LECTURE 19: Universal Law of Gravitation

Select LEARNING OBJECTIVES:

i. Introduce the general form of the force of gravity between two objects.
ii. Strength the ability to do proportional reasoning.
iii. Introduce the idea of equilibrium.

TEXTBOOK CHAPTERS:

- Giancoli (Physics Principles with Applications 7th) :: 5-5, 5-6, 5-7
- Knight (College Physics : A strategic approach 3rd) :: 6.4, 6.5, 6.6
- BoxSand :: N/A

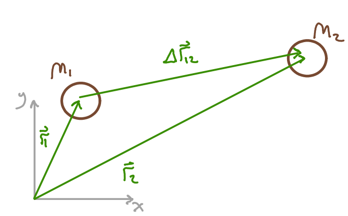
WARM UP: What direction is the static friction pointing in if a car is going around a banked turn at the minimum speed possible?

Up to this point, we have been working with the definition that the force of gravity from earth on an object is equal to the mass of the object times the acceleration due to gravity….

$$|\vec{F}^{g}_{E1}| = m_1 g$$

This is all well and good, except for when the object is far from the surface of the earth. It turns out, there is a universal law of gravity for any two massive objects which is described by the relationship below….

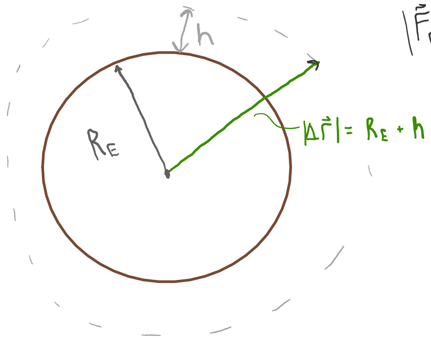
$$|\vec{F}^{G}_{12}| = \frac{G m_1 m_2}{|\Delta \vec{r}_{12}|^2}$$



In the above relationship, notice how the magnitude of the force of gravity is proportional to one over the distance squared; this type of relationship is known as an inverse square law. The "G" seen above is known as the gravitational constant where…

$$G = 6.67 \times 10^{-11} \ \frac{Nm^2}{kg^2}$$

EXAMPLE: Use the universal law of gravity to show that the acceleration due to gravity near the Earth's surface is roughly 9.81 m/s^2.



$$|\vec{F}^G_{E1}| = \frac{G m_E m_1}{|\Delta\vec{r}|^2}$$

$$|\vec{F}^G_{E1}| = \frac{G m_E m_1}{(R_E+h)^2}$$

*NEAR SURFACE OF EARTH... $h \approx 0$

$$|\vec{F}^G_{E1}| = \frac{G m_E m_1}{R_E^2}$$

$$\frac{(6.67\times10^{-11}\,\frac{Nm^2}{kg^2})(5.97\times10^{24}\,kg)}{(6.37\times10^{6}\,m)^2} \approx 9.81\,m/s^2 \equiv g$$

EXAMPLE: What is the effective value of g on the top of Mt. Hood, 3,429 m (11,249 ft) above sea level?

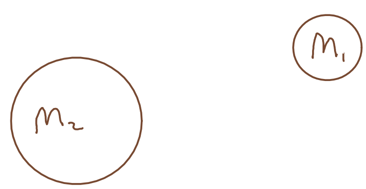
$$|\vec{F}^G_{E1}| = \frac{G m_E m_1}{|\Delta\vec{r}|^2}$$

$$|\vec{F}^G_{E1}| = \frac{G m_E m_1}{(R_E+h)^2}$$

$$\frac{(6.67\times10^{-11}\,\frac{Nm^2}{kg^2})(5.97\times10^{24}\,kg)}{(6.37\times10^{6}\,m + 3429\,m)^2} \approx 9.80\,m/s^2$$

PRACTICE: The figure below shows a binary star system. The mass of star 2 is twice the mass of star 1. Compared to the magnitude of force from 2 on to 1, the magnitude of the force from 1 on to 2 is

(1) One quarter as large.
(2) Half as large.
(3) The same magnitude.
(4) Twice as large.
(5) Four times as large.



