UNIT 5
GRAVITATION

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5.1 THE FORCE OF GRAVITATION

LONG QUESTIONS

Q.1 State and explain Newton's law of gravitation. ***(K.B+A.B+U.B)***

(GRW 2011, 12, 13, 15, LHR 2013)

Ans: **LAW OF GRAVITATION**

Introduction:

In the universe, there exists a force between the bodies due to which everybody of the universe attracts every other body. This force is known as force of gravitation.

Statement:

According to Newton's law of gravitation:

"Everybody in the universe attracts every other body with a **force** which is **directly proportional** to the **product of their masses** and **inversely proportional** to the **square of the distance** between their centers.**"**

Explanation:

Consider two bodies **A** and **B** of masses $\mathbf{m_1}$, and $\mathbf{m_2}$, respectively. According to law of gravitation, the gravitational force of attraction **F** with which two masses m_1 and m_2 separated by a distance **d** attract each other as shown in the figure***:***

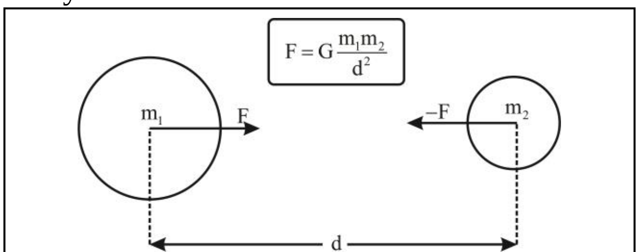

Figure: Gravitational Force Between Two Masses

Above two masses attract each other with a gravitational force of equal magnitude.

Mathematical Derivation:

$$F \propto m_1m_2$$

$$F \propto \frac{1}{d^2}$$

$$F \propto \frac{m_1m_2}{d^2}$$

$$F = G\frac{m_1m_2}{d^2}$$

Gravitational Constant:

G is a constant of proportionality and it is called gravitational constant. It is also called **universal constant** of gravitation. If $m_1 = m_2 = 1$ kg and d = 1 m, then F = G. Thus G is a force which 1 kg object exerts on another 1 kg object placed 1 m away from it. In SI units, the value of gravitational constant G is 6.67×10^{-11} Nm^2 kg^{-2}. Its value is same everywhere.

Dependence of Gravitational Force on Mass:

Due to small value of G and comparatively small masses the gravitational force of attraction between different objects around us is very small, so we do not feel it. However, if the mass of one or both the objects is very large, then we can observe the effect of gravitational force easily.

Gravitational Force of the Earth:

Since the mass of Earth is very large, it attracts nearby objects with a significant force. The weight of an object on the Earth is the result of gravitational force of attraction between the Earth and the object.

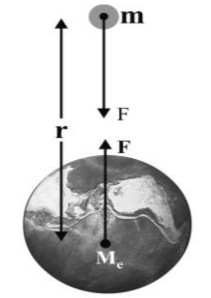

Figure: **Weight of Body is Due to Gravitational Pull of the Earth**

Q.2 Explain the Gravitational field? *(K.B+A.B+U.B)* **(GRW 2013)**

Ans:

GRAVITATIONAL FIELD

Definition:

"The **space around the earth** in which its **gravitational force** acts on a body is called gravitational field".

Explanation:

According to the Newton's law of gravitation, the gravitational force between a body of mass m and the Earth is given by:

$$F = G\frac{mM_e}{r^2}$$

Where M_e is the **mass of the Earth** and r is the **distance of the body** from the centre of the Earth. The **weight** of a body is due to the **gravitational force** with which Earth attracts a body.

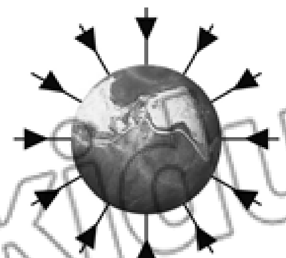

Figure: **Gravitational Field All Around Us**

Field Force:

The gravitational force exists around the Earth and is acting on the bodies whether the bodies are in contact with the Earth or not. So, we can say that **gravitational force is a field force** i.e. gravitational force is a non-contact force. Or

The region of the space surrounding by a body, such as charged particle or a magnet or earth, with in which it can exert a force on another similar bodies not in contact with it.

Example:

The velocity of a body, thrown up, goes on decreasing while on returns its velocity goes on increasing.

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This is due to the gravitational pull of the Earth acting on the body whether the body is in contact with the Earth or not. Such a force is called the field force. It is assumed that a **gravitational field** exists all around the Earth. This field is directed towards the centre of the Earth. The gravitational field becomes weaker and weaker as we go farther and farther away from the Earth.

