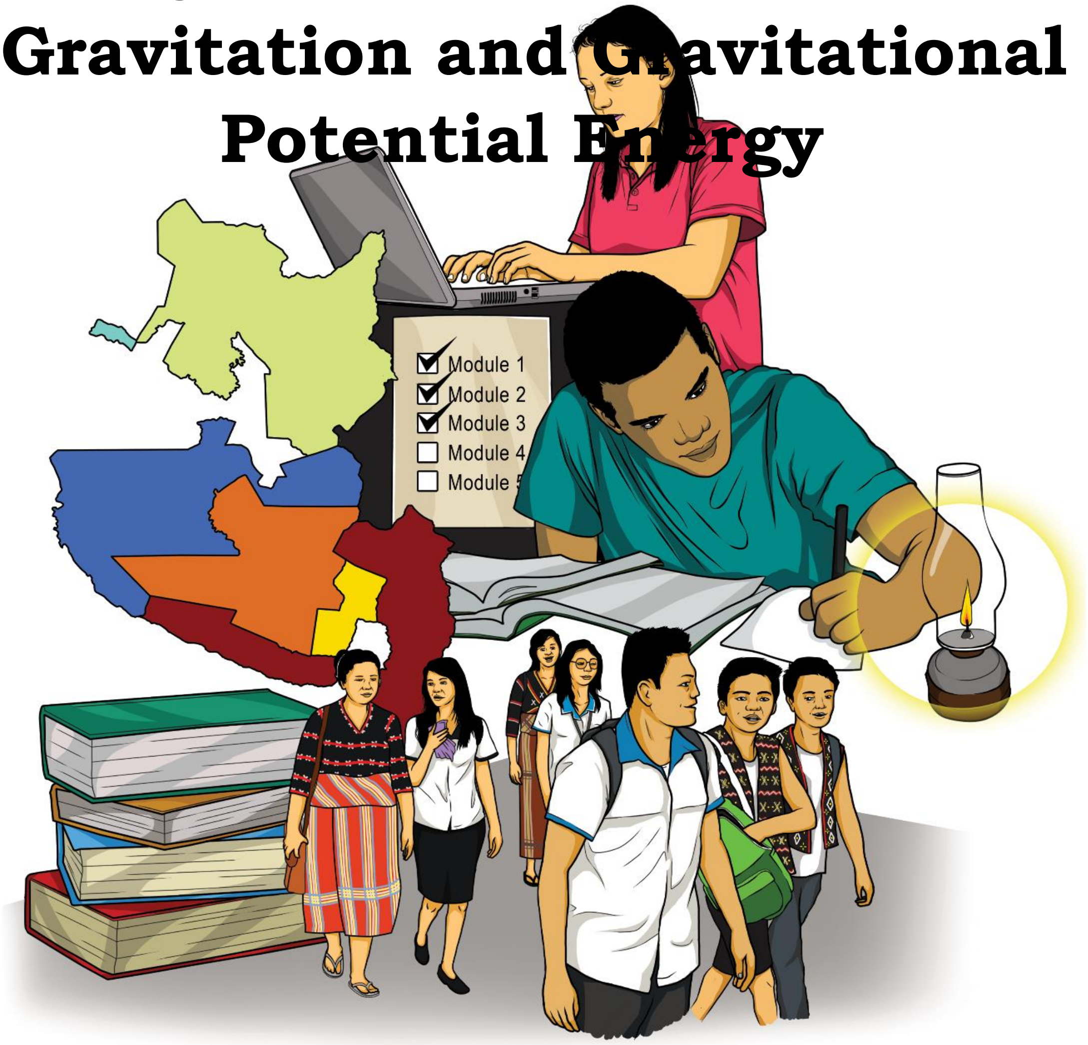
12

DepED
DEPARTMENT OF EDUCATION

General Physics 1

Quarter 2 – Module 2
Gravitation and Gravitational Potential Energy



SELF-LEARNING MODULE

SLM

DEPARTMENT OF EDUCATION - SOCCSKSARGEN

Subject Area – Grade Level: General Physics 1 – Grade 12
Self-Learning Module (SLM)
Quarter 2 – Module _2_: Title: Gravitation and Gravitational Potential Energy
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Introductory Message

For the facilitator:

Welcome to the **General Physics 1 - 12** Alternative Delivery Mode (ADM) Module on **Gravitation and Gravitational Potential Energy.**

This module was collaboratively designed, developed and reviewed by educators both from public and private institutions to assist you, the teacher or facilitator in helping the learners meet the standards set by the K to 12 Curriculum while overcoming their personal, social, and economic constraints in schooling.

This learning resource hopes to engage the learners into guided and independent learning activities at their own pace and time. Furthermore, this also aims to help learners acquire the needed 21st century skills while taking into consideration their needs and circumstances.

In addition to the material in the main text, you will also see this box in the body of the module:

Notes to the Teacher

This contains helpful tips or strategies that will help you in guiding the learners.

As a facilitator you are expected to orient the learners on how to use this module. You also need to keep track of the learners' progress while allowing them to manage their own learning. Furthermore, you are expected to encourage and assist the learners as they do the tasks included in the module.

For the learner:

Welcome to the **General Physics 1** – 12. Alternative Delivery Mode (ADM) Module on **Gravitation and Gravitational Potential Energy.**

The hand is one of the most symbolized part of the human body. It is often used to depict skill, action and purpose. Through our hands we may learn, create and accomplish. Hence, the hand in this learning resource signifies that you as a learner is capable and empowered to successfully achieve the relevant competencies and skills at your own pace and time. Your academic success lies in your own hands!

This module was designed to provide you with fun and meaningful opportunities for guided and independent learning at your own pace and time. You will be enabled to process the contents of the learning resource while being an active learner.

This module has the following parts and corresponding icons:

What I Need to Know	This will give you an idea of the skills or competencies you are expected to learn in the module.
What I Know	This part includes an activity that aims to check what you already know about the lesson to take. If you get all the answers correct (100%), you may decide to skip this module.
What's In	This is a brief drill or review to help you link the current lesson with the previous one.
What's New	In this portion, the new lesson will be introduced to you in various ways such as a story, a song, a poem, a problem opener, an activity or a situation.
What is It	This section provides a brief discussion of the lesson. This aims to help you discover and understand new concepts and skills.
What's More	This comprises activities for independent practice to solidify your understanding and skills of the topic. You may check the answers to the exercises using the Answer Key at the end of the module.
What I Have Learned	This includes questions or blank sentence/paragraph to be filled in to process what you learned from the lesson.

