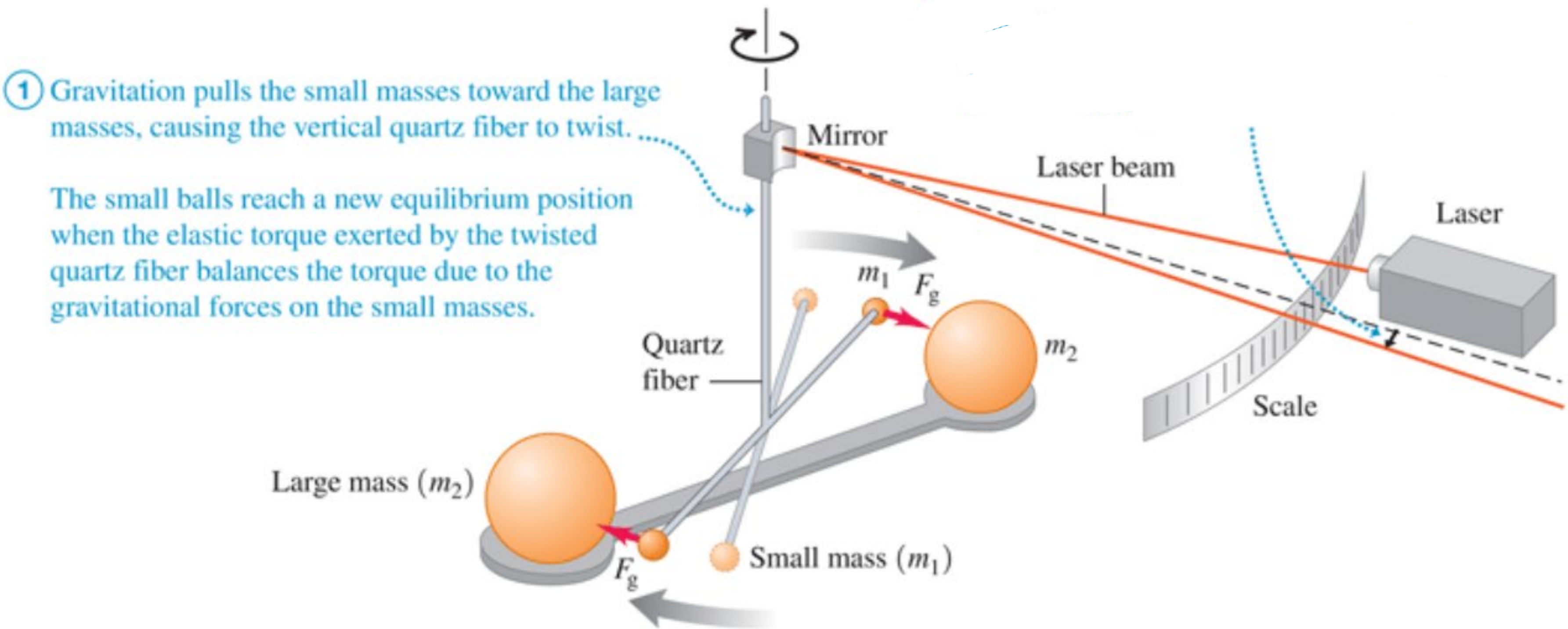
Determining the value of G

Cavendish torsion balance



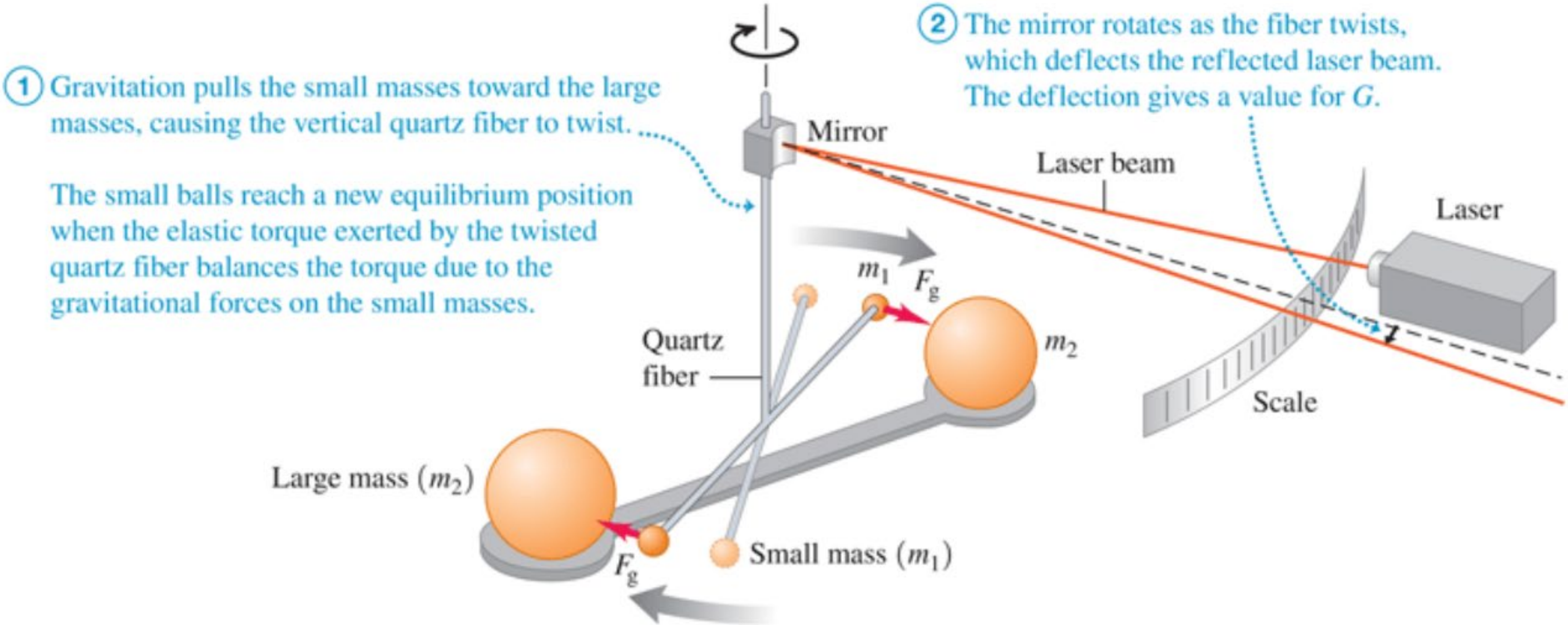
Determining the value of G

Cavendish torsion balance



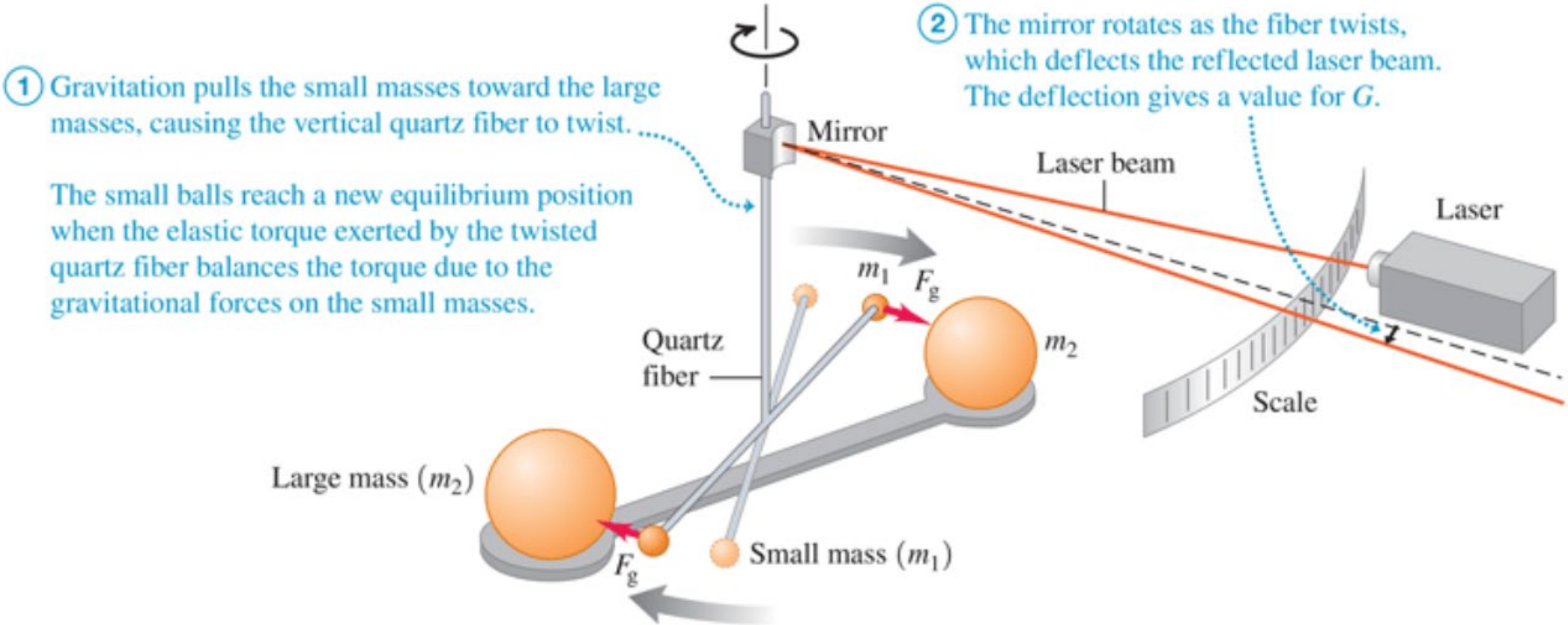
Determining the value of G

Cavendish torsion balance



Determining the value of G

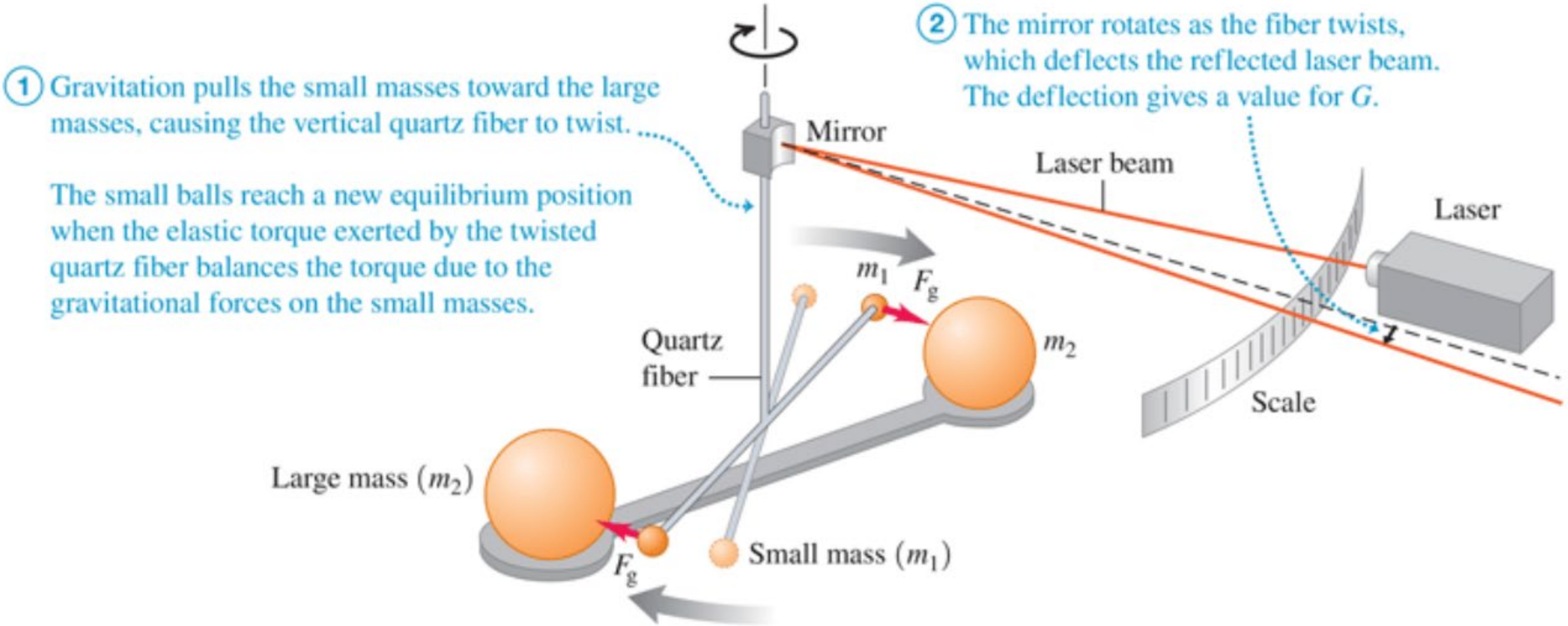
Cavendish torsion balance



The principle of the Cavendish balance, used for determining the value of G. The angle of deflection has been exaggerated here for clarity.

Determining the value of G

Cavendish torsion balance



The principle of the Cavendish balance, used for determining the value of G. The angle of deflection has been exaggerated here for clarity.

$$G = 6.67408(31) * 10^{-11} \frac{N \cdot m^2}{kg^2}$$

The mass m_1 of one of the small spheres of a Cavendish balance is 0.0100 kg, the mass m_2 of the nearest large sphere is 0.500 kg, and the center-to-center distance between them is 0.0500 m. Find the gravitational force F_g on each sphere due to the other.

The mass m_1 of one of the small spheres of a Cavendish balance is 0.0100 kg, the mass m_2 of the nearest large sphere is 0.500 kg, and the center-to-center distance between them is 0.0500 m. Find the gravitational force F_g on each sphere due to the other.

$m_1 = 1 * 10^{-2}$ kg

The mass m_1 of one of the small spheres of a Cavendish balance is 0.0100 kg, the mass m_2 of the nearest large sphere is 0.500 kg, and the center-to-center distance between them is 0.0500 m. Find the gravitational force F_g on each sphere due to the other.

$m_1 = 1*10^{-2}\,kg, \quad m_2 = 5*10^{-1}\,kg$

The mass m_1 of one of the small spheres of a Cavendish balance is 0.0100 kg, the mass m_2 of the nearest large sphere is 0.500 kg, and the center-to-center distance between them is 0.0500 m. Find the gravitational force F_g on each sphere due to the other.

$m_1 = 1*10^{-2}\,kg, \quad m_2 = 5*10^{-1}\,kg, \quad d = 5*10^{-2}\,m$

The mass m_1 of one of the small spheres of a Cavendish balance is 0.0100 kg, the mass m_2 of the nearest large sphere is 0.500 kg, and the center-to-center distance between them is 0.0500 m. Find the gravitational force F_g on each sphere due to the other.

$m_1 = 1*10^{-2}\,kg$, $m_2 = 5*10^{-1}\,kg$, $d = 5*10^{-2}\,m$

The mass m_1 of one of the small spheres of a Cavendish balance is 0.0100 kg, the mass m_2 of the nearest large sphere is 0.500 kg, and the center-to-center distance between them is 0.0500 m. Find the gravitational force F_g on each sphere due to the other.

$m_1 = 1 * 10^{-2}\,kg,\ m_2 = 5 * 10^{-1}\,kg,\ d = 5 * 10^{-2}\,m$

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

ASU

The mass m_1 of one of the small spheres of a Cavendish balance is 0.0100 kg, the mass m_2 of the nearest large sphere is 0.500 kg, and the center-to-center distance between them is 0.0500 m. Find the gravitational force F_g on each sphere due to the other.

$$m_1 = 1 * 10^{-2}\,kg,\quad m_2 = 5 * 10^{-1}\,kg,\quad d = 5 * 10^{-2}\,m$$

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

$$F_g = \frac{(6.67 * 10^{-11})(1 * 10^{-2})(5 * 10^{-1})}{25 * 10^{-4}}\,N$$

ASU

The mass m_1 of one of the small spheres of a Cavendish balance is 0.0100 kg, the mass m_2 of the nearest large sphere is 0.500 kg, and the center-to-center distance between them is 0.0500 m. Find the gravitational force F_g on each sphere due to the other.

$m_1 = 1*10^{-2}\,kg, \quad m_2 = 5*10^{-1}\,kg, \quad d = 5*10^{-2}\,m$

