I. Objectives

1. Investigate the mathematical processes and conversions required to calculate the force exerted on an object by the Sun, Moon, planets, and dwarf planets.
2. Calculate circular and escape velocities.
3. Determine the relationships among a solar system objects's mass, radius, and the force it exerts on an object.

II. Introduction

How much would you weigh on the Moon, on another planet or dwarf planet, or even on the Sun? Let's see where the formula comes from that will help us calculate your weight on another solar system object (this formula also works for objects other than those in our solar system). Keep in mind that your weight is actually the acceleration of gravity due to the Earth, planet, dwarf planet, moon, or star on which you are standing (although we know its not really possible to stand on a star), and should be measured in force units of newtons.

In order for objects, including molecules, apples, or rockets, to orbit or escape from a planet, dwarf planet, moon, or star, the object must have a large enough velocity to overcome the gravitational pull or acceleration of gravity (sometimes incorrectly called the "force of gravity") of the planet, dwarf planet, moon, or star. The two types of velocities we will study in this lab are circular velocity and escape velocity. The mass or volume of the object trying to escape is not important, usually because it is much, much smaller than that of the planet, dwarf planet, moon, or star it is attempting to escape from, but the mass and radius of the planet, dwarf planet, moon, or star from which the object is trying to escape are important.

III. Theory and Calculations

We need the Universal Law of Gravitation, the ratio of the radius of a planet, moon, or star to the Earth, and the ratio of the mass of the Earth to a planet, moon, or star. Note that subscripts used in the formulas help distinguish one quantity from another.

1. The Universal Law of Gravitation can be written in the general form: $F = \frac{GMm}{r^2}$

2. $F_E = \frac{GM_E m}{r_E^2}$, where G is the gravitational constant, F_E is the force on the object due to the Earth's gravity, M_E is the mass of the Earth, m is the mass of the object, and r_E is the radius of the Earth

3. $F_p = \dfrac{GM_p m}{r_p^2}$, where F_p is the force on the object due to a planet's gravity,

M_p is the mass of the planet, m is the mass of the object, and r_p is the radius of the planet.

4. $\dfrac{F_p}{F_E} = \dfrac{\dfrac{GM_p m}{r_p^2}}{\dfrac{GM_E m}{r_E^2}}$ by dividing the equation in step 3 by the equation in step 2

5. $\dfrac{F_p}{F_E} = \dfrac{GM_p m}{r_p^2} \; x \; \dfrac{r_E^2}{GM_E m}$ using the equation in step 4

6. $\dfrac{F_p}{F_E} = \dfrac{M_p}{r_p^2} \; x \; \dfrac{r_E^2}{M_E}$ by "cancelling" G and m on the right side of the equation in step 5

7. $\dfrac{F_p}{F_E} = \dfrac{M_p}{M_E} \; x \; \dfrac{r_E^2}{r_p^2}$ by rearranging the right side of the equation in step 6

8. $\dfrac{F_p}{F_E} = \dfrac{M_p}{M_E} \; x \left(\dfrac{r_E}{r_p}\right)^2$ by grouping the squared quantities on the right side of the equation in step 7. This provides us with the ratio of the force of gravity on a planet (or other object) compared with the force of gravity on Earth.

9. The formula for circular velocity, v_c, is:

$$v_c = \sqrt{\frac{GM_p}{r_p}}$$

where G is the gravitational constant, M_p is the mass of the star, planet, or moon in kilograms, and r_p is the radius of the star, planet, or moon in meters.

10. The formula for escape velocity, v_e, is:

$$v_e = \sqrt{\frac{2GM_p}{r_p}}$$

IV. Prelab Definitions

1. Universal Law of Gravitation

2. acceleration of gravity

3. gravitational potential energy

4. kinetic energy

5. mass

6. weight

7. newton

8. force

9. velocity

10. circular velocity

11. escape velocity

V. Prelab Questions

1. What force does F_E represent?

2. What force does F_p represent?

3. What does the ratio F_p/F_E represent?

4. What radius does r_E represent? What is its numerical value in km?

5. What radius does r_p represent?

6. What mass does M_E represent? What is its numerical value in kg?

7. What mass does M_p represent?

8. What constant does G represent? What is its numerical value?

9. What velocity does v_c represent?

10. What velocity does v_e represent?

VI. Lab Procedure

1. In the *Sun, Planets, Dwarf Planets, and Moon Masses, Radii, Forces, and Velocities* table below, convert the radii of each solar system object to meters. C = B *x* 1,000.

2. Calculate the ratio of the radius of the Earth and the radius of each solar system object, r_E/r_p. D = 6,378/B.

3. Calculate $(r_E/r_p)^2$. E = D^2.

4. Calculate the ratio of the mass of the planet and the mass of the Earth, M_p/M_E. I = H/(5.97 *x* 10^{24}).

5. Calculate the ratio of the forces of two solar system objects, F_p/F_E, in column J. J = E *x* I.

6. Calculate GM_p/r_p. Remember that G = 6.67 *x* 10^{-11}. K = G *x* H/C.

7. Calculate $2GM_p/r_p$. L = 2 *x* K.

8. Calculate the circular velocity, v_c, in column N. N = $\sqrt{K}$.

9. Calculate the escape velocity, v_e, in column P. P = $\sqrt{L}$.

Sun, Planets, Dwarf Planets, and Moon Masses, Radii, Forces, and Velocities

A	B	C	D	E	H	I	J	K	L	N	P
Solar system object	r_p in km	r_p in m	r_E/r_p	$(r_E/r_p)^2$	M_p in kg	M_p/M_E	F_p/F_E	GM_p/r_p	$2GM_p/r_p$	v_c in m/s	v_e in m/s
Sun	695,590				1.99×10^{30}						
Mercury	2,439				3.30×10^{23}						
Venus	6,052				4.87×10^{24}						
Earth	6,378				5.97×10^{24}						
Moon	1,738				7.35×10^{22}						
Mars	3,398				6.42×10^{23}						
Ceres	487				9.43×10^{20}						
Jupiter	71,494				1.90×10^{27}						
Saturn	60,330				5.68×10^{26}						
Uranus	25,559				8.68×10^{25}						
Neptune	24,750				1.02×10^{26}						
Pluto	1,151				1.27×10^{22}						
Haumea	1,518				4.20×10^{21}						
Makemake	750				4.00×10^{21}						
Eris	1,300				1.67×10^{22}						

VII. Lab Discussion

1. What is F_p/F_E for the Moon? If an object exerts a force of 10 N on Earth, what force does it exert on the Moon?

2. What is F_p/F_E for Jupiter? If an object exerts a force of 10 N on Earth, what force does it exert on Jupiter?

3. If an object has a mass of 100 kg on Earth, what is its mass on the Sun? Does an object's mass change simply by moving it?

4. Around which solar system object would a satellite be able to move the slowest and still maintain an orbit?

5. The small, dense, rocky terrestrial planets, Mercury, Venus, Earth, Mars, have little atmosphere when compared with the large, gaseous, low density Jovian planets, Jupiter, Saturn, Uranus, and Neptune. How might a planet's escape velocity affect types and amounts of the gases in its atmosphere?