	***What I Can Do***	This section provides an activity which will help you transfer your new knowledge or skill into real life situations or concerns.
	***Assessment***	This is a task which aims to evaluate your level of mastery in achieving the learning competency.
	***Additional Activities***	In this portion, another activity will be given to you to enrich your knowledge or skill of the lesson learned. This also tends retention of learned concepts.
	***Answer Key***	This contains answers to all activities in the module.

At the end of this module you will also find:

References	This is a list of all sources used in developing this module.

The following are some reminders in using this module:

1. Use the module with care. Do not put unnecessary mark/s on any part of the module. Use a separate sheet of paper in answering the exercises.
2. Don't forget to answer *What I Know* before moving on to the other activities included in the module.
3. Read the instruction carefully before doing each task.
4. Observe honesty and integrity in doing the tasks and checking your answers.
5. Finish the task at hand before proceeding to the next.
6. Return this module to your teacher/facilitator once you are through with it.

If you encounter any difficulty in answering the tasks in this module, do not hesitate to consult your teacher or facilitator. Always bear in mind that you are not alone.

We hope that through this material, you will experience meaningful learning and gain deep understanding of the relevant competencies. You can

What I Need To Know

This module contains three (3) lessons which are:
Lesson 1: Universal Gravitation
Lesson 2: Gravitational Field and Gravitational Potential Energy
Lesson 3: Orbits and Kepler's Law of Planetary Motion

Learning Objectives:

1. State Newton's law of universal gravitation;
2. Solve problems involving Newton's law of gravitation, gravitational force, weight and acceleration due to gravity;
3. Discuss the physical significance of gravitational fields;
4. Apply the concept of gravitational potential energy in physics problems
5. Calculate quantities related to planetary or satellite motion; and
6. For circular orbits, relate Kepler's 3rd Law of Planetary motion to Newton's Law of Gravitation and Centripetal Acceleration.

What I Know

Pre-Assessment

Multiple Choice. Read the questions carefully. Choose the letter of the correct answer and write it on your notebook or answer sheets provided.

1. What will happen to your weight if the mass of the earth is increased but there's no change in its radius?
   a. It will not change c. It will increase
   b. It will decrease d. It will double
2. In which situation applies the law of the universal gravitation?
   a. Throwing of object upward
   b. Pushing a car
   c. Kicking a stone
   d. Falling of an apple towards the ground
3. What relationship exist between the gravitational force and masses of the two objects?
   a. inversely proportional c. equal
   b. directly proportional d. none of the above
4. Which of the following is true of the gravitational force between two massive objects?
   a. always equal
   b. depends on how massive the objects are
   c. depends inversely on the square of the distance between the objects
   d. all of the above
5. What is the gravitational force between two objects of masses with 40 kg and 50 kg if they are 2 meters apart?
   a. $3.3 x 10^{-8}$ N b. $3.3 x 10^{8}$ N c. $3.3 x 10^{-9}$ N d. $3.3 x 10^{9}$ N

6. What referred to as the amount of work done in bringing a body from infinity to the given point in the gravitational field of the other?
   a. Kinetic energy c. Work
   b. Gravitational potential energy d. Energy

7. What is the region of space surrounding a body in which another body experiences a force off gravitational attraction?
   a. Gravitational force c. Gravitational field
   b. Gravitational Potential Energy d. Gravitation

8. If all of the objects have around the same mass, which of the following objects has the most gravitational potential energy?
   a. A chair set on the ground
   b. A book on a high shelf on the first floor of a house
   c. A ball stuck on the roof of a two-story house
   d. A cat investigating a basement

9. As we get farther away from an object, what happens to the magnitude of the gravitational force?
   a. Increases c. Stays the same
   b. Decreases d. None of these is correct

10. What does every object create in the space around it?
   a. Gravitational field c. Electric field
   b. Magnetic field d. None of these is correct
11. Which of the following terms describe the path that a planet travels around the sun?
   a. Orbit b. Barycenter c. Ellipse d. Precession
12. Which of the following Kepler's Laws' refers to as "laws of Harmonies"?
   a. 1st Law b. 2^{nd} Law c. 3^{rd} Law d. 4^{th} Law
13. What is the shape of the planets' orbit?
   a. Circle b. Focus c. ellipse d. perihelion
14. When the planet orbits the sun, which of the following is one of the foci of the elliptical orbit?
   a. Axis b. Center c. Perihelion d. Sun
15. If a satellite is in an elliptical orbit, what happens when the satellite is at the point in its orbit when it is closest?
   a. It has its greatest speed c. Its speed remains unchanged
   b. It has its lowest speed d. It gets too close and falls into the Earth.

Lesson 1	Newton's Law of Universal Gravitation

Learning Objectives:

1. State Newton's law of universal gravitation; and
2. Solve problems involving Newton's law of gravitation, gravitational force, weight and acceleration due to gravity.

What's In

Activity 1. Match Me!

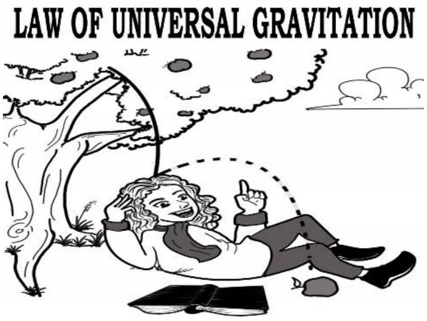
Direction: Match the word found in column B to its description found in column A. Choose the letter of the correct answer and write it on your notebook.

Column A	Column B
1. A force that depends on the earth's gravitational attraction	a. Weight b. Ocean tide c. Gravity d. Isaac Newton e. Inertia
2. Credited by describing mathematics of gravity	
3. A natural phenomena occurs on earth due to the gravity of moon	
4. Force that attracts all objects towards each other	

What's New

Activity 2. Newton's Gravitation Discovery

Instruction: Answer the question about the picture below in 2-3 sentences. Write your answer on your activity notebook or on a separate sheet of paper.



Question: Why is it that the apple never drops sideways or upwards or any other direction except perpendicular to the ground?

Answer: ____
____
____

What Is It

All Matters are Affected by Gravity

Gravity, also called **gravitation**, in *mechanics*, is the universal *force* of attraction acting between all matters; an invisible force that pulls the objects toward each other.

Earth's **gravity** is what keeps you on the ground and what makes things fall. It is responsible for a ball you throw in the air to come down, for a spoon you drop on the floor, for a car to coast downhill even when you are not stepping on a gas and many more circumstances.

Earth's gravity comes from all its mass. All its mass makes a combined gravitational pull on all the mass in your body. That's what gives you weight. On Earth all bodies have a *weight*, or downward force of gravity, proportional to their mass, which Earth's mass exerts on them. Gravity is measured by the acceleration that gives to freely falling objects. At *Earth's* surface the acceleration due to gravity is about 9.8 m/s^2.