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

$$F_g = \frac{(6.67*10^{-11})(1*10^{-2})(5*10^{-1})}{25*10^{-4}} N$$

$$= \left(\frac{6.67}{5}\right)*10^{-14+4} N$$

The mass m_1 of one of the small spheres of a Cavendish balance is 0.0100 kg, the mass m_2 of the nearest large sphere is 0.500 kg, and the center-to-center distance between them is 0.0500 m. Find the gravitational force F_g on each sphere due to the other.

$m_1 = 1*10^{-2}$ kg, $m_2 = 5*10^{-1}$ kg, $d = 5*10^{-2}$ m

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

$$F_g = \frac{(6.67*10^{-11})(1*10^{-2})(5*10^{-1})}{25*10^{-4}} N$$

$$= \left(\frac{6.67}{5}\right)*10^{-14+4} N = \boxed{1.33*10^{-10} N}$$

ASU

Suppose the two spheres in Example 13.1 are placed with their centers 0.0500 m apart at a point in space far removed from all other objects. What is the magnitude of the acceleration of each, relative to an inertial system?

Suppose the two spheres in Example 13.1 are placed with their centers 0.0500 m apart at a point in space far removed from all other objects. What is the magnitude of the acceleration of each, relative to an inertial system?

Suppose the two spheres in Example 13.1 are placed with their centers 0.0500 m apart at a point in space far removed from all other objects. What is the magnitude of the acceleration of each, relative to an inertial system?

$$F_{1\to 2} = m_2 a_2$$

Suppose the two spheres in Example 13.1 are placed with their centers 0.0500 m apart at a point in space far removed from all other objects. What is the magnitude of the acceleration of each, relative to an inertial system?

$$F_{1\to2} = m_2 a_2 \;\&\; F_{2\to1} = m_1 a_1$$

Suppose the two spheres in Example 13.1 are placed with their centers 0.0500 m apart at a point in space far removed from all other objects. What is the magnitude of the acceleration of each, relative to an inertial system?

$$F_{1\to 2} = m_2 a_2 \ \& \ F_{2\to 1} = m_1 a_1$$

$$\& \ F_{1\to 2} = F_{2\to 1} = 1.33 * 10^{-10} N$$

Suppose the two spheres in Example 13.1 are placed with their centers 0.0500 m apart at a point in space far removed from all other objects. What is the magnitude of the acceleration of each, relative to an inertial system?

$$F_{1\to 2} = m_2 a_2 \ \& \ F_{2\to 1} = m_1 a_1$$

$$\& \ F_{1\to 2} = F_{2\to 1} = 1.33 * 10^{-10} N$$

So $$a_2 = \frac{F_{1\to 2}}{m_2}$$

ASU

Suppose the two spheres in Example 13.1 are placed with their centers 0.0500 m apart at a point in space far removed from all other objects. What is the magnitude of the acceleration of each, relative to an inertial system?

$$F_{1\to 2} = m_2 a_2 \ \& \ F_{2\to 1} = m_1 a_1$$

$$\& \ F_{1\to 2} = F_{2\to 1} = 1.33 * 10^{-10} N$$

So $$a_2 = \frac{F_{1\to 2}}{m_2} = \frac{1.33*10^{-10} N}{5*10^{-1} Kg}$$

Suppose the two spheres in Example 13.1 are placed with their centers 0.0500 m apart at a point in space far removed from all other objects. What is the magnitude of the acceleration of each, relative to an inertial system?

$$F_{1\to 2} = m_2 a_2 \ \& \ F_{2\to 1} = m_1 a_1$$

$$\& \ F_{1\to 2} = F_{2\to 1} = 1.33 * 10^{-10} N$$

So $$a_2 = \frac{F_{1\to 2}}{m_2} = \frac{1.33*10^{-10} N}{5*10^{-1} kg}$$

$$\Rightarrow \quad a_2 = 0.266 * 10^{-9} \frac{m}{s^2}$$

Suppose the two spheres in Example 13.1 are placed with their centers 0.0500 m apart at a point in space far removed from all other objects. What is the magnitude of the acceleration of each, relative to an inertial system?