Gravitational Filed Strength:

"In the **gravitational field of the Earth,** the **gravitational force** per unit mass is called **gravitational field strength** of the Earth.**"** At any place its value is equal to the value of g at that point. Near the surface of the Earth, the gravitational field strength is **10 Nkg^{-1}.**

5.1 SHORT QUESTIONS

Q.1. Define Force of Gravitation. *(K.B)* **(LHR 2017)**

Ans: Given on page #182

Q.2. State Law of gravitation. *(K.B+A.B)* **(LHR 2013, 2014, 17, GRW 2015,17)**

Ans: Given on page #182

Q.3. What is the relation between Law of Gravitation and Newton's Third law of motion? *(K.B)*

OR Explain that gravitational forces are consistent with Newton's third law of motion.

Ans: **LAW OF GRAVITATION AND NEWTON'S THIRD LAW OF MOTION**

It is to be noted that mass m_1 attracts m_2 towards it with a force F while mass m_2 attracts m_1 with a force of the same magnitude F but in **opposite direction**. If the force acting on m_1 is considered as **action** then the force acting on m_2 will be **reaction**. The action and reaction due to force of gravitation are equal in magnitude but opposite in direction.

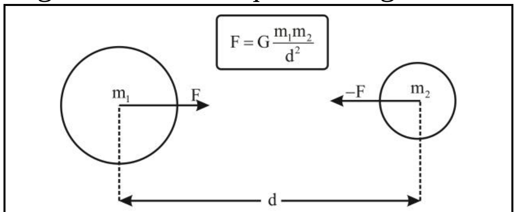

Figure: Action and Reaction Forces

This is in consistent with Newton's third law of motion which states, **"**To every action there is always an equal but opposite reaction.**"**

Q.4. What will happen if Earth suddenly stops revolving around the Sun? *(K.B)*

Ans: **EARTH SUDDENLY STOPS REVOLVING**

If Earth suddenly stops revolving around the Sun then due to attraction of the Sun and the Earth, it will fall down on the sun.

Q.5. Why don't we observe force of attraction between any two objects around us? *(K.B)*
(GRW 2014, LHR 2017)

Ans: **NOT FEELING FORCE OF GRAVITATION**

Since the gravitational force between different objects around us is very small, so we do not feel it, because the value of G is very small. However, if the mass of one or both the objects is very large, then we can observe the effect of gravitational force easily.

Q.6. What is the gravitational force acting on the body placed at the surface of Earth? *(K.B)*

Ans: **GRAVITATIONAL FORCE ON EARTH's SURFACE**

Since the mass of the Earth is very large, it attracts nearby objects with a significant force. The weight of an object on the Earth is a result of the gravitational attraction between the two.

Q.7. What is difference between G and g? *(C.B)*

Ans: The basic difference between g and G is that **'g' is the Gravitational acceleration while 'G ' is the Gravitational constant and its value is 6.673×10^{-11} Nm^2kg^{-2}.** The value of g changes with altitude and its value on the surface of earth is **$9.8ms^{-2}$** while the value of G remains constant.

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EXAMPLE 5.1

Two lead spheres each of mass 1000 kg are kept with their centres 1 m apart. Find the gravitational force with which they attract each other. ***(U.B+A.B)***

Solution:

Given Data:

Mass of first lead sphere = m_1 = 1000 kg = 10^3 kg

Mass of Second lead sphere = m_2 = 1000 kg = 10^3 kg

Distance between lead sphere = d = 1m

Gravitational constant = G = 6.673×10^{-11} Nm^2kg^{-2}

To Find:

Gravitational force between lead sphere = F =?

Calculations:

According to Law of Gravitation

$$F = G\frac{m_1m_2}{d^2}$$

Putting values

$$F = \frac{6.673\times10^{-11}\times10^3\times10^3}{(1)^2}$$

$$F = 6.673\times10^{-5}\,N$$

Result:

Hence, the gravitational force between two lead spheres is $6.673\times10^{-5}\,N$

5.1 MULTIPLE CHOICE QUESTIONS

1. **Who predicted about artificial satellites about 300 years ago?** ***(K.B)***
(A) Galileo (B) Newton
(C) Einstein (D) Faraday

2. **Unit of gravitational field strength is:** ***(K.B)***
(A) N (B) N kg^{-1}
(C) J (D) N m

3. **If the distance between two masses is half then the force of gravitation becomes:** ***(U.B)***
(A) One fourth (B) Four times
(C) Doubled (D) Half

4. **In System International, the value of G is:** ***(K.B)*** **(GRW 2012)**
(A) 6.4 x 10^6 Nm^2kg^{-2} (B) 6.4 x 10^{-11} Nm^2kg^{-2}
(C) 6.67 x 10^{11} Nm^2kg^{-2} (D) 6.67 x 10^{-11} Nm^2kg^{-2}