Every object that has **mass** exerts a gravitational pull, or ***force***, on every other mass. The size of the pull depends on the masses of the objects. In fact, you exert a gravitational force on the people around you. So, as you sit on the chair in the science laboratory, you are gravitationally attracted to your lab partner, to the desk you are working at, and even to your physics book and other things. Newton's revolutionary idea was that gravity is universal - ALL objects attract in proportion to the product of their masses. Gravity is universal. And most gravitational forces are so minimal to be noticed. These are only recognizable as the masses of objects become large.

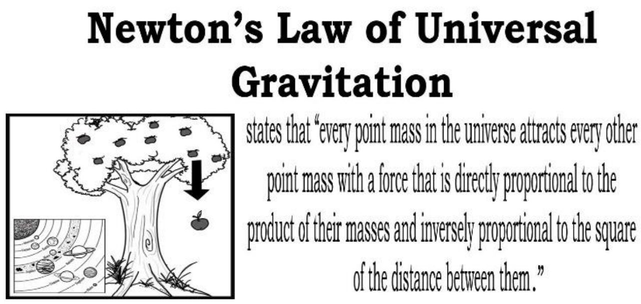
Newton proved that the force that acts on all objects that causes it to fall toward the ground is the same force that causes the moon to fall around or orbit the Earth. This universal force also acts between the Earth and the Sun, or any other star and its satellites. Even the orbiting of the sun to our galaxy and the binding of galaxies into clusters are all because of the gravitational force. Therefore, gravitation is the force that forms the Universe.

The Universality of Gravitation

As mentioned, gravitational interactions do not simply exist between the earth and other objects; and not simply between the sun and other planets. Gravitational interactions exist between all objects in the universe.

Newton's law of universal gravitation is about the **universality** of gravity, which extends gravity beyond Earth. Newton's place in the *Gravity Hall of Fame* is not due to his discovery of gravity, but rather due to his discovery that gravitation is universal. **ALL objects attract each other with a force of gravitational attraction. Gravity is universal**.

Newton's law of universal gravitation states that every point mass in the universe attracts every other point mass with a force that is directly proportional to the product of their masses and inversely proportional to the square of the distance between them.



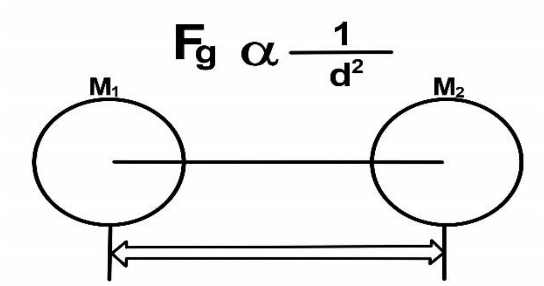
Newton's conclusion about the magnitude of gravitational forces is summarized symbolically as

$$F_g \propto \frac{m_1 m_2}{d^2}$$

Where F_g represents the force of gravity between two objects
$\propto$ means " proportional to"
m_1 represents the mass of object 1
m_2 represents the mass of object 2
d represents the distance separating the object's centers

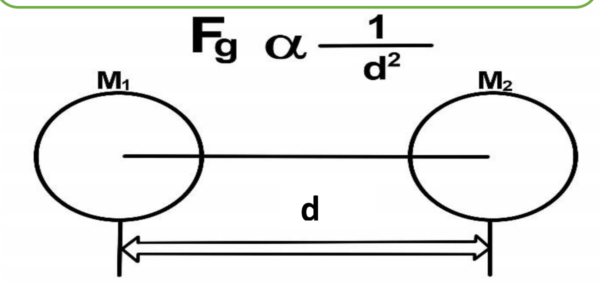
Since the gravitational force is directly proportional to the mass of both interacting objects, more massive objects will attract each other with a greater gravitational force. If the mass of one of the objects is doubled, then the force of gravity between them is doubled. If the mass of one of the objects is tripled, then the force of gravity between them is tripled. If the mass of both objects is doubled, then the force of gravity between them is quadrupled; and so on. Thus, gravitational force increases as mass of either object increases.

Gravitational force is directly proportional to the product of masses of two objects

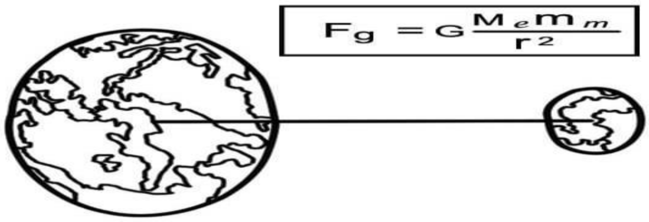


Since gravitational force is inversely proportional to the square of the separation distance between the two interacting objects, more separation distance will result in weaker gravitational forces. So as two objects are separated from each other, the force of gravitational attraction between them also decreases. If the separation distance between two objects is doubled (increased by a factor of 2), then the force of gravitational attraction is decreased by a factor of 4 (2 raised to the second power). If the separation distance between any two objects is tripled (increased by a factor of 3), then the force of gravitational attraction is decreased by a factor of 9 (3 raised to the second power). Thus, gravitational force decreases as distance of two objects increases.

Gravitational force is inversely proportional to the square of distance between the objects.



Another means of representing the proportionalities is to express the relationships in the form of an equation using a constant of proportionality. This equation is shown below.



The constant of proportionality (G) in the above equation is known as the **universal gravitation constant**. The precise value of G was determined experimentally by Henry Cavendish in the century after Newton's death.

The value of G is found to be G **= 6.67 x 10^{-11} N m^2/kg^2**.

When the units on G are substituted into the equation above and multiplied by **m_1• m_2** units and divided by **d^2** units, the result will be **Newtons** - the unit of force.

Sample Problem

Determine the force of gravitational attraction between the earth (m = 5.98 x 10^{24} kg) and a 70-kg physics student if the student is standing at sea level, a distance of 6.38 x 10^6 m from earth's center.