$$F_{1\to 2} = m_2 a_2 \quad \& \quad F_{2\to 1} = m_1 a_1$$

$$\& \quad F_{1\to 2} = F_{2\to 1} = 1.33 * 10^{-10} N$$

so

$$a_2 = \frac{F_{1\to 2}}{m_2} = \frac{1.33*10^{-10} N}{5*10^{-1} kg}$$

$$\Rightarrow \quad a_2 = 0.266 * 10^{-9} \frac{m}{s^2} = 2.66 * 10^{-10} m/s^2$$

Suppose the two spheres in Example 13.1 are placed with their centers 0.0500 m apart at a point in space far removed from all other objects. What is the magnitude of the acceleration of each, relative to an inertial system?

$$F_{1\to 2} = m_2 a_2 \; \& \; F_{2\to 1} = m_1 a_1$$

$$\& \; F_{1\to 2} = F_{2\to 1} = 1.33 * 10^{-10} N$$

So

$$a_2 = \frac{F_{1\to 2}}{m_2} = \frac{1.33*10^{-10} N}{5*10^{-1} kg}$$

$$\Rightarrow \; a_2 = 0.266*10^{-9} \frac{m}{s^2} = 2.66*10^{-10} m/s^2$$

$$\& \; a_1 = \frac{F_{2\to 1}}{m_1}$$

Suppose the two spheres in Example 13.1 are placed with their centers 0.0500 m apart at a point in space far removed from all other objects. What is the magnitude of the acceleration of each, relative to an inertial system?

$$F_{1\to2} = m_2 a_2 \;\; \& \;\; F_{2\to1} = m_1 a_1$$

$$\& \;\; F_{1\to2} = F_{2\to1} = 1.33 * 10^{-10} N$$

so $$a_2 = \frac{F_{1\to2}}{m_2} = \frac{1.33*10^{-10} N}{5*10^{-1} kg}$$

$$\Rightarrow \;\; a_2 = 0.266 * 10^{-9} \frac{m}{s^2} = 2.66 * 10^{-10}\, m/s^2$$

$$\& \;\; a_1 = \frac{F_{2\to1}}{m_1} = \frac{1.33*10^{-10} N}{1*10^{-2} kg}$$

ASU

Suppose the two spheres in Example 13.1 are placed with their centers 0.0500 m apart at a point in space far removed from all other objects. What is the magnitude of the acceleration of each, relative to an inertial system?

$$F_{1\to2} = m_2 a_2 \ \& \ F_{2\to1} = m_1 a_1$$

$$\& \ F_{1\to2} = F_{2\to1} = 1.33 * 10^{-10} N$$

so $$a_2 = \frac{F_{1\to2}}{m_2} = \frac{1.33*10^{-10} N}{5*10^{-1} kg}$$

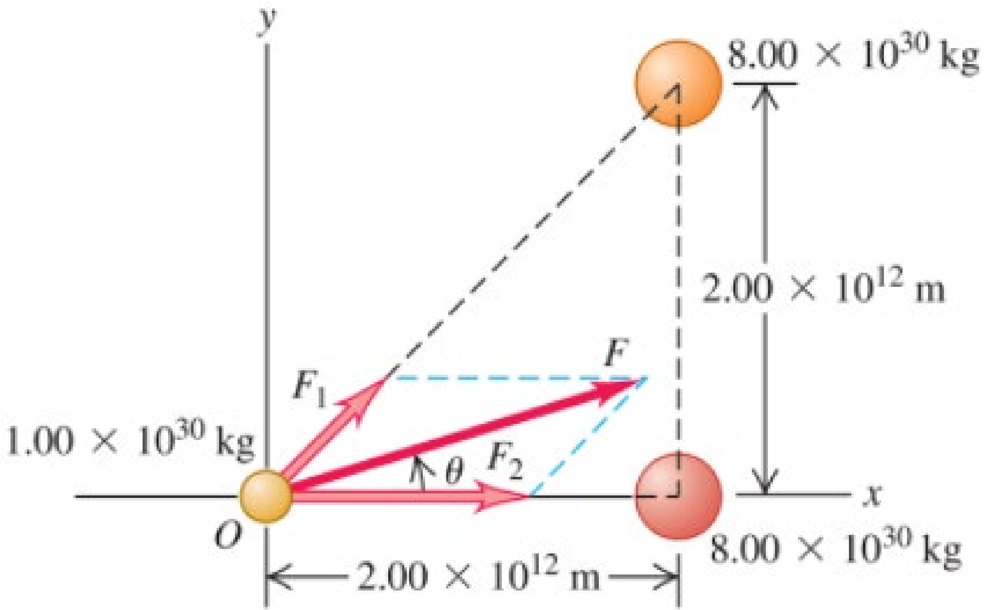
$$\Rightarrow a_2 = 0.266*10^{-9} \frac{m}{s^2} = 2.66*10^{-10} m/s^2$$

$$\& \ a_1 = \frac{F_{2\to1}}{m_1} = \frac{1.33*10^{-10} N}{1*10^{-2} kg}$$

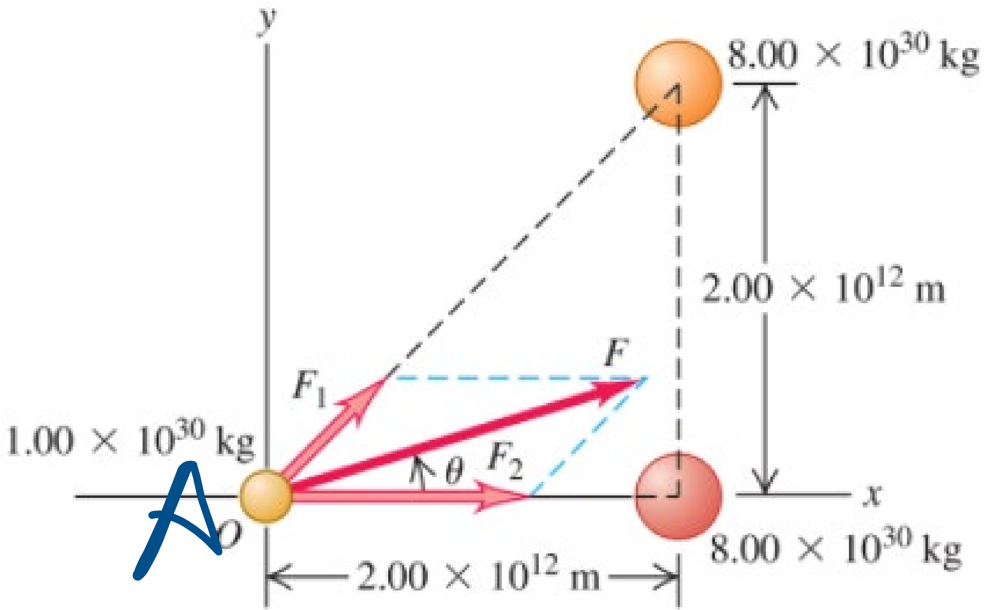
$$\Rightarrow a_1 = 1.33*10^{-8} \frac{m}{s^2}$$

ASU

Many stars belong to *systems* of two or more stars held together by their mutual gravitational attraction. Figure 13.5 shows a three-star system at an instant when the stars are at the vertices of a 45° right triangle. Find the total gravitational force exerted on the small star by the two large ones.

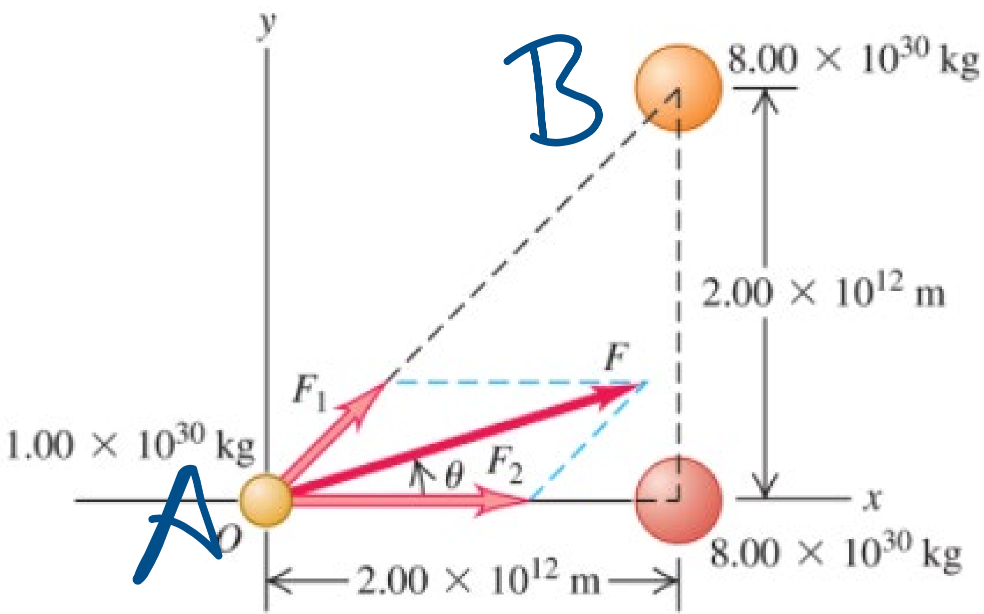


Many stars belong to *systems* of two or more stars held together by their mutual gravitational attraction. Figure 13.5 shows a three-star system at an instant when the stars are at the vertices of a 45° right triangle. Find the total gravitational force exerted on the small star by the two large ones.



