Moon

Lesson 4 – The Gravitational Force and Your Weight: What's the Connection?

The Gravitational Force and Your Weight: What's the Connection?

Grade Level: 9th –12th

Objectives:

- Conversion of standard units into SI units of measurement
- Solve equations using the universal law of gravitation
- Compare and contrast gravitational force on different planetary bodies

Arizona State Standards:

- **1M-P2.** Construct, interpret, and demonstrate meaning for real numbers and absolute value in problem solving situations. **PO 8.** Convert standard notation into scientific notation, including negative exponents and vice versa.
- **5SC- P7.** Demonstrate the understanding of gravitation as a universal force that each mass exerts on any other mass. **PO1.** Use the universal law of gravitation to predict how the gravity force changes with a change of distance and/or mass.

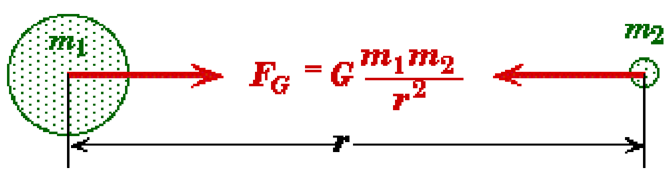
Time needed: 1 class period

Materials:

- Calculators
- Heavy and light objects

Introduction:

Gravity is the force with which the Earth, Moon, or other massive body attracts an object towards itself. By definition, this is the weight of the object. All objects on Earth experience a force of gravity, which is, directed "downward" towards the center of the Earth. The force of gravity on an object on Earth is always equal to the weight of the object as given by the equation:



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

Equation 1.

F_G = Magnitude of the Gravitational Force (N)

m_1 = Mass of one body (kg)

m_2 = Mass of a second body (kg)

G = 6.672×10^{-11} $N.m^2/kg^2$ (Universal Gravitational Constant)

r = Distance between the centers of mass of the two objects (m)

Procedure:

Start by holding up a heavy object such as a book in one hand and a light object such as a piece of paper or feather in the other hand. Ask what will happen if you let go of the objects. Students should answer that the objects will fall to the ground. Ask why the objects fall to the ground. Students will probably answer: because of GRAVITY. Write the word GRAVITY on the board or overhead. Next, drop the objects and ask why the book hit the ground first. Students might say because the book weighs more or that air resistance held the feather up longer.

Next drop a heavy book and a lighter book at the same time. They will hit the ground at the same time. Explain that in a vacuum, where there is no air resistance, all objects, when dropped at the same time, will hit the ground at the same time. This is the result of gravity. Now ask the students, what is gravity? Write their answers on the board next to the word GRAVITY and discuss the validity of each answer. Explain that gravity is an attractive force that every particle or object in the universe exerts on each other. It can be described by the equation above. Write this equation on the board and explain each variable.

Now, what if we were to drop the feather/piece of paper and book at the same time while standing on the surface of the Moon. What would happen? Apollo 15 astronaut, Dave Scott, did an experiment similar to this while on the Moon. He dropped a hammer and a feather at the same time. What do you think happened? The objects hit the surface at the same time. This is because the Moon has no atmosphere and thus no air resistance to slow down the fall of the feather.

How is gravity related to **weight**? Included in the module is a set of gravity blocks. Show them to the class and explain that they represent the same block on different planets. Have students pick up 2 blocks, by the handle, one in each hand. Have students compare all three blocks and comment on what they feel and sense. Tell them that even though each of the blocks hypothetically has the same mass, because gravity is different on the Moon, Mars, and Earth, the blocks have different weights.

Now, lets define what weight is. Weight is the **mass** of something multiplied by the **acceleration due to gravity** of the planetary body that is attracting the object. The following equation describes weight:

Weight (Newton's) = mass (kg) x g (kg m/s^2)

Where ***g*** is the **acceleration due to gravity** of the planet you are on.

For example, on Earth your weight in **Newton's** would be expressed by the following equation:

Weight (Newton's) = mass (kg) x 9.8 (kg m/s^2) **Equation 2.**

Because on Earth ***g*** is 9.8 m/s^2

Therefore, you need to know your mass to calculate your weight. Mass can be calculated using the same equation because you already know your weight on Earth. For example if you weigh 100 lbs on Earth, what is your mass?

First you have to convert your weight in pounds to Newton's using the conversion factor below.

1 pound = 4.448 Newton's

The conversion looks like this:

100 lbs x 4.448 Newton's/lb = **444.8 N** (your weight on Earth)

Now use this new weight in **Equation 2** to get the following:

444.8 N = your mass (kg) x 9.8 (kg m/s²) $444.8\ N = \text{your mass (kg)} \times 9.8\ (kg\ m/s^2)$

$444.8\ N / 9.8\ (Kg\ m/s^2) = \text{your mass (kg)}$

$= 45.4\ kg$

Once you know your mass you can calculate your weight on the Moon and on other planets using **Equation 2**. But before you do this you must figure out the acceleration due to gravity on other planets using the following equation:

$$g = G\ m_p / r^2$$

Equation 3.

- g is acceleration due to gravity
- G is the **Universal Gravitation Constant** = 6.67259×10^{-11} units are $N * m^2/kg^2$
- m_p (kg) is the mass of the planetary object you are on
- r^2 (m) is the distance between you and the center of the planet, this is also the radius of the planet

If the instructor would like to explain where Equation 3 comes from see below.

We can use **Newton's second law** to figure out the acceleration due to gravity for the Earth. According to this law $F = ma$. Rearrange the equation to get $a = F/m$. Next substitute **Equation 1**. for F to get the following:

$$a \text{ or } g = \frac{G\ m_E\ m / r^2}{m}$$

Equation 4.