The solution of the problem involves substituting known values of G (6.67 x 10^{-11} N m^2/kg^2), m_1 (5.98 x 10^{24} kg), m_2 (70 kg) and d (6.38 x 10^6 m) into the universal gravitation equation and solving for F_g. The solution is as follows:

Given:

G= 6.67 x 10^{-11} N m^2/kg^2

Mass of the earth= 5.98 x 10^{24} kg **F_g= ?**

Mass of physics student= 70 kg

Distance from earth's center = 6.38 x 10^6 m

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

$$F_g = \frac{\left(6.67x10^{-11}\frac{Nm^2}{Kg^2}\right)(5.98x10^{24}kg)(70kg)}{(6.38\times10^6m)^2}$$

$$F_g = \frac{\left(6.67x10^{-11}\frac{N\cancel{m}^2}{\cancel{Kg}^2}\right)(4.186x10^{26}\cancel{Kg}^2)}{4.07x10^{13}\cancel{m}^2}$$

$$F_g = \frac{2.79x10^{16}N}{4.07x10^{13}}$$

$$F_g = 685.50 \text{ N}$$

What's More

Solve the gravitational force of the following problem. Write the given values, formula and your solution on the answer sheets provided. Box your final answer.
(Note: Use a scientific calculator)

1. Determine the force of gravitational attraction between the earth (5.98×10^{24} kg) and a 100 kg football player, when he is at a distance of 6.38×10^{6} m from earth's center.

What I Have Learned

Direction. Identify the following. Write your answer on a separate sheet of paper.

______1. The force that holds all objects on Earth.
______2. The force by which a planet or other body draws objects toward its center. The force of gravity keeps all the planets in orbit around the sun.
______3. This law states that every point mass in the universe attracts every other point mass with a force that is directly proportional to the product of their masses and inversely proportional to the square of the distance between them.

What I Can Do

Grab it Tea!

Check your understanding about Newton's law of universal gravitation by answering the following questions. Write your answer on your notebook.

1. State Newton's law of universal gravitation.

2. Having recently completed her first Physics course, Jane Gravy has devised a new business plan based on her teacher's *Physics for Better Living* theme. Jane learned that objects weigh different amounts at different distances from Earth's center. Her plan involves buying gold by the weight at one altitude and then selling it at another altitude at the same price per weight. Should Jane buy at a high altitude and sell at a low altitude or vice versa? And why?

Lesson 2 Gravitational Field and Gravitational Potential Energy

Learning Objectives:
1. Discuss the physical significance of gravitational fields; and
2. Apply the concept of gravitational potential energy in physics Problems.

What's In

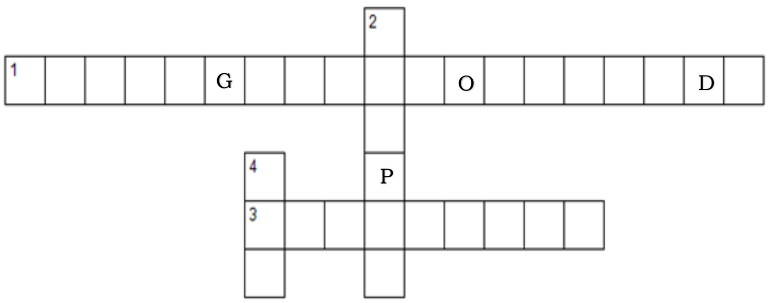
Direction. Identify the following questions and write your answer on the separate sheet of paper.

________________1. The law which states that every object in the universe attracts every other object with a force that is directly proportional to the product of their masses and inversely proportional to the square of the distance between them.

________________2. The value of the gravitational constant, G.

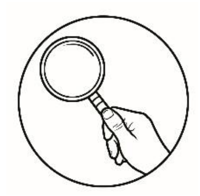
What's New

Direction: Read the clues below and fill in the correct answer.



Across:
1. Region of space surrounding a body
3. P in GPE

Down:
2. Unit of GPE
4. Work done in bringing a body to a gravitaional field



What Is It

GRAVITATIONAL FIELD

Newton's Law of Gravitation states that the gravitational force $\underline{F}$ between two point masses M and m separated by a distance **r** acts along the line joining their centers and is proportional to the masses and inversely proportional to the square of their separations. $$F \propto \frac{Mm}{r^2}$$

In the SI unit system, the constant of proportionality is G, the gravitational constant, which has a value of $6.67\times10^{-11}\mathrm{Nm^2kg^{-2}}$. Newton's Law of Gravitation becomes:

$$F=\frac{GMm}{r^2} \qquad (1)$$

We can restate the Newton's law of gravitation in a useful way using the concept of gravitational field. Instead of calculating the interaction of force between two masses by using equation above, eq 1, we consider a mass that creates a gravitational field in the space around us as shown in figure 1. **But what is gravitational field, and how do we know when one is present?**

The gravitational field is the gravitational force per unit mass that would be exerted on a small mass at that point. It is a vector field, and points in the direction of the force that the mass would feel. For a point particle of mass M, the magnitude of the resultant gravitational field strength g, at distance rr from M, is

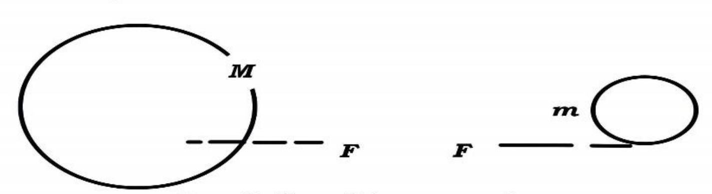
$$g=\frac{GM}{r^2} \qquad (2)$$

where G = the gravitational constant = 6.67 x 10^{-11} $\mathrm{N.m^2/kg^2}$
M = the mass of the attracting body
r = the distance between their center
The gravitational force acting on a mass m, which is also described as its weight, is:

$$F=mg$$

At the surface of the Earth, g has a magnitude of $\underline{GM}$ = 9.81 $\mathrm{m/s^2}$, where R_E is the radius of the Earth.

Figure 1



Gravitational Forces on two masses

The gravitational* field** is the gravitational force exerted per unit mass on a small mass at a point in the field. Like force, it is a vector quantity: a point mass ***M at the origin produces the gravitational field

$$g = g(r) = -\frac{Gm}{r^3} r\underline{r}$$

where $\underline{r}$ *is the position relative to the origin and where r=*$|\underline{r}|$. *Its magnitude is*

$$g = -\frac{Gm}{r^2}$$

and (due to the minus sign) at each point $\underline{g}$ is directed opposite to $\underline{r}$, i.e. towards the central mass.

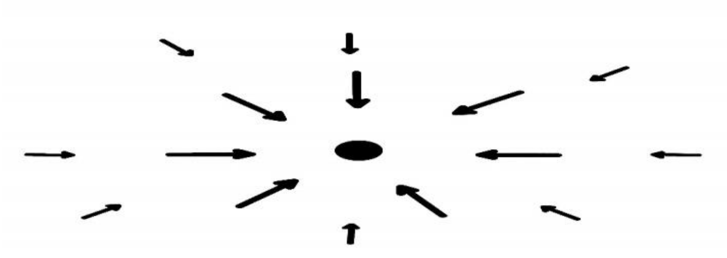
This means that a small test mass *m* at position $\underline{r}$ will experience the force

$$F = mg = -\frac{Gm}{mr^3} r$$

due to the presence of the mass ***M***. While this force depends on *m*m, the ratio $\underline{g}$=$\underline{F}$/m, i.e. the gravitational field at $\underline{r}$, is independent of *m*.