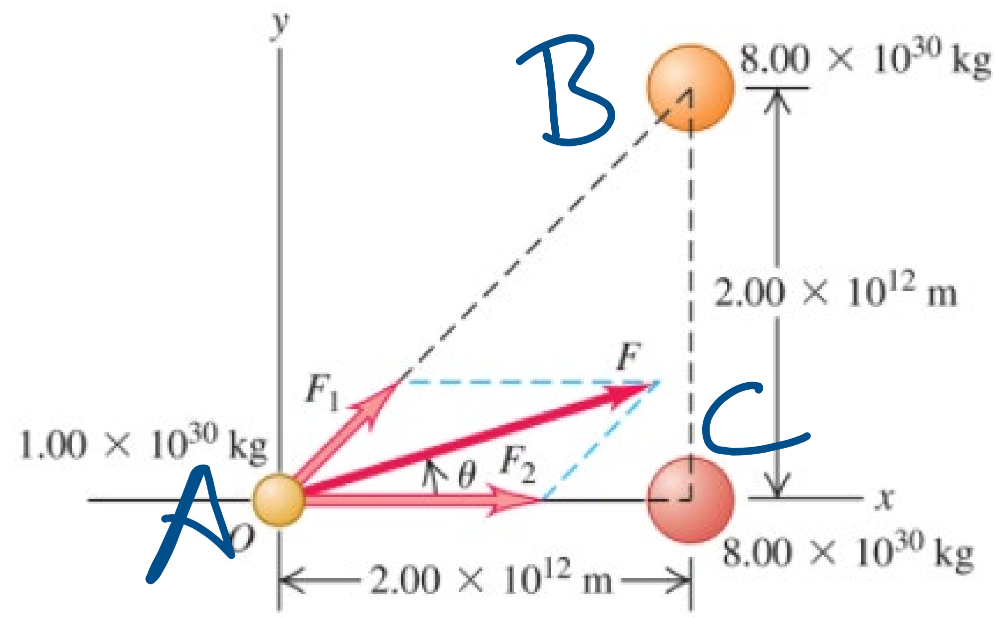
ASU

Many stars belong to *systems* of two or more stars held together by their mutual gravitational attraction. Figure 13.5 shows a three-star system at an instant when the stars are at the vertices of a 45° right triangle. Find the total gravitational force exerted on the small star by the two large ones.



ASU

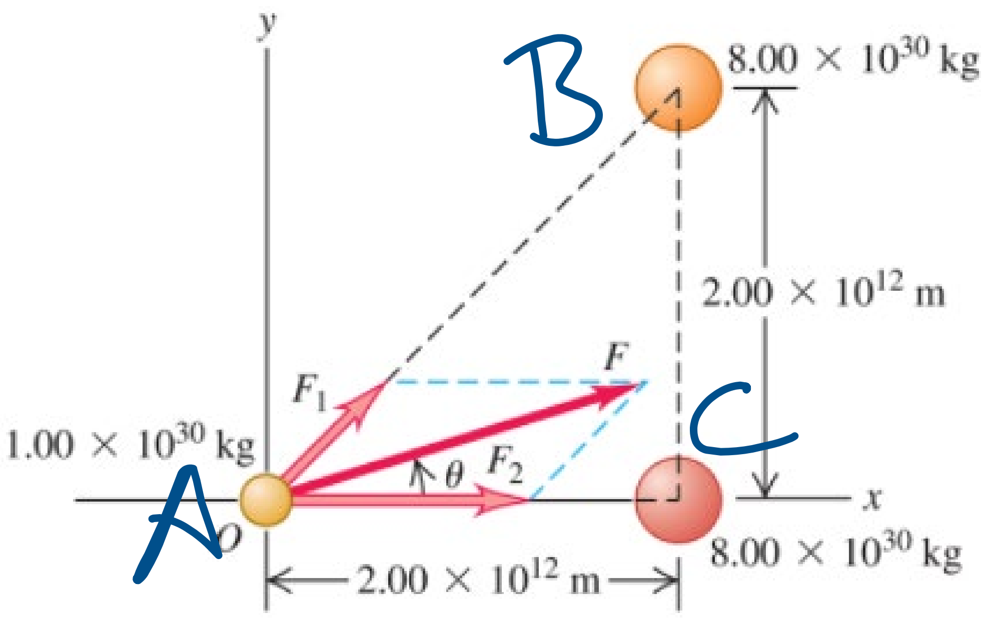
Many stars belong to *systems* of two or more stars held together by their mutual gravitational attraction. Figure 13.5 shows a three-star system at an instant when the stars are at the vertices of a 45° right triangle. Find the total gravitational force exerted on the small star by the two large ones.



ASU

Many stars belong to *systems* of two or more stars held together by their mutual gravitational attraction. Figure 13.5 shows a three-star system at an instant when the stars are at the vertices of a 45° right triangle. Find the total gravitational force exerted on the small star by the two large ones.

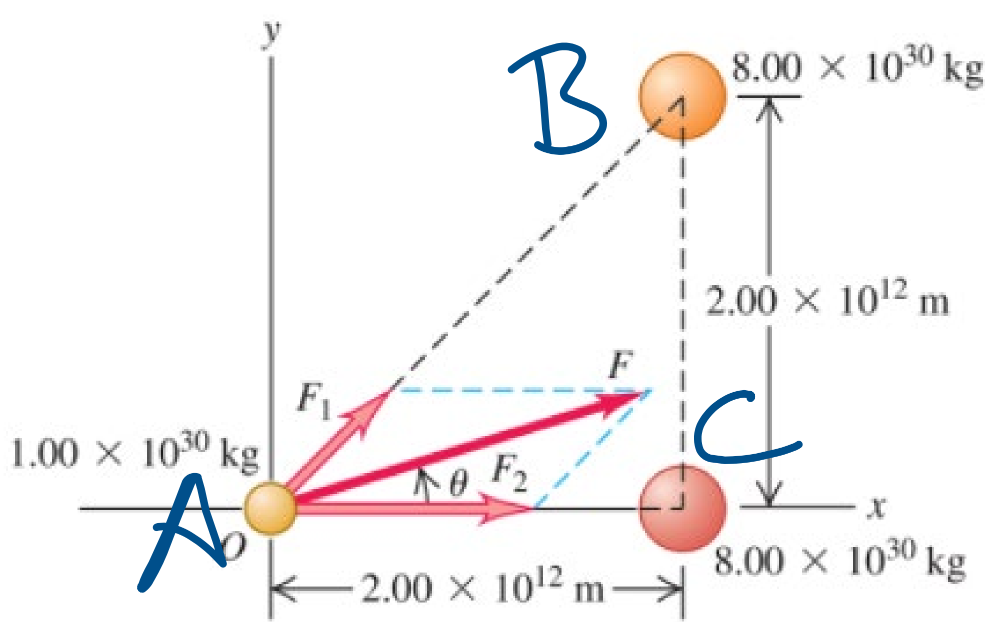
$$\vec{F}_A = \vec{F}_{B\to A} + \vec{F}_{C\to A}$$



Many stars belong to *systems* of two or more stars held together by their mutual gravitational attraction. Figure 13.5 shows a three-star system at an instant when the stars are at the vertices of a 45° right triangle. Find the total gravitational force exerted on the small star by the two large ones.

$$\vec{F}_A = \vec{F}_{B\to A} + \vec{F}_{C\to A}$$

$$\vec{F}_{B\to A} = \left(G\frac{M_B M_A}{r_{AB}^2}\right)\left(\hat{\imath}\cos 45^\circ + \hat{\jmath}\sin 45^\circ\right)$$

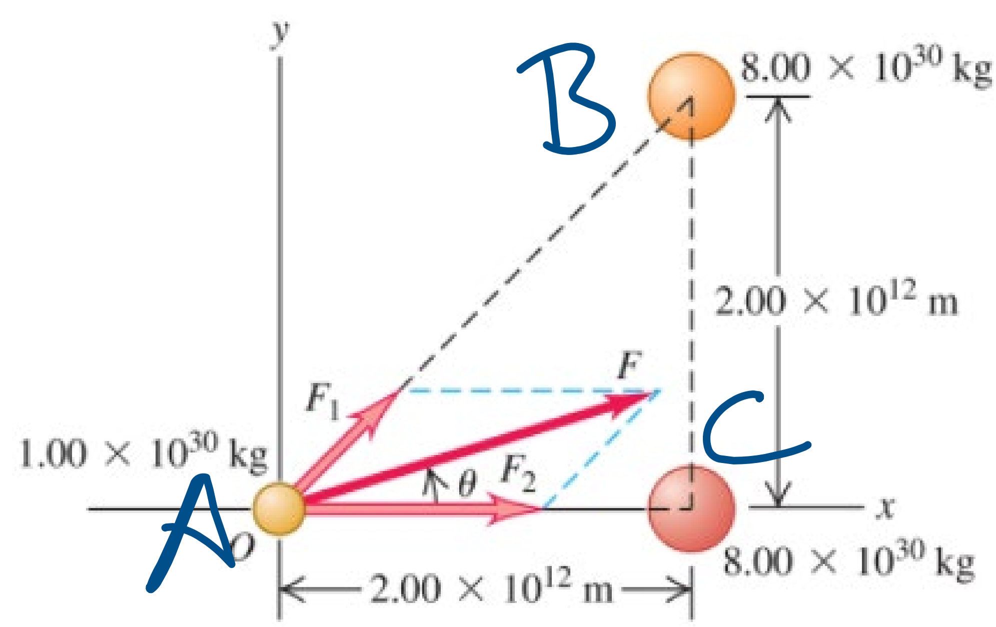


Many stars belong to *systems* of two or more stars held together by their mutual gravitational attraction. Figure 13.5 shows a three-star system at an instant when the stars are at the vertices of a 45° right triangle. Find the total gravitational force exerted on the small star by the two large ones.