The m's cancel out and we are left with **Equation 3.**

$$g = G\ m_p / r^2$$

Now insert the correct value for each variable into **Equation 3** to get:

$$a \text{ or } g = 6.67259 \times 10^{-11}\ Nm^2/kg^2 \times 5.98 \times 10^{24}\ kg / (6.38 \times 10^6\ m)^2 = 9.8\ m/s^2$$

Assessment:
Students will work individually to complete the **Student Sheet** and turn in for a grade.

Extension:
Ask the students to figure out their weight if they were in orbit 200 km above the Earth, the planet Jupiter?

Vocabulary:
Gravity, weight, mass, acceleration due to gravity, Newton, Universal Gravitation Constant, Newton's Second Law

References:
http://www.physicsclassroom.com/Class/newtlaws/u2l2b.html#grav

Additional Resources:
- http://www.exploratorium.edu/ronh/weight/
- http://kids.msfc.nasa.gov/Puzzles/Weight.asp
- http://www.teachervision.com/lesson-plans/lesson-353.html
- http://www.1728.com/gravity.htm
- http://www.ac.wwu.edu/~vawter/PhysicsNet/Topics/Gravity/NewtonLawGravity.html
- http://www.ph.surrey.ac.uk/satellites/main/orbits4.html
- http://www.shodor.org/cserd/Resources/Activities/MassWeight/index.php
- http://www.sciencejoywagon.com/physicszone/lesson/01motion/linear/accgravi/gravity1.htm
- http://sportsfigures.espn.com/sportsfigures/lp_inline_inertia.jsp
- http://www.sciencenet.org.uk/database/Physics/Lists/gravity.html

Name ______________________

Student Sheet: Gravity and Your Weight on Other Planets

Have you ever wondered why you weigh what you do? Would you weigh the same on the Moon, or on Jupiter? For that matter, what is weight, and how does it relate to mass and gravity? In this exercise you will determine your weight on the Moon and on other planets and compare this weight to what you weigh on Earth. You will also discover the difference between your weight and your mass.

Complete the following exercise and answer the questions at the end.

Part I.

What is your **WEIGHT** on Earth? _____________ **pounds (lb)**

In order to figure out your weight on other worlds you need to convert pounds into **Newton's** (N). A Newton is a measure of force and is equal to **kg x m/s^2.**

1 pound = 4.448 Newton's

Put your weight, *in pounds*, in the blank of the equation below to calculate your weight in Newton's.

_______________ **lbs** x $\frac{4.448\ \text{N}}{1\ \text{lbs}}$ =_________**N**

Your weight in
Newton's on Earth

Part II.

Calculate your **MASS** using the equation ***W = m x g*** which is explained below.

Your WEIGHT (N) = your MASS (kg) x g (m/s^2)   Equation A.

_______________ N = ______________kg x 9.8 m/ s^2
(Your weight) **(Your mass)**

Rearrange the equation:

______________ kg = $\frac{\text{\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_}}{9.8\ \text{m/s}^2}$ ← **Your weight (N)**
(Your mass)

Part III.

In order to find your weight on another planet, you have to know the acceleration due to gravity (***g***) on the planet. To figure out the ***g*** of other planets use the following equation:

$$g = G\, m_p / r^2$$

Equation B

HINT

Use the attached table to find the correct values for the mass and radius of the planets.

- ***g*** is acceleration due to gravity **(What you want to know)**
- ***G*** is the **Universal Gravitation Constant** = 6.67259 x 10^{-11} units are N * m^2/kg^2
- m_p (kg) is the mass of the planetary object you are on
- r^2 (m) is the distance between you and the center of the planet, this is also the radius of the planet

Use ***Equation B*** to calculate the acceleration due to gravity on the following planets *(use the space provided to show your work)*:

The Moon's ***g*** = ____________

Mars' ***g*** = ____________

Jupiter's ***g*** = ______________

Saturn's ***g*** = ______________

Titan's ***g*** (Saturn's largest moon) = ______________

Part IV.

Once you have calculated the gravity on each planet use ***Equation A*** to find your weight on that planet in **Newton's**.

For example, your weight in Newton's on Earth can be calculated like this:

$$W = mass_{you} \times 9.8\ m/s^2$$

Your weight on the Moon ________________ Newton's ________________ lbs

Your weight on Mars ________________ Newton's ________________ lbs

Your weight on Jupiter ________________ Newton's ________________ lbs

Your weight on Saturn ________________ Newton's ________________ lbs

Your weight on Titan ________________ Newton's ________________ lbs

Next, you must convert your weight from Newton's back to pounds using the following equation:

______________ N x $\frac{\text{1 lbs}}{\text{4.448 N}}$ = __________ lbs (your weight in pounds)
(Your weight)

TABLE OF IMPORTANT DATA

Planetary Body	Mass (kg)	Radius (m)
Earth	**5.98×10^{24}**	**6.38×10^{6}**
Moon	**7.35×10^{22}**	**1.74×10^{6}**
Mars	**0.64185×10^{24}**	**3.397×10^{6}**
Jupiter	**1.9×10^{27}**	**7.14×10^{7}**
Saturn	**5.7×10^{26}**	**6.0×10^{7}**
Titan	**1.3455×10^{23}**	**2.575×10^{6}**

Universal Gravitation Constant = 6.67259 x 10-11

Part V. Questions to consider:

1. How does your weight on the moon compare to your weight on Earth? Using the Important Data Table, what factors might control the strength or magnitude of the gravitational force?

2. What is the difference between MASS and WEIGHT?

3. How much would an object with a mass of 5 kg weigh on Mars?

4. PROBLEM: What would a person who weighed 100 pounds on Earth weigh if he/she were in orbit 200 km above the Earth? Above Jupiter? *Show your work!*