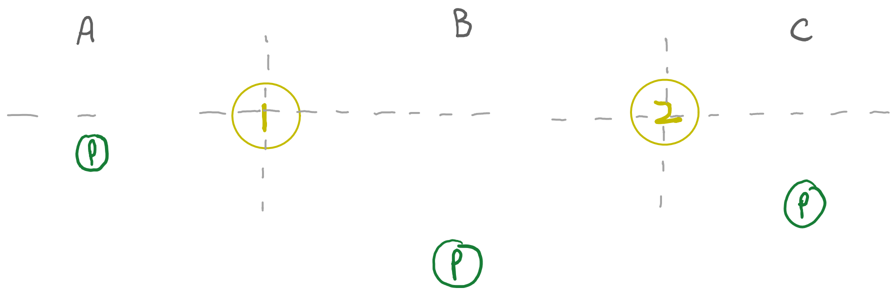
PRACTICE: A planet, a distance r away from its local star, has a magnitude of gravitational force $|\vec{F}^G|$ applied to it. If it was to be located a distance 3r away, what magnitude gravitational force would be applied to it.

1. $F^G/2$
2. $3F^G/2$
3. $F^G/4$
4. $F^G/3$
5. $F^G/9$

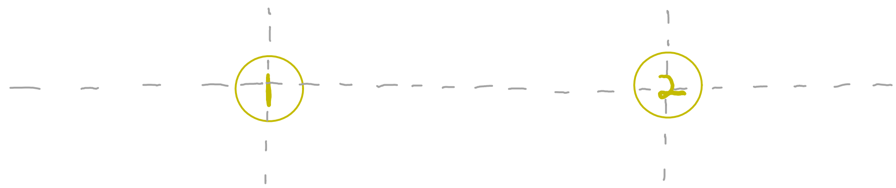
PRACTICE: A planet, a distance r away from its local star, has a magnitude of gravitational force $\left|\vec{F}^G\right|$ applied to it. If it was to be located a distance 3r/2 away, what magnitude gravitational force would be applied to it.

1. $F^G/2$
2. $3F^G/2$
3. $2F^G/3$
4. $4F^G/9$
5. $3F^G/9$

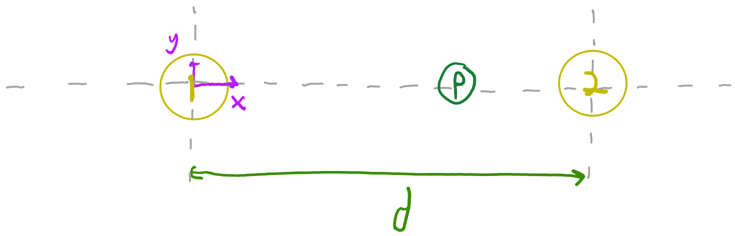
PRACTICE: Two massive stars are separated by some distance. In Which region could a planet be in equilibrium?



PRACTICE: Star 1 is four times as massive as star 2. Where along the line that connects two massive stars could a planet be in equilibrium.



PRACTICE: Star 1 is four times as massive as star 2 and the two are separated by a distance d. If a planet is placed at the equilibrium point, how far is it from star 1?

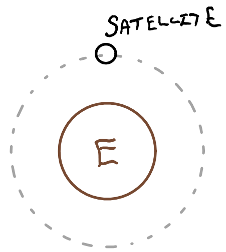


PRACTICE: A planet has 4 times the mass of the Earth, but the acceleration due to gravity on the planet's surface is the same as on the Earth's surface. The planet's radius is

(1) $R_E/4$
(2) $R_E/2$
(3) R_E
(4) $2R_E$
(5) $4R_E$

PRACTICE: A satellite orbits the earth with constant speed at a height above the surface equal to the Earth's radius divided by two. The magnitude of the satellite's acceleration is

(1) $(4/9)*g_{\text{on Earth}}$
(2) $(1/4)*g_{\text{on Earth}}$
(3) $(4/3)*g_{\text{on Earth}}$
(4) $(3/2)*g_{\text{on Earth}}$
(5) $(2)*g_{\text{on Earth}}$



Questions for discussion

(1) It is often stated that gravity does not exist in outer space. Discuss this statement.
(2) Discuss the validity of the following line of reasoning: The Earth exerts a gravitational force of magnitude $|\vec{F}^G|$ on a satellite orbiting Earth. The satellite also exerts a gravitational force on Earth. Since the mass of the satellite is much much smaller than the mass of the Earth, the magnitude of the gravitational force that the satellite exerts on Earth is much much smaller than the magnitude of the gravitational force that the Earth exerts on the satellite.