$$\vec{F}_A = \vec{F}_{B\to A} + \vec{F}_{C\to A}$$

$$\vec{F}_{B\to A} = \left(G\frac{M_B M_A}{d_{AB}^2}\right)\left(\hat{\imath}\cos 45^\circ + \hat{\jmath}\sin 45^\circ\right)$$

$$\vec{F}_{C\to A} = \left(\frac{G M_C M_A}{d_{AC}^2}\right)\hat{\imath}$$



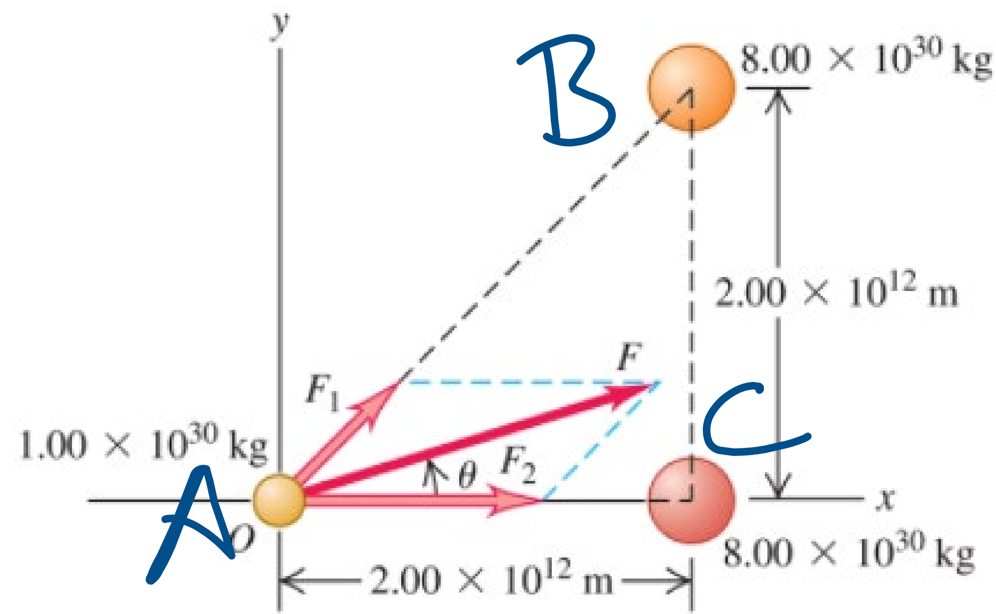
Many stars belong to *systems* of two or more stars held together by their mutual gravitational attraction. Figure 13.5 shows a three-star system at an instant when the stars are at the vertices of a 45° right triangle. Find the total gravitational force exerted on the small star by the two large ones.

$$d_{AB}^2 = d_{AC}^2 + d_{CB}^2$$

$$\vec{F}_A = \vec{F}_{B \to A} + \vec{F}_{C \to A}$$

$$\vec{F}_{B \to A} = \left(G \frac{M_B M_A}{d_{AB}^2}\right)\left(\hat{i} \cos 45^\circ + \hat{j} \sin 45^\circ\right)$$

$$\vec{F}_{C \to A} = \left(\frac{G M_C M_A}{d_{AC}^2}\right)\hat{i}$$



ASU

Many stars belong to *systems* of two or more stars held together by their mutual gravitational attraction. Figure 13.5 shows a three-star system at an instant when the stars are at the vertices of a 45° right triangle. Find the total gravitational force exerted on the small star by the two large ones.

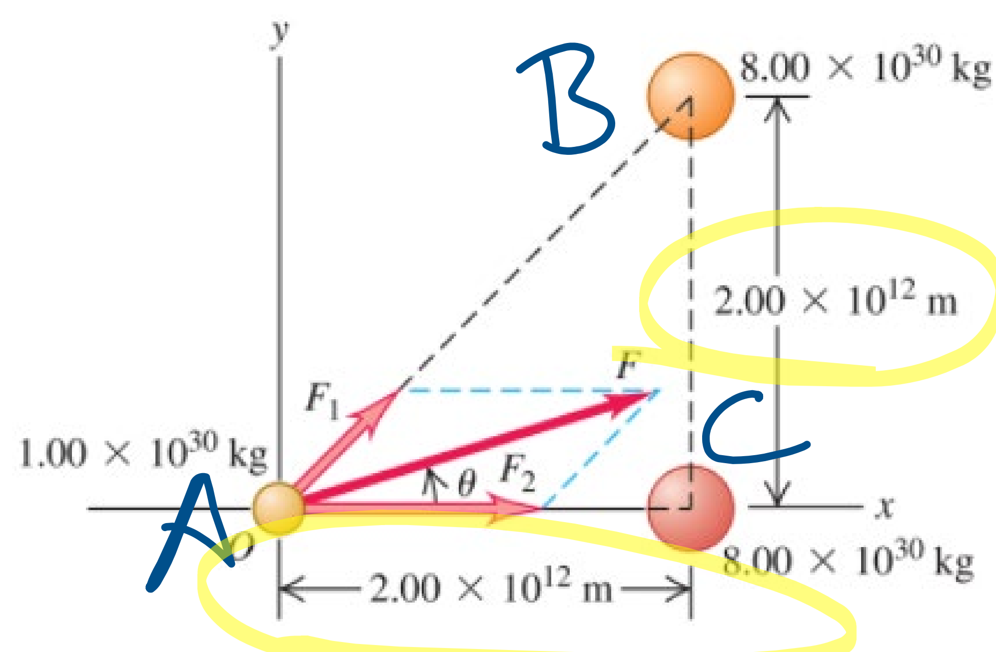
$$\vec{F}_A = \vec{F}_{B \to A} + \vec{F}_{C \to A}$$

$$\vec{F}_{B \to A} = \left(G\frac{M_B M_A}{d_{AB}^2}\right)(\hat{\imath}\cos 45^\circ + \hat{\jmath}\sin 45^\circ)$$

$$\vec{F}_{C \to A} = \left(\frac{G M_C M_A}{d_{AC}^2}\right)\hat{\imath}$$

$$d_{AB}^2 = d_{AC}^2 + d_{CB}^2 \;\&$$

$$d_{AC}^2 = d_{CB}^2 = 4 * 10^{24}\, m^2$$



ASU

Many stars belong to *systems* of two or more stars held together by their mutual gravitational attraction. Figure 13.5 shows a three-star system at an instant when the stars are at the vertices of a 45° right triangle. Find the total gravitational force exerted on the small star by the two large ones.

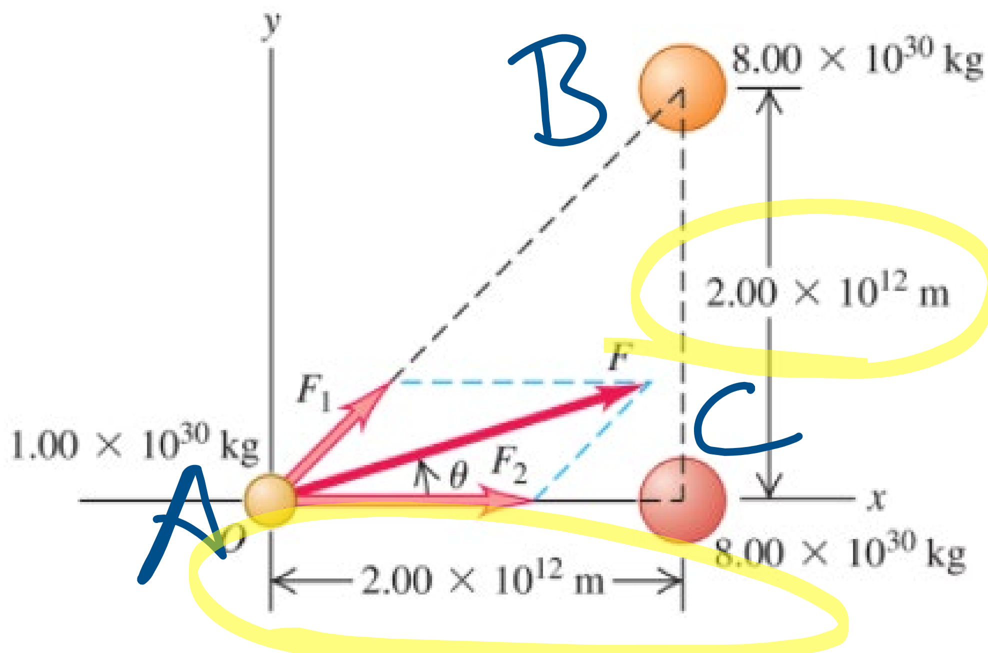
$$\vec{F}_A = \vec{F}_{B\to A} + \vec{F}_{C\to A}$$

$$d_{AB}^2 = d_{AC}^2 + d_{CB}^2 \;\&$$

$$d_{AC}^2 = d_{CB}^2 = 4*10^{24}\,m^2 \;\&$$

$$\vec{F}_{B\to A} = \left(G\frac{M_B M_A}{d_{AB}^2}\right)\left(\hat{i}\cos 45^\circ + \hat{j}\sin 45^\circ\right) \quad \cos 45^\circ = \frac{1}{\sqrt{2}}$$

$$\vec{F}_{C\to A} = \left(\frac{G M_C M_A}{d_{AC}^2}\right)\hat{i}$$



ASU

Many stars belong to *systems* of two or more stars held together by their mutual gravitational attraction. Figure 13.5 shows a three-star system at an instant when the stars are at the vertices of a 45° right triangle. Find the total gravitational force exerted on the small star by the two large ones.

$$d_{AB}^2 = d_{AC}^2 + d_{CB}^2 \ \&$$

$$d_{AC}^2 = d_{CB}^2 = 4*10^{24}\ m^2 \ \&$$

$$\vec{F}_A = \vec{F}_{B\to A} + \vec{F}_{C\to A}$$

$$\vec{F}_{B\to A} = \left(G\frac{M_B M_A}{d_{AB}^2}\right)(\hat{\imath}\cos 45^\circ + \hat{\jmath}\sin 45^\circ) \quad \cos 45^\circ = \frac{1}{\sqrt{2}}$$

$$\vec{F}_{C\to A} = \left(\frac{G M_C M_A}{d_{AC}^2}\right)\hat{\imath}$$

Now $\vec{F}_{B\to A} = \left(G\frac{M_B M_A}{2 d_{AC}^2}\right)\left(\frac{1}{\sqrt{2}}\right)(\hat{\imath}+\hat{\jmath})$

<u>Note</u>: $M_A = 1*10^{30}\,kg \ \& \ M_B = M_C = 8*10^{30}\,kg$

Many stars belong to *systems* of two or more stars held together by their mutual gravitational attraction. Figure 13.5 shows a three-star system at an instant when the stars are at the vertices of a 45° right triangle. Find the total gravitational force exerted on the small star by the two large ones.