5. **Radius of earth is:** ***(K.B)***
(A) 6.4 x 10^6 km (B) 6.4 x 10^6 m
(C) 6 x 10^6 m (D) 6 x 10^6 km

6. **The SI unit of gravitational force is:** ***(K.B)***
(A) Nm^2kg^{-2} (B) Newton
(C) ms^{-2} (D) Both “a” and “b”

7. **What will be the value of G if mass of the earth becomes four times:** ***(U.B)***
(A) No change (B) Four times
(C) One fourth (D) Doubled

8. If mass of both the bodies is 1kg and distance between their centers is 1m then the gravitational force will be equal to: ***(A.B)***

(A) G (B) g
(C) V (D) None of above

9. Gravitational force on the surface of earth is equal to: ***(K.B)***

(A) G (B) g
(C) Weight (D) All of above

10. Weight of the body of mass 10 kg on the surface of moon: ***(A.B)*** **(LHR 2016)**

(A) 160 N (B) 16N
(C) 1.62 N (D) None of above

5.2 MASS OF THE EARTH

LONG QUESTIONS

Q.1. Determine the mass of the earth by using Newton's law of gravitation. ***(A.B+U.B)***

OR How the mass of the earth can be determined? **(Ex. 5.10, GRW 2014, 2017, LHR 2015)**

Ans: **<u>MASS OF THE EARTH</u>**

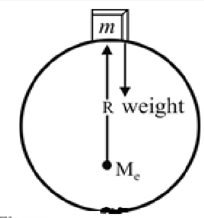

Figure: **<u>Weight of the Body is Equal to Gravitational Force Between the Body and the Earth</u>**

Consider a body of **mass** m is placed on the surface of the Earth as shown in the figure:

Let **mass of the Earth** is Me and **radius of Earth** be R. The **distance** between the body and centre of the Earth is equal to the **radius of the Earth** R**.**

According to the law of gravitation, the gravitational force **F** of the Earth acting on the body is given by,

$$F = G\frac{mM_e}{R^2}$$

We know that the force of gravitation with which Earth attracts the body towards its centre is equal to the weight of the body. Therefore,

$$F = w = mg$$

Or

$$mg = G\frac{mM_e}{R^2} \qquad \therefore g = G\frac{M_e}{R^2}$$

And

$$\boxed{M_e = \frac{R^2 g}{G}}$$

As we know that,

$g = 10\ ms^{-2}$

$R = 6.4 \times 10^6$ m

And $G = 6.673 \times 10^{-11}$ Nm^2kg^{-2}

By putting the value of g, R and G in above equation,

$$M_e = \frac{\left(6.4\times10^6\right)^2(10)}{6.673\times10^{-11}}$$

$$M_e = 6\times10^{24}\,kg$$

<u>Conclusion</u>:

Thus, the mass of the earth is approximately 6 x 10^{24} kg.

5.2 MULTIPLE CHOICE QUESTIONS

1. **The mass of Earth is approximately: *(K.B)***
   (A) 6.9×10^{24} kg (B) 6.0×10^{-24} kg
   (C) 6.0×10^{24} kg (D) 5500×10^{24} kg
2. **Radius of the Earth is? *(K.B)*** **(GRW 2017)**
   (A) 6×10^{24} m (B) 6.4×10^{6} m
   (C) 6400 km (D) Both b and c
3. **Value of G is : *(K.B)***
   (A) 6×10^{24} m (B) 6.673×10^{-11} Nm^2kg^{-2}
   (C) 10 ms^{-2} (D) Both b and c
4. **Formula for mass of the Earth: *(A.B)*** **(GRW 2017)**
   (A) $M_e = R^2g/G$ (B) $M_e = Rg/G$
   (C) $M_e = R^2g/G^2$ (D) $M_e = R^2G/g$

5.3 VARIATIONS OF g WITH ALTITUDE

LONG QUESTIONS

Q.1. Explain how the value of g varies with altitude. *(K.B+U.B+A.B)* **(Ex. 5.13, GRW 2015)**

Ans: **VARIATION IN G WITH ALTITUDE**

Introduction:

As we know that,

$$g = G\frac{M_e}{R^2}$$

The above equation show that the acceleration due to gravity **g** depends on the radius of Earth at its surface. The value of g is **inversely proportional** to the **square of the radius of the Earth.** Acceleration due to gravity does not remain constant. It decreases with altitude. **Altitude** is the **height** of an object or place **above sea level**. The value of g is greater at sea level than at the hills.