Formally, the gravitational force on an extended object can be treated as if acting at a single point, its center of gravity. If the gravitational field is uniform across the object this is the same as its center of mass.

This is of course simple: we know this field has strength GM/r2, and points towards the mass—the direction of the attraction. Let us draw it anyway, or, at least, let's draw in a few vectors showing its strength at various points:



Sample Problem:

What is the gravitational field strength at the surface of Jupiter mass of 1.9 x 10^{27} kg radius 7.1 x 10^7 m?

Given: M = 1.9 x 10^{27} kg, radius = 7.1 x 10^7 m, G = 6.67 x 10-11 Nm^2/kg^2

Solution:

$$g = \frac{-GM}{r^2}$$

$$= \frac{-(6.67 \times 10^{-11}\ Nm^2/kg^2)(1.9 \times 10^{27}\ kg}{(7.1 \times 107\ m)^2}$$

***g* = 25.13 N/kg**

Gravitational fields are vector fields. They can be visualized in two ways - either by drawing an arrow representing the gravitational field vector at that point, or by drawing field lines.

If there are many masses, the resultant gravitational field at any point is the vector sum of the gravitational fields at that point due to each mass. Thus, the fields from each mass are independent of each other.

GRAVITATIONAL POTENTIAL ENERGY

The **gravitational potential energy (GPE)** of an object of mass m in a gravitational field is the energy stored as a result of the object's location in the field. If the field is due to a uniform spherical mass $\boldsymbol{M}$, and the particle is outside $\boldsymbol{M}$ at a distance r from the centre of $\boldsymbol{M}$, then the particle's gravitational potential energy is:

$$U_{grav} = -\frac{GMm}{r}$$

Where: Ugrav = Universal gravitational potential energy

G = gravitational constant

M = Mass of the body attracting to another m

M = mass of the body attracting to M

r = distance between their center

so that it is zero at infinity (as $\boldsymbol{r}$ becomes very large). This is the gravitational potential energy of the system consisting of the two objects interacting gravitationally. If mm is not negligible when compared to M, it is important to remember that the sum of the kinetic energies (and any other energies) of both objects with Ugrav is conserved.

The general expression for gravitational potential energy arises from the law of gravity and is equal to the work done against gravity to bring a mass to a given point in space. Because of the inverse square nature of the gravity force, and it makes sense to choose the zero of gravitational potential energy at an infinite distance away. A Gravitational Potential Energy (GPE) near a planet is then negative since gravity does positive work as the mass approaches. This negative potential is indicative of a "bound state", once a mass is near a large body, it is trapped until something can provide enough energy to allow it to escape.

Sample Problem:

An astronaut is outside performing a spacewalk near the International Space Station. With her spacesuit and all equipment, she has a mass of 200 kg. The space station has a mass of 419,600 kg. What is the gravitational potential energy when she is 10.0 m from the center of mass of the space station?

Answer: The formula can be used to find the potential energy:

$$U = -G\frac{m_1 m_2}{r}$$

U = 0 when the distance between the astronaut and the space station is infinite, and so this equation represents the change in potential energy if you bring the astronaut from an infinite distance away to a position 10.0 m from the center of mass of the station. The force acting on the astronaut is away from the position where $U = 0$, and this is why the equation has a negative sign, and the potential energy we find will be negative.

$$U = -(6.673 \times 10^{-11}\ N \cdot m^2/kg^2)\left(\frac{(200\ kg)(419{,}600\ kg)}{10.0\ m}\right)$$

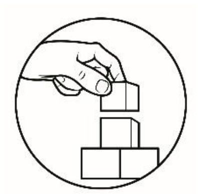
$U = -0.000560$ N·m

$\boldsymbol{U = -5.60 \times 10^{-4}}$ **J**

The gravitational potential energy of her position 10.0 m from the center of mass of the station is -5.60×10^{-4} J.

The **gravitational field potential** due to a uniform spherical mass M, at a point outside M a distance r from the centre of M, is given by

$$V_{grav} = \frac{U_{grav}}{m} = -\frac{GM}{r}$$



What's More

Activity 1: Complete Me!

Instruction: Use the equation $g = GM/r^2$ to calculate the gravitational field of sun, planets, satellites or the moon found in inside the table below. Remember that gravitational constant G is equal to 6.67×10^{-11} N.m²/kg².

Table 1: Data on Planetary Masses, radii and gravitational field.

Body	Mass (kg)	Radius (m)	Gravitational Field (N/kg)
Sun	1.99×10^{30}	6.96×10^{8}	
Moon	7.35×10^{22}	1.74×10^{6}	
Mercury	3.28×10^{23}	2.57×10^{6}	
Venus	4.82×10^{24}	6.31×10^{6}	
Earth	5.98×10^{24}	6.38×10^{6}	

EXERCISES:

Solve the Problem below on a separate sheet. Show you solutions.

Data required:

$G = 6.67 \times 10^{-11}$ N m² kg⁻²

mass of the Earth = 6.0×10^{24} kg

radius of the Earth = 6.4×10^{6} m

gravitational field strength close to the surface of the Earth is 9.8 N kg^{-1}

1. What is the gravitational potential energy of a 60 kg student on the surface of the Earth? What then, is the minimum energy that would be required to get this student completely out of the Earth's gravitational field?

2. You're in the design of mission carrying humans to the surface of the planet Mars, which has a radius of 3.38×10^6 m and a mass of 6.24×10^{23} kg. The Earth weigh of the Mar's lander is 39,200 N. Calculate its weight and the acceleration due to Mar's gravity at 6.0×10^6 m above the surface of Mars.

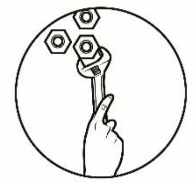
What I Have Learned

This time you're going to assess yourself with your learning by answering the following questions:

MODIFIED TRUE OR FALSE.

Direction: Write TRUE if it is correct. If it is FALSE, change the underlined word to make the sentence TRUE. Write your answer on the separate sheet.