$$\vec{F}_A = \vec{F}_{B\to A} + \vec{F}_{C\to A}$$

$$d_{AB}^2 = d_{AC}^2 + d_{CB}^2 \;\&$$

$$d_{AC}^2 = d_{CB}^2 = 4*10^{24}\,m^2 \;\&$$

$$\vec{F}_{B\to A} = \left(G\frac{M_B M_A}{d_{AB}^2}\right)\left(\hat{\imath}\cos 45^\circ + \hat{\jmath}\sin 45^\circ\right) \qquad \cos 45^\circ = \frac{1}{\sqrt{2}}$$

$$\vec{F}_{C\to A} = \left(G\frac{M_C M_A}{d_{AC}^2}\right)\hat{\imath}$$

Now $\vec{F}_{B\to A} = \left(G\frac{M_B M_A}{2d_{AC}^2}\right)\left(\frac{1}{\sqrt{2}}\right)(\hat{\imath}+\hat{\jmath})$

<u>Note</u>: $M_A = 1*10^{30}\,kg$ & $M_B = M_C = 8*10^{30}\,kg$

So $(F_A)_x = \left(G\frac{M_B M_A}{d_{AC}^2}\right)\left(\frac{1}{2\sqrt{2}} + 1\right)$

Many stars belong to *systems* of two or more stars held together by their mutual gravitational attraction. Figure 13.5 shows a three-star system at an instant when the stars are at the vertices of a 45° right triangle. Find the total gravitational force exerted on the small star by the two large ones.

$$\vec{F}_A = \vec{F}_{B\to A} + \vec{F}_{C\to A}$$

$d_{AB}^2 = d_{AC}^2 + d_{CB}^2$ &

$d_{AC}^2 = d_{CB}^2 = 4*10^{24} m^2$ &

$$\vec{F}_{B\to A} = \left(G\frac{M_B M_A}{d_{AB}^2}\right)(\hat{\imath}\cos 45^\circ + \hat{\jmath}\sin 45^\circ)$$

$\cos 45^\circ = \frac{1}{\sqrt{2}}$

$$\vec{F}_{C\to A} = \left(\frac{G M_C M_A}{d_{AC}^2}\right)\hat{\imath}$$

Now $\vec{F}_{B\to A} = \left(G\frac{M_B M_A}{2 d_{AC}^2}\right)\left(\frac{1}{\sqrt{2}}\right)(\hat{\imath}+\hat{\jmath})$

<u>Note</u>: $M_A = 1*10^{30} kg$ & $M_B = M_C = 8*10^{30} kg$

So $(F_A)_x = \left(G\frac{M_B M_A}{d_{AC}^2}\right)\left(\frac{1}{2\sqrt{2}} + 1\right)$ &

$(F_A)_y = \left(\frac{G M_B M_A}{d_{AC}^2}\right)\frac{1}{2\sqrt{2}}$

From previous slide

$$(F_A)_x = \left(G\frac{M_B M_A}{d^2_{AC}}\right)\left(\frac{1}{2\sqrt{2}} + 1\right)$$

$$(F_A)_y = \left(\frac{G M_B M_A}{d^2_{AC}}\right)\frac{1}{2\sqrt{2}}, \quad \text{but}$$

$$\frac{G M_B M_A}{d^2_{AC}} = \frac{(6.67 * 10^{-11})(8 * 10^{30})(10^{30})}{4 * 10^{24}} N$$

From previous slide

$$(F_A)_x = \left(G\frac{M_B M_A}{d_{AC}^2}\right)\left(\frac{1}{2\sqrt{2}} + 1\right)$$

$$(F_A)_y = \left(\frac{G M_B M_A}{d_{AC}^2}\right)\frac{1}{2\sqrt{2}}, \quad \text{but}$$

$$\frac{G M_B M_A}{d_{AC}^2} = \frac{(6.67 * 10^{-11})(8 * 10^{30})(10^{30})}{4 * 10^{24}} N = 1.33 * 10^{26} N$$

ASU

From previous slide

$$(F_A)_x = \left(G\frac{M_B M_A}{d_{AC}^2}\right)\left(\frac{1}{2\sqrt{2}} + 1\right)$$

$$(F_A)_y = \left(\frac{G M_B M_A}{d_{AC}^2}\right)\frac{1}{2\sqrt{2}}, \quad \text{but}$$

$$\frac{G M_B M_A}{d_{AC}^2} = \frac{(6.67 * 10^{-11})(8 * 10^{30})(10^{30})}{4 * 10^{24}} N = 1.33 * 10^{26} N$$

so $(F_A)_x = (1.33 * 10^{26} N)\left(\frac{1}{\sqrt{8}} + 1\right)$

From previous slide

$$(F_A)_x = \left(G\frac{M_B M_A}{d^2_{AC}}\right)\left(\frac{1}{2\sqrt{2}} + 1\right)$$

$$(F_A)_y = \left(\frac{G M_B M_A}{d^2_{AC}}\right)\frac{1}{2\sqrt{2}}, \quad \text{but}$$

$$\frac{G M_B M_A}{d^2_{AC}} = \frac{(6.67*10^{-11})(8*10^{30})(10^{30})}{4*10^{24}} N = 1.33*10^{26} N$$

so $(F_A)_x = (1.33*10^{26} N)\left(\frac{1}{\sqrt{8}} + 1\right) = 1.80*10^{26} N$

From previous slide

$$(F_A)_x = \left(G\frac{M_B M_A}{d^2_{AC}}\right)\left(\frac{1}{2\sqrt{2}} + 1\right)$$

$$(F_A)_y = \left(\frac{G M_B M_A}{d^2_{AC}}\right)\frac{1}{2\sqrt{2}}, \quad \text{but}$$

$$\frac{G M_B M_A}{d^2_{AC}} = \frac{(6.67 * 10^{-11})(8 * 10^{30})(10^{30})}{4 * 10^{24}} N = 1.33 * 10^{26} N$$

so $\quad (F_A)_x = (1.33 * 10^{26} N)\left(\frac{1}{\sqrt{8}} + 1\right) = 1.80 * 10^{26} N$

& $\quad (F_A)_y = (1.33 * 10^{26} N)\frac{1}{\sqrt{8}} = 4.7 * 10^{25} N$

From previous slide

$$(F_A)_x = \left(G\frac{M_B M_A}{d^2_{AC}}\right)\left(\frac{1}{2\sqrt{2}} + 1\right)$$

$$(F_A)_y = \left(\frac{G M_B M_A}{d^2_{AC}}\right)\frac{1}{2\sqrt{2}}, \quad \text{but}$$

$$\frac{G M_B M_A}{d^2_{AC}} = \frac{(6.67*10^{-11})(8*10^{30})(10^{30})}{4*10^{24}} N = 1.33*10^{26} N$$

so $(F_A)_x = (1.33*10^{26} N)\left(\frac{1}{\sqrt{8}} + 1\right) = 1.80*10^{26} N$

& $(F_A)_y = (1.33*10^{26} N)\frac{1}{\sqrt{8}} = 4.7*10^{25} N$

$$\Rightarrow \quad F_A = \sqrt{(F_A)_x^2 + (F_A)_y^2} = (18^2 + 4.7^2)^{1/2} 10^{25} N$$

$\Rightarrow F_A = 1.86*10^{26} N$

From previous slide

$$(F_A)_x = \left(G\frac{M_B M_A}{d^2_{AC}}\right)\left(\frac{1}{2\sqrt{2}} + 1\right)$$

$$(F_A)_y = \left(\frac{G M_B M_A}{d^2_{AC}}\right)\frac{1}{2\sqrt{2}}, \text{ but}$$

$$\frac{G M_B M_A}{d^2_{AC}} = \frac{(6.67*10^{-11})(8*10^{30})(10^{30})}{4*10^{24}} N = 1.33*10^{26} N$$

so $(F_A)_x = (1.33*10^{26} N)\left(\frac{1}{\sqrt{8}} + 1\right) = 1.80*10^{26} N$

& $(F_A)_y = (1.33*10^{26} N)\frac{1}{\sqrt{8}} = 4.7*10^{25} N$

$$\Rightarrow \quad F_A = \sqrt{(F_A)_x^2 + (F_A)_y^2} = (18^2 + 4.7^2)^{1/2} 10^{25} N$$

$$\Rightarrow F_A = 1.86*10^{26} N \quad \theta = \tan^{-1}\left(\frac{(F_A)_y}{(F_A)_x}\right)$$

From previous slide

$$(F_A)_x = \left(G\frac{M_B M_A}{d^2_{AC}}\right)\left(\frac{1}{2\sqrt{2}} + 1\right)$$

$$(F_A)_y = \left(\frac{G M_B M_A}{d^2_{AC}}\right)\frac{1}{2\sqrt{2}}, \quad \text{but}$$

$$\frac{G M_B M_A}{d^2_{AC}} = \frac{(6.67 * 10^{-11})(8 * 10^{30})(10^{30})}{4 * 10^{24}} N = 1.33 * 10^{26} N$$

so $(F_A)_x = (1.33 * 10^{26} N)\left(\frac{1}{\sqrt{8}} + 1\right) = 1.80 * 10^{26} N$

& $(F_A)_y = (1.33 * 10^{26} N)\frac{1}{\sqrt{8}} = 4.7 * 10^{25} N$

$$\Rightarrow \quad F_A = \sqrt{(F_A)_x^2 + (F_A)_y^2} = (18^2 + 4.7^2)^{1/2} 10^{25} N$$

$\Rightarrow F_A = 1.86 * 10^{26} N \quad \theta = \tan^{-1}\left(\frac{(F_A)_y}{(F_A)_x}\right) = \tan^{-1}\left(\frac{4.7}{18}\right)$

From previous slide

$$(F_A)_x = \left(G\frac{M_B M_A}{d^2_{AC}}\right)\left(\frac{1}{2\sqrt{2}} + 1\right)$$

$$(F_A)_y = \left(\frac{G M_B M_A}{d^2_{AC}}\right)\frac{1}{2\sqrt{2}}, \quad \text{but}$$

$$\frac{G M_B M_A}{d^2_{AC}} = \frac{(6.67*10^{-11})(8*10^{30})(10^{30})}{4*10^{24}} N = 1.33*10^{26} N$$

so $\quad (F_A)_x = (1.33*10^{26} N)\left(\frac{1}{\sqrt{8}}+1\right) = 1.80*10^{26} N$

& $\quad (F_A)_y = (1.33*10^{26} N)\frac{1}{\sqrt{8}} = 4.7*10^{25} N$

$$\Rightarrow \quad F_A = \sqrt{(F_A)_x^2 + (F_A)_y^2} = (18^2 + 4.7^2)^{1/2} 10^{25} N$$

$$\Rightarrow \quad \boxed{F_A = 1.86*10^{26} N} \quad \theta = \tan^{-1}\left(\frac{(F_A)_y}{(F_A)_x}\right) = \tan^{-1}\left(\frac{4.7}{18}\right)$$

$$\Rightarrow \quad \boxed{\theta = 14.6^\circ}$$

ASU

§13.2

§13.2

Weight

§13.2

Weight

Object weigh
about 17%
of that on
earth

$$w = F_g = \frac{G m_E m}{R_E^2}$$

Weight of an object at the earth's surface ...

$$w = F_g = \frac{G m_E m}{R_E^2}$$

Weight of an object at the earth's surface ...

