11 Gravity and the Solar System

Name____________________

Worksheet

AP Physics B

1. Use Newton's First Law of Motion to describe how a planet would move if the inward force of gravity from the sun were to suddenly disappear. ANSWER IN COMPLETE SENTENCES

The equation for the law of universal gravitation is:

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

where **F** is the force of attraction between masses $\mathbf{m_1}$ and $\mathbf{m_2}$ separated by distance **d**, and **G** is 6.67×10^{-11} Nm^2/kg^2.

SHOW ALL WORK WITH PROPER EQUATIONS, UNITS, AND SIGNIFICANT FIGURES

2. Calculate the weight of a 50.0 kg mass on the moon using Newton's Law of Universal Gravitation. (The mass of the moon is approximately 7.36×10^{22} kg; the radius is 1.738×10^{6} m.)

3. Now calculate the weight of the 50.0 kg mass on the moon using the special case of Newton's Second Law you derived in Unit 6 (F_g=mg). The acceleration due to gravity on the moon is about 1/6 that of earth.
EXPRESS YOUR ANSWER WITH 2 SIGNIFICANT FIGURES

Your answers to questions 2 and 3 should be very similar, as you simply used different techniques to calculate the same quantity.

MASS AND DISTANCE CHANGES AND THEIR GRAVITATIONAL EFFECTS

Changing the mass of an object or its distance from another object will affect the gravitational force that attracts the two objects. By substituting changes in any of the variables into the equation for the Law of Universal Gravitation, we can predict how the others change.

Suppose the distance of separation is reduced to one-third of its former value. Then substituting **1/3 d** for **d** in the equation gives:

$$F_{new} = \frac{Gm_1m_2}{(\frac{1}{3}d)^2} = \frac{Gm_1m_2}{\frac{1}{9}d^2} = \frac{9}{1}(\frac{Gm_1m_2}{d^2}) = 9F_{old}$$

And we see the force is increased nine-fold.

Suppose that the distance did not change, but one of the masses somehow is doubled. Then substituting $\mathbf{2m_1}$ for $\mathbf{m_1}$ in the equation gives:

$$F_{new} = \frac{G(2m_1m_2)}{d^2} = 2(\frac{Gm_1m_2}{d^2}) = 2F_{old}$$

So we see the force doubles.

Finally suppose that the distance of separation is doubled. Then substituting **2d** for **d** in the equation gives:

$$F_{new} = \frac{Gm_1m_2}{(2d)^2} = \frac{Gm_1m_2}{4d^2} = \frac{1}{4}(\frac{Gm_1m_2}{d^2}) = \frac{1}{4}F_{old}$$

And we see the force is only 1/4 as much.

Use this method to solve the following problems. Write the equation and make the appropriate substitutions.

4. If both masses are tripled, what happens to the force?

5. If the masses are not changed, but the distance of separation is reduced to 2/3 the original distance, what happens to the force?

6. If the masses are not changed, but the distance of separation is tripled, what happens to the force?

7. If **both** masses are doubled, and the distance of separation is tripled, show what happens to the force.

8. If one of the masses is doubled, the other remains unchanged, and the distance of separation is quadrupled, show what happens to the force.

CALCULATING THE WEIGHT OF AN OBJECT IN ORBIT

One can use the Law of Universal Gravitation to calculate the weight of an orbiting object. The masses used in the calculation are those of the orbiting object and the planet. The distance used is the distance from the center of the circling object to the center of the planet. This means that you must **add the radius of the planet to the altitude of the orbiting body.**

It is also important that you use **meters** for the distance, not kilometers or any other such unit.

EXAMPLE:
A 15.0 kg object orbits the planet Mars at an altitude of 200 km. What is the weight of the object if Mars has a radius of 3,430 km and a mass of 6.34 × 10^{23} kg?

METHOD:
First, change all distances into meters. One kilometer is equal to 1,000 meters, so:

the altitude is $200\,km \times \frac{1{,}000\,m}{1\,km} = 200{,}000\,m$ and the radius is $3{,}430\,km \times \frac{1{,}000\,m}{1\,km} = 3{,}430{,}000\,m$

Now you must add the altitude to the radius of the planet to get the total distance from the center of the planet to the center of the orbiting object: $3{,}430{,}000\,m + 200{,}000\,m = 3{,}630{,}000\,m$

Finally, plug in all of the various values into the Law of Universal Gravitation and solve:

$$F_g = \frac{Gm_1m_2}{d^2} = \frac{(6.67 \times 10^{-11}\frac{Nm^2}{kg^2})(6.34 \times 10^{23}\,kg)(15kg)}{(3{,}630{,}000m)^2} = \frac{6.343 \times 10^{14}\,Nm^2}{1.318 \times 10^{13}\,m^2} = 48.1\,N$$

Show all equations and units on the following problems, and express answers with 3 significant figures.

9. At closest approach, the 722 kg Voyager 2 probe flew by Neptune at an altitude of 29,240 km.

A) What was the probe's weight at that moment if Neptune has a radius of 24,900 km and a mass of 9.99 × 10^{25} kg?

B) Use the information from part **A** to calculate the acceleration due to gravity at that altitude above Neptune.

10. The center of the moon and the center of the earth are 3.80×10^5 km apart. The mass of the moon is approximately 7.36×10^{22} kg, while earth's mass is about 5.98×10^{24} kg.

A) Calculate the earth's pull on the moon.

B) What is the size of the moon's pull on the earth? EXPLAIN OR SHOW WORK

11. The space shuttle typically orbits 40<u>0</u> km above the earth's surface. The earth has a mass of 5.98×10^{24} kg and a radius of 6,380 km.

A) How much would a 20<u>0</u>0 kg part for the space station weigh when it has been lifted to that orbit in the shuttle's cargo bay?

B) Use your result from part **A** (or alternatively you can combine the two equations you now know for F_g) to determine the acceleration due to gravity at that altitude.

C) Use your knowledge of circular motion to determine the orbital speed of the shuttle's cargo.

12. Thus far in the course we have ignored that on the Earth's surface an object must have a slightly unbalanced force to rotate with the Earth, pretending that the normal force precisely balances the object's weight. A student with a mass of 65.0 kg stands at the equator. The radius of the Earth is 6.38×10^6 m, and of course it rotates once per day.

A) What is the magnitude of the **<u>centripetal force</u>** (in newtons) required to keep the student on the Earth's surface?

B) Since the centripetal force is unbalanced, what is the *true* magnitude of the normal force on the student? (The student weighs 637 N, and with $\Sigma \boldsymbol{F} = m\boldsymbol{a}$ you should find the normal force is actually less than 637 N.)