1. The *gravitational field* is the gravitational force per unit mass that would be exerted on a small mass at that point.
2. The *gravitational potential energy (GPE)* of an object of mass *m* in a gravitational field is the energy stored as a result of the object's location in the field.
3. $F=\frac{GMm}{r^3}$ is the Newton's Law of Gravitation formula.
4. The general expression for gravitational potential energy arises from the law of gravity and is equal to the work done against *acceleration* to bring a mass to a given point in space.
5. The gravitational force acting on a mass *m*, which is also described as its weight, is ***F=mg.***



What I Can Do

ACTIVITY 2: TELL ME!

On a separate sheet of paper, cite 3 situations where you are practically affected by the gravitational field and gravitational potential energy.

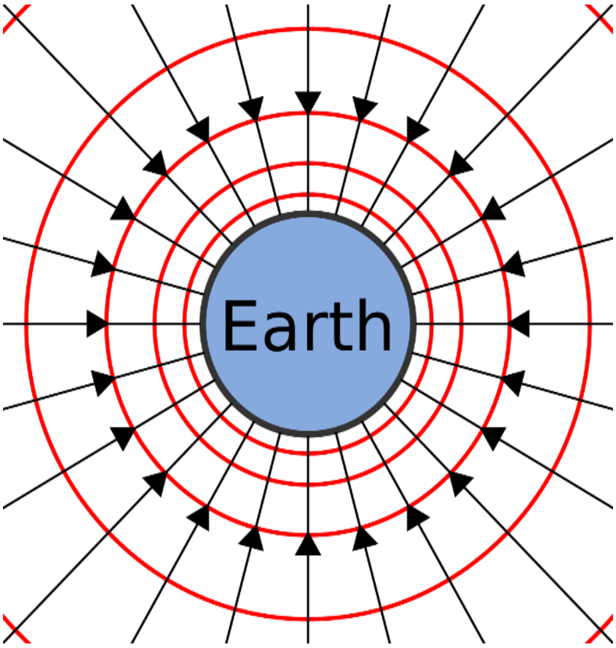
Lesson 3	Orbits and Kepler's Laws of Planetary Motion

Learning Objectives:

1. Calculate quantities related to planetary or satellite motion; and
2. For circular orbits, relate Kepler's 3^{rd} Law of Planetary motion to Newton's Law of Gravitation and Centripetal Acceleration

What's In

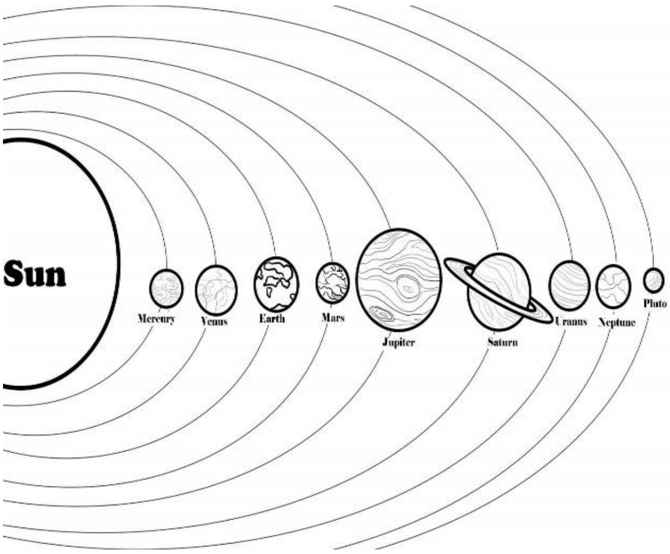
Based on the illustration, at what region is the gravitational field strongest? Write your answer in your notebook.



What's New

Activity 1: Orbit

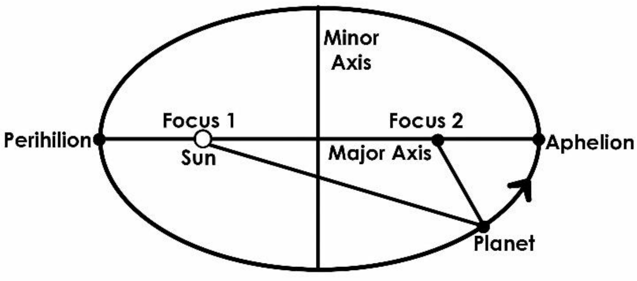
In the diagram below, draw arrows to represent both gravity and motion. Write your description in the box provided.

Diagram	Description
	

What is It

Kepler's Law of Planetary Motion

The Law of Ellipses

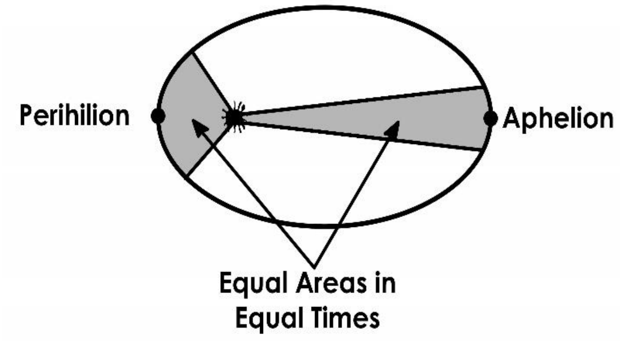


An elliptical orbit of a planet
(greatly exaggerated)

Kepler's first law - sometimes referred to as the law of ellipses - explains that planets are orbiting the sun in a path described as an ellipse. An ellipse is a special curve in which the sum of the distances from every point on the curve to two other points is a constant. The two other points are known as the **foci** of the ellipse. The closer together that these points are, the more closely that the ellipse resembles the shape of a circle.

In fact, a circle is the special case of an ellipse in which the two foci are at the same location. Kepler's first law is rather simple - all planets orbit the sun in a path that resembles an ellipse, with the sun being located at one of the foci of that ellipse and nothing at another focus.

The Law of Equal Areas



Kepler's second law - sometimes referred to as the law of equal areas - describes the speed at which any given planet will move while orbiting the sun. The speed at which any planet moves through space is constantly changing. A planet moves fastest when it is closest to the sun and slowest when it is furthest from the sun. Yet, if an imaginary line were drawn from the center of the planet to the center of the sun, that line would sweep out the same area in equal periods of time. For instance, if an imaginary line were drawn from the earth to the sun, then the area swept out by the line in every 31-day a month would be the same. This is depicted in the diagram below. As can be observed in the diagram, the areas formed when the earth is closest to the sun can be approximated as a wide but short triangle; whereas the areas formed when the earth is farthest from the sun can be approximated as a narrow but long triangle. These areas are the same size. Since the *base* of these triangles are shortest when the earth is farthest from the sun, the earth would have to be moving more slowly in order for this imaginary area to be the same size as when the earth is closest to the sun.