... equals gravitational force the earth exerts on object.

$$w = F_g = \frac{G m_E m}{R_E^2}$$

Gravitational constant

Weight of an object at the earth's surface ...

... equals gravitational force the earth exerts on object.

$$w = F_g = \frac{G m_E m}{R_E^2}$$

Gravitational constant

Mass of the earth

Weight of an object at the earth's surface ...

$$w = F_g = \frac{G m_E m}{R_E^2}$$

... equals gravitational force the earth exerts on object.

Gravitational constant

Mass of the earth

Weight of an object at the earth's surface ...

$$w = F_g = \frac{G m_E m}{R_E^2}$$

Mass of object

... equals gravitational force the earth exerts on object.

ASU

Weight of an object at the earth's surface ...

... equals gravitational force the earth exerts on object.

Gravitational constant

Mass of the earth

Mass of object

Radius of the earth

$$w = F_g = \frac{G m_E m}{R_E^2}$$

Gravitational constant

Mass of the earth

Weight of an object at the earth's surface ...

... equals gravitational force the earth exerts on object.

$$w = F_g = \frac{G m_E m}{R_E^2}$$

Mass of object

Radius of the earth

$$g = \frac{G m_E}{R_E^2}$$

Gravitational constant

Mass of the earth

Weight of an object at the earth's surface ...

$$w = F_{\mathrm{g}} = \frac{G m_{\mathrm{E}} m}{R_{\mathrm{E}}^{2}}$$

Mass of object

... equals gravitational force the earth exerts on object.

Radius of the earth

Acceleration due to gravity at the earth's surface

$$g = \frac{G m_{\mathrm{E}}}{R_{\mathrm{E}}^{2}}$$

ASU

Gravitational constant

Mass of the earth

Weight of an object at the earth's surface ...

$$w = F_g = \frac{G m_E m}{R_E^2}$$

Mass of object

... equals gravitational force the earth exerts on object.

Radius of the earth

Gravitational constant

Acceleration due to gravity at the earth's surface

$$g = \frac{G m_E}{R_E^2}$$

Gravitational constant

Mass of the earth

Weight of an object at the earth's surface ...

... equals gravitational force the earth exerts on object.

$$w = F_g = \frac{G m_E m}{R_E^2}$$

Mass of object

Radius of the earth

Gravitational constant

Mass of the earth

Acceleration due to gravity at the earth's surface

$$g = \frac{G m_E}{R_E^2}$$

Gravitational constant

Mass of the earth

Weight of an object at the earth's surface ...

... equals gravitational force the earth exerts on object.

$$w = F_g = \frac{G m_E m}{R_E^2}$$

Mass of object

Radius of the earth

Gravitational constant

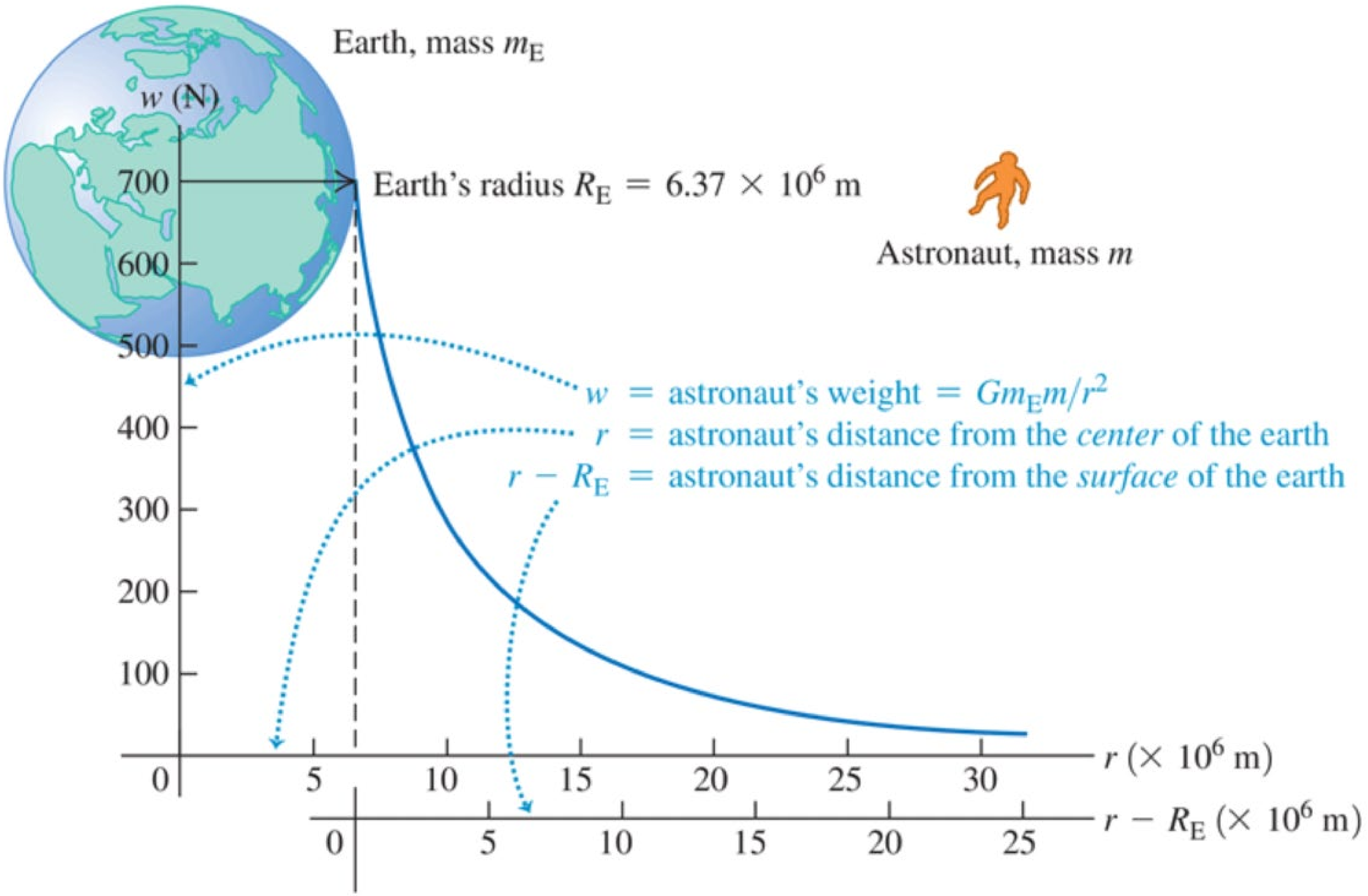
Mass of the earth

Acceleration due to gravity at the earth's surface

$$g = \frac{G m_E}{R_E^2}$$

Radius of the earth

In an airliner at high altitude, you are farther from the center of the earth than when on the ground and hence weigh slightly less. Can you show that at an altitude of 10 km above the surface, you weigh 0.3% less than you do on the ground?


Earth, mass m_E
w (N)
700
600
500
400
300
200
100
0
Earth's radius $R_E = 6.37 \times 10^6$ m
Astronaut, mass m
w = astronaut's weight = Gm_Em/r^2
r = astronaut's distance from the *center* of the earth
$r - R_E$ = astronaut's distance from the *surface* of the earth
5 10 15 20 25 30
r ($\times 10^6$ m)
0 5 10 15 20 25
$r - R_E$ ($\times 10^6$ m)