The Law of Harmonies

Kepler's third law - sometimes referred to as the **Law of Harmonies** - compares the orbital period and radius of orbit of a planet to those other planets. Unlike Kepler's first and second laws that describe the motion characteristics of a single planet, the third law makes a comparison between the motion characteristics of different planets. The comparison being made is that the ratio of the squares of the periods to the cubes of their average distances from the sun is the same for every one of the planets. As an illustration, consider the orbital period and average distance from sun (orbital radius) for Earth and Mars as given in the table below.

Planet	**Period (s)**	**Average Distance (m)**	**T^2/a^3 (s^2/m^3)**
Earth	3.156×10^7 s	1.4957×10^{11}	2.977×10^{-19}
Mars	5.93×10^7 s	2.278×10^{11}	2.975×10^{-19}

Observe that the T^2/a^3 ratio is the same for Earth as it is for mars. In fact, if the same T^2/a^3 ratio is computed for the other planets, it can be found that this ratio is nearly the same value for all the planets (see table below). Amazingly, every planet has the same T^2/a^3 ratio.

Planet	Period (yr)	Average Distance (au)	T^2/a^3 (yr^2/au^3)
Mercury	0.241	0.39	0.98
Venus	.615	0.72	1.01
Earth	1.00	1.00	1.00
Mars	1.88	1.52	1.01
Jupiter	11.8	5.20	0.99
Saturn	29.5	9.54	1.00
Uranus	84.0	19.18	1.00
Neptune	165	30.06	1.00
Pluto	248	39.44	1.00

(**NOTE**: The average distance value is given in astronomical units where 1 a.u. is equal to the distance from the earth to the sun - 1.4957×10^{11} m. The orbital period is given in units of earth-years where 1 earth year is the time required for the earth to orbit the sun - 3.156×10^{7} seconds.)

Kepler's third law provides an accurate description of the period and distance for a planet's orbits about the sun. Additionally, the same law that describes the T^2/a^3 ratio for the planets' orbits about the sun also accurately describes the T^2/a^3 ratio for any satellite (whether a moon or a man-made satellite) about any planet. There is something much deeper to be found in this T^2/a^3 ratio - something that must relate to fundamental principles of motion

In this section let us try to solve problems, involving Kepler's Third Law.

Kepler's 3rd Law: $T^2 = a^3$

*** This equation only works for objects which are orbiting the sun. ***

Kepler's 3rd law is a mathematical formula. It means that if you know the period of a planet's orbit (T = how long it takes the planet to go around the Sun), then you can determine that planet's distance from the Sun (a = the semi major axis of the planet's orbit).

It also tells us that planets that are far away from the Sun have longer periods than those close to **Kepler's third law** deals with the length of time a planet takes to orbit the Sun, called the period of revolution. The law states that the square of the period of revolution is proportional to the cube of the planet's average distance to the sun:

$$T^2=a^3$$

Because of the way a planet moves along its orbit, its average distance from the Sun is half of the long diameter of the elliptical orbit (the semi major axis.) The period, **T**, is measured in years and the semi major axis, **a**, is measured in astronomical units (AU), the average distance from the Earth to the Sun.

Kepler's third law is a mathematical relation between a planet's period and its average distance. With a little simple algebra we can determine one of the values if we are given the other. First of all it helps to rearrange the relationship slightly and apply a little cleverness:

$$\frac{\text{Period}^2}{\text{Average Distance}^3} = \text{Constant}$$

Kepler's third law can be rearranged and turned in to "an equality" as it is shown below. The **Constant** is just a number. However, it is important to know that this **Constant** is the same for anything orbiting the Sun. The value of this **Constant** depends on the units you use to measure the **Period** and **Average Distance**.

$$\frac{\text{Period}^2\ [\textbf{years}]}{\text{Average Distance}^3\ [\textbf{AU}]} = 1$$

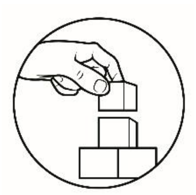
If you measure the **Period** in [years] and the **Average Distance** in *astronomical units* [AU] [an astronomical unit is defined as the average distance between the Earth and the Sun] then the **Constant** equals **1**. Why is this? Well the Earth has a period of 1 year and an average distance if 1 AU. Stick these numbers into the equation above and the **Constant** equals 1. Now, since this constant is the same for everything orbiting the Sun, as long as you measure the period in years and the average distance in AUs then the **Constant** is always 1.

Example 1.

Determine the period of an object that orbits the Sun at an average distance of 4 AU. Plug the average distance into the equation above, do a little algebra:

Solution: $T^2/a^3=1$; $T^2/4^3=1$; $T^2/64=1$; $P^2=64$; $P=\sqrt{64}$;
$P = 8$ (years)

An object with an average distance of 4 AU takes 8 years to go around the Sun.



What's More

Now that you have already know how to solve, complete the table below using a separate sheet of paper.

Planet	**Orbital period** (years)	**Semi-major axis** (A.U.'s)	**T^2**	**a^3**	**T^2/a^3**
Mercury	0.241	0.39			
Venus	0.615	0.723			
Earth	1	1			1
Mars	1.881	1.524	3.538161	3.539	.9995

What I Have Learned

Now that you have leared a lot from orbit and Kepler's Law of Planetary motion, Let us summarize what you have learned from by answering the following questions. Write your answer on a separate sheet of paper.

1. What does Kepler's 1st Law of Planetary motion mean?
   ____
   ____
   ____.

2. What does Kepler's 2nd Law of Planetary motion tells us about?
   ____
   ____
   ____.

3. How Kepler's 3rd Law relates to "The closer the planet is to the Sun, the greater its speed"?
   ____
   ____
   ____.

What I Can Do

After learning Kepler's Law of Planetary motion, let us relate Kepler's third law of planetary motion to Newton's Law of gravitation and centripetal acceleration.

On a separate sheet of paper, explain in 3-5 sentences the importance of Kepler's Law.

____
____
____

Assessment

Multiple Choice. Read the questions carefully. Choose the letter of the correct answer and write it on your notebook.