Density

$$\rho = \frac{\text{mass}}{\text{Volume}}$$

Density

$$\rho = \frac{\text{mass}}{\text{Volume}}$$

$$\rho_{EARTH} = 5500\,kg/m^3$$

Density

$$\rho = \frac{\text{mass}}{\text{Volume}}$$

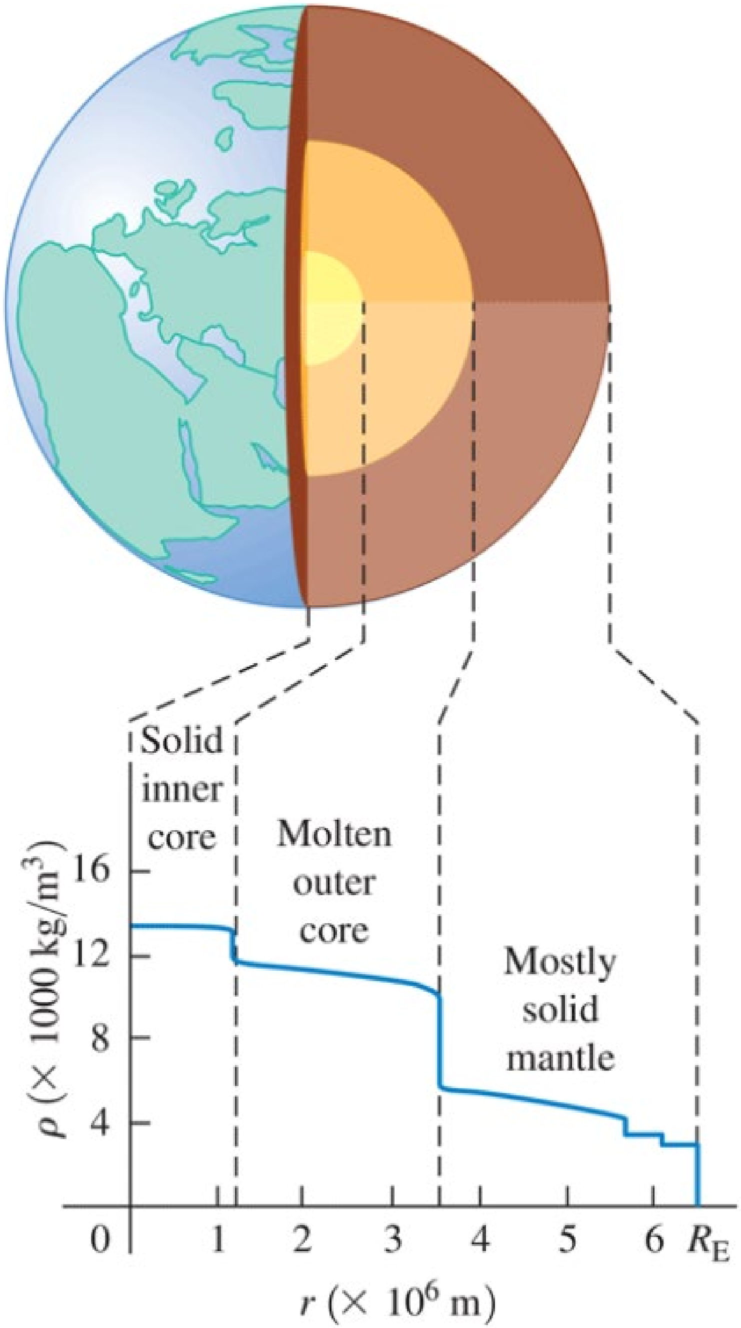
$$\rho_{EARTH} = 5500\,\text{kg/m}^3 = 5.5\,\text{g/cm}^3$$

Density

$$\rho = \frac{\text{mass}}{\text{Volume}}$$

$$\rho_{EARTH} = 5500\,\text{kg/m}^3 = 5.5\,\text{g/cm}^3$$

$$\rho_{WATER} = 1\,\text{g/cm}^3$$


Solid inner core
Molten outer core
Mostly solid mantle
16
12
8
4
0
1
2
3
4
5
6
R_E
ρ ($\times$ 1000 kg/m^3)
r ($\times$ 10^6 m)

ASU

A robotic lander with an earth weight of 3430 N is sent to Mars, which has radius $R_M = 3.39 \times 10^6$ m and mass $m_M = 6.42 \times 10^{23}$ kg (see Appendix F). Find the weight F_g of the lander on the Martian surface and the acceleration there due to gravity, g_M.

A robotic lander with an earth weight of 3430 N is sent to Mars, which has radius $R_M = 3.39 \times 10^6$ m and mass $m_M = 6.42 \times 10^{23}$ kg (see Appendix F). Find the weight F_g of the lander on the Martian surface and the acceleration there due to gravity, g_M.

$m_L g = 3430 N$

A robotic lander with an earth weight of 3430 N is sent to Mars, which has radius $R_M = 3.39 \times 10^6$ m and mass $m_M = 6.42 \times 10^{23}$ kg (see Appendix F). Find the weight F_g of the lander on the Martian surface and the acceleration there due to gravity, g_M.

$m_L g = 3430\,N, \; R_m = 3.39 * 10^6 m$

A robotic lander with an earth weight of 3430 N is sent to Mars, which has radius $R_M = 3.39 \times 10^6$ m and mass $m_M = 6.42 \times 10^{23}$ kg (see Appendix F). Find the weight F_g of the lander on the Martian surface and the acceleration there due to gravity, g_M.

$M_L g = 3430 N$, $R_m = 3.39 * 10^6 m$, $M_m = 6.42 * 10^{23} kg$

A robotic lander with an earth weight of 3430 N is sent to Mars, which has radius $R_M = 3.39 \times 10^6$ m and mass $m_M = 6.42 \times 10^{23}$ kg (see Appendix F). Find the weight F_g of the lander on the Martian surface and the acceleration there due to gravity, g_M.

$M_L g = 3430\,N$, $R_m = 3.39 * 10^6\,m$, $M_m = 6.42 * 10^{23}\,kg$

$$F_g = \frac{G M_m M_L}{R_m^2}$$

A robotic lander with an earth weight of 3430 N is sent to Mars, which has radius $R_M = 3.39 \times 10^6$ m and mass $m_M = 6.42 \times 10^{23}$ kg (see Appendix F). Find the weight F_g of the lander on the Martian surface and the acceleration there due to gravity, g_M.

$$M_L g = 3430\,N,\ R_m = 3.39 * 10^6 m,\ M_m = 6.42 * 10^{23} kg$$

$$F_g = \frac{G M_m M_L}{R_m^2} = \frac{(6.67*10^{-11})(6.42*10^{23})\left(\frac{3430}{9.8}\right)}{3.39^2 * 10^{12}} N$$

A robotic lander with an earth weight of 3430 N is sent to Mars, which has radius $R_M = 3.39 \times 10^6$ m and mass $m_M = 6.42 \times 10^{23}$ kg (see Appendix F). Find the weight F_g of the lander on the Martian surface and the acceleration there due to gravity, g_M.

$$M_L g = 3430\,N, \quad R_m = 3.39 * 10^6 m, \quad M_m = 6.42 * 10^{23} kg$$

$$F_g = \frac{G M_m M_L}{R_m^2} = \frac{(6.67 * 10^{-11})(6.42 * 10^{23})\left(\frac{3430}{9.8}\right)}{3.39^2 * 10^{12}} N$$

$$\Rightarrow \quad F_g = 1304 * 10^{-11+23+12} N$$

A robotic lander with an earth weight of 3430 N is sent to Mars, which has radius $R_M = 3.39 \times 10^6$ m and mass $m_M = 6.42 \times 10^{23}$ kg (see Appendix F). Find the weight F_g of the lander on the Martian surface and the acceleration there due to gravity, g_M.

$$M_L g = 3430 N, \quad R_m = 3.39 * 10^6 m, \quad M_m = 6.42 * 10^{23} kg$$

$$F_g = \frac{G M_m M_L}{R_m^2} = \frac{(6.67*10^{-11})(6.42*10^{23})\left(\frac{3430}{9.8}\right)}{3.39^2 * 10^{12}} N$$

$$\Rightarrow \quad F_g = 1304 * 10^{-11+23+12} N = 1304 N$$

A robotic lander with an earth weight of 3430 N is sent to Mars, which has radius $R_M = 3.39 \times 10^6$ m and mass $m_M = 6.42 \times 10^{23}$ kg (see Appendix F). Find the weight F_g of the lander on the Martian surface and the acceleration there due to gravity, g_M.

$M_L g = 3430\,N$, $R_m = 3.39 * 10^6 m$, $M_m = 6.42 * 10^{23} kg$

$$F_g = \frac{G M_m M_L}{R_m^2} = \frac{(6.67*10^{-11})(6.42*10^{23})\left(\frac{3430}{9.8}\right)}{3.39^2 * 10^{12}} N$$

$$\Rightarrow \boxed{F_g = 1304 * 10^{-11+23+12} N = 1304 N = 1.3*10^3 N}$$

ASU

A robotic lander with an earth weight of 3430 N is sent to Mars, which has radius $R_M = 3.39 \times 10^6$ m and mass $m_M = 6.42 \times 10^{23}$ kg (see Appendix F). Find the weight F_g of the lander on the Martian surface and the acceleration there due to gravity, g_M.

$$M_L g = 3430\,N, \quad R_m = 3.39 * 10^6 m, \quad M_m = 6.42 * 10^{23} kg$$

$$F_g = \frac{G M_m M_L}{R_m^2} = \frac{(6.67*10^{-11})(6.42*10^{23})\left(\frac{3430}{9.8}\right)}{3.39^2 * 10^{12}} N$$

$$\Rightarrow \boxed{F_g = 1304 * 10^{-11+23+12} N = 1304 N = 1.3*10^3 N}$$

$$g_m = \frac{F_g}{m} = \left(\frac{1300}{3430/9.8}\right)\frac{m}{s^2}$$

A robotic lander with an earth weight of 3430 N is sent to Mars, which has radius $R_M = 3.39 \times 10^6$ m and mass $m_M = 6.42 \times 10^{23}$ kg (see Appendix F). Find the weight F_g of the lander on the Martian surface and the acceleration there due to gravity, g_M.

$$m_L g = 3430\,N, \quad R_m = 3.39*10^6 m, \quad M_m = 6.42*10^{23} kg$$

$$F_g = \frac{G M_m M_L}{R_m^2} = \frac{(6.67*10^{-11})(6.42*10^{23})\left(\frac{3430}{9.8}\right)}{3.39^2 * 10^{12}} N$$

$$\Rightarrow \boxed{F_g = 1304*10^{-11+23+12} N = 1304 N = 1.3*10^3 N}$$

$$g_m = \frac{F_g}{m} = \left(\frac{1300}{3430/9.8}\right)\frac{m}{s^2} = \left(\frac{1300*9.8}{3430}\right) m/s^2$$

A robotic lander with an earth weight of 3430 N is sent to Mars, which has radius $R_M = 3.39 \times 10^6$ m and mass $m_M = 6.42 \times 10^{23}$ kg (see Appendix F). Find the weight F_g of the lander on the Martian surface and the acceleration there due to gravity, g_M.

$$M_L g = 3430\,N,\ R_m = 3.39*10^6 m,\ M_m = 6.42*10^{23} kg$$

$$F_g = \frac{G M_m M_L}{R_m^2} = \frac{(6.67*10^{-11})(6.42*10^{23})\left(\frac{3430}{9.8}\right)}{3.39^2 * 10^{12}} N$$

$$\Rightarrow \boxed{F_g = 1304*10^{-11+23+12} N = 1304 N = 1.3*10^3 N}$$

$$g_m = \frac{F_g}{m} = \left(\frac{1300}{3430/9.8}\right)\frac{m}{s^2} = \left(\frac{1300*9.8}{3430}\right) m/s^2$$

$$\Rightarrow \boxed{g_m = 3.7\, m/s^2}$$