1. What is the gravitational force between two objects of masses with 40 kg and 50 kg if they are 2 meters apart?
   a. 3.3×10^{-8} N b. 3.3×10^{8} N c. 3.3×10^{-9} N d. 3.3×10^{9} N
2. In which situation applies the law of the Universal gravitation?
   a. Throwing of ball upward
   b. Dropping of a fork towards the ground
   c. Pushing a box
   d. Kicking a can
3. If you drop a baseball, basketball, and a soccer ball at the same time and at the same height, which one will hit the ground first?
   a. Baseball b. Basketball c. Soccer ball d. All the three balls
4. What relationship exist between the gravitational force and distances of the two objects?
   a. inversely proportional c. equal
   b. directly proportional d. none of the above
5. On what factors do the strength of the force of gravitational attraction in between two objects depend?
   a. The masses of objects and gravitational pull
   b. The mass of the planet and the mass of the object
   c. The masses of objects and the distance between them
   d. All of the above
6. In which of the situations the force acting on two-point masses is directly proportional?
   a. sum of masses c. distance between masses
   b. difference of masses d. product of masses
7. What is the mass of Earth when its radius is 6,400 km and gravitational field strength is 9.81 N/kg?
   a. 6.0×10^{24} kg b. 5×10^{23} kg c. 4.0×10^{9}kg d. 9×10^{24} kg
8. Which refers to the work done on an object that brings it to certain point in space?
   a. Gravitational Potential Energy c. Kinetic Energy
   b. Potential Energy d. Mechanical Energy
9. What is the direction of the gravitational field?
   a. towards the earth
   b. away from the earth
   c. has no direction
   d. in a specific direction making an angle with earth
10. What is the weight of a 100 kg body on the moon's surface if the value of gravitation on moon's surface is 1.6 m/s?
    a. 80 N b. 100 N c. 120 N d. 160 N

11. Which of the following is not one of Kepler's Law of Planetary Motion?
    a. The square of a planet's period is proportional to its distance from the sun cubed.
    b. The area of a planet's orbital plane is inversely proportional to its speed.
    c. A planet sweeps out equal area in an equal time intervals.
    d. Planets move around the sun in elliptical orbits.
12. From Kepler's third law, what s the average distance of an asteroid from the sun with an orbital period of 64 years?
    a. 4 astronomical units
    b. 16 astronomical units
    c. 64 astronomical units
    d. 256 astronomical units
13. According to Kepler's first law, the planet moves in an elliptical orbit around the sun. Which of the following best describes the location of the sun when a planet is orbiting around it?
    a. At a geometrical center
    b. At one focus
    c. At both foci
    d. On the opposite side of the same ellipse
14. An Astronomical Unit or AU is the average distance between?
    a. The Sun and Moon
    b. The Sun and Earth
    c. The Earth and Moon
    d. The Sun and Mercury
15. If a planet's average distance from the Sun is 12 AU, what is its orbital period?
    a. 5.24 yrs b. 41.6 yrs c.10 yrs d. 50 yrs

Additional Activities

Kepler's third law says that T^2/a^3 is the same for all objects orbiting the Sun. Vesta is a minor planet (asteroid) that takes 3.63 years to orbit the Sun. Calculate the average Sun-Vesta distance.

Answer Key

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

$$F_g = \frac{\left(6.67x10^{-11}\frac{Nm^2}{Kg^2}\right)(5.98x10^{24}kg)(100kg)}{(6.38X10^6m)^2}$$

$$F_g = \frac{\left(6.67x10^{-11}\frac{Nm^2}{Kg^2}\right)(5.98x10^{26}Kg^2)}{4.07x10^{13}m^2}$$

$$F_g = \frac{3.99x10^{16}N}{4.07x10^{13}}$$

$$F_g = 980.34\ N$$

Pr **e-Assessment**

1. A 2. D 3. B 4. B 5. A 6. B 7. C 8. C 9. B 10. A 11. A 12. B 13. C 14. B 15. A

What's In

1. B 2. A 3. E 4. C 5. D

What's More

What I Have Learned

1. Gravity 2. Gravity 3. Newton's Law

What I Can Do

1.Newton's law of universal gravitation states that every point mass in the universe attracts every other point mass with a force that is directly proportional to the product of their masses and inversely proportional to the square of the distance between them.

2.Buy at high altitude and sell at low altitude

- The mass of the purchased gold would be the same at both altitudes. Yet it would weigh less at higher altitudes. So to make a profit, Jane should buy at high altitudes and sell at low altitudes. She would have more profit to sell at the lower altitudes.

3.Since weight is directly dependent upon the mass of the Earth, Randy would weigh **10% more** if the mass of the Earth is increased by 10%. But no worries. Randy would not look any different since his mass would remain as is.

What's In

1. Gravitational Law 2. 6.67 x 10^{-11} N.m^2/kg^2

What's New

1. Gravitational Field 2. Joules 3. Potential 4. GPE

What's More

Gravitational Field (N/kg)
2.7 x 10^9
1.62 x 10^9
3.31 x 10^9
8.07 x 10^9
9.8 x 10^9
3.64 x 10^9

What I have Learned

1. True 2. True 3. r^2 4. Gravity 5. True

What's More

1. GPE = -GMm/r = $(-6.67 \times 10^{-11} \times 6.0 \times 10^{24} \times 60) / 6.4 \times 10^{6} = -3.8 \times 10^{9}$ J

1. To get the student away from the Earth's field completely will require taking him to infinity where his GPE will be zero. Thus we need to give him at least 3.8×10^9 J of energy somehow

2.Solution:: The distance r from the center of Mars

$r = 6.0 \times 10^6 \text{ m} + 3.38 \times 10^6 \text{ m} = 9.4 \times 10^6 \text{ m}$

The mass m of the lander is its earth weight W divided by the acceleration of gravity on the earth:

$$m = \frac{W}{g} = \frac{39{,}200 \text{ N}}{9.8 \text{ m/s}^2} = \mathbf{4000 \text{ kg}}$$

$$F = \frac{GMm}{r2} = \frac{(6.67 \times 10^{-11} \text{ Nm}^2/\text{kg}^2)(4{,}000 \text{ kg})(6.42 \times 10^{23} \text{ kg})}{(9.4 \times 10^6 \text{ m})2}$$

$$= \mathbf{1940 \text{ N}}$$

$$g = \frac{F}{m} = \frac{1940 \text{ N}}{4{,}000 \text{ kg}} = \mathbf{0.48 \text{ m/s}^2}$$

What's More

Planet	T^2	a^3	T^2/a^3
Mercury	0.0581	0.0593	0.9791
Venus	0.3782	0.3779	1.000
Earth	1	1	1

Post Assessment

1. A 2. B 3. D 4. A 5. C 6. D 7. A 8. A 9. A 10. D 11. B 12. B 13. B 14. B 15. B

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EDITOR'S NOTE

This Self-learning Module (SLM) was developed by DepEd SOCCSKSARGEN with the primary objective of preparing for and addressing the new normal. Contents of this module were based on DepEd's Most Essential Learning Competencies (MELC). This is a supplementary material to be used by all learners of SOCCSKSARGEN Region in all public schools beginning SY 2020-2021. The process of LR development was observed in the production of this module. This is version 1.0. We highly encourage feedback, comments, and recommendations

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