Explanation:

Consider a body of **mass** m at an **altitude** h. The distance of the body from the centre of the Earth is **R+h** as shown in the figure:

By using above equation, we have

$$g_h = G\frac{M_e}{(R+h)^2}$$

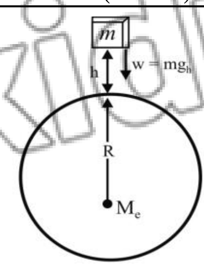

Figure: **Weight of a Body Decreases as its Height Increases from the Surface of the Earth**

According to the above equation, we come to know that at a height equal to one Earth radius above the surface of the Earth, g becomes one fourth of its value on the Earth. Similarly, at a distance of two Earth's radius above the Earth's surface, the value of g becomes one ninth of its value on the Earth.

EXAMPLE 5.2

Calculate the value of g, the acceleration due to gravity at an altitude 1000 km. The mass of the Earth is 6.0 x 10^{24} kg. The radius of the Earth is 6400 km. ***(U.B+A.B)***

Solution:

Given Data:

Altitude = h = 1000 km

Mass of the Earth = M_e = 6×10^{24} kg

Radius of the Earth = R = 6400 km

R + h = 6400 km +1000 km = 7400 km

= 7.4×10^6 m

To Find:

Gravitational acceleration at height $= g_h = ?$

Calculations:

We know, $g_h = G\dfrac{M_e}{(R+h)^2}$

Putting values,

$$g_h = \frac{6.673\times10^{-11}\,Nm^2kg^{-2}\times6.0\times10^{24}\,kg}{\left(7.4\times10^6\,m\right)^2}$$

$$g_h = 7.3ms^{-2}$$

Result:

Hence, the value of g, the acceleration due to gravity at an altitude of 1000 km will be 7.3 ms^{-2}.

5.3 SHORT QUESTIONS

Q.1 What is effect of the followings on the gravitational acceleration? ***(K.B+U.B)***

(i) Mass of freely falling body

(ii) Distance of freely falling body from the centre of earth

Ans: **EFFECTS ON GRAVITATIONAL ACCELERATION**

Effect of Mass:

There is no effect of mass of the body on gravitational acceleration because according to the relation:

$$g = G\frac{M_e}{R^2}$$

This relation shows that gravitational acceleration is independent of the mass of freely falling body.

Effect of Distance From the Center of the Earth:

Gravitational acceleration is **inversely proportional** to the **square of distance** of freely falling body from the centre of earth. If the distance of the body is increased from the centre of the earth gravitational acceleration will be less and vice versa.

Q.2 Is there any difference between the value of 'g' at the equator and at the poles? ***(K.B+U.B)***

Ans: **VALUE OF "g"**

As the shape of the earth is not perfect sphere but elliptical. The distance at the equator to the center of earth is more, so gravitational acceleration 'g' at equator will be less. However, as the distance at the poles to the center of the earth is less, so gravitation acceleration 'g' will be more.

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Q.3 If we go on top of the mountain, will our weight increase or decrease? *(U.B)*

Ans: **VARIATIONS IN WEIGHT**

If the distance from the centre of the Earth increases from the average radius of the Earth, the value of 'g' will decrease. This is the reason due to which the value of 'g' is less on the top of mountains. So our weight will be decreased.

Q.4 Does an apple attract the Earth towards it? *(K.B)* **(Mini Exercise Pg. # 111)**

Ans: **ATTRACTION OF APPLE**

Yes, Apple attracts the earth but this force is very very small so it is unable to pull the earth.

Q.5 With what force an apple weighing 1N attracts the Earth? *(U.B)* **(Mini Exercise Pg. # 111)**

Ans: **FORCE OF APPLE**

Apple weighing 1N attracts the earth with a force of 1 N.

Q.6 Does the weight of an apple increase, decrease or remain constant when taken to the top of a mountain. *(U.B)* **(Mini Exercise Pg. # 111)**

Ans: **WEIGHT OF APPLE**

As we go to the mountains, value of g decreases. So weight of the apple decreases.

(As $w = mg$)

5.3 MULTIPLE CHOICE QUESTIONS

1. **As we go up the value of g: *(K.B)***
   (A) Unchanged (B) Increases
   (C) Decreases (D) Doubled
2. **When an object is at a height equal to radius of earth above the surface of the Earth. What is the value of g_h? *(U.B)*** **(LHR 2013)**
   (A) 4g (B) 2g
   (C) g/2 (D) g/4
3. **What is not true about g? *(K.B)***
   (A) g is different at different places (B) g is greater at poles
   (C) g is less at poles (D) g decrease as go higher
4. **If the weight of an object on the surface of earth is w. Its weight on the surface of moon will be: *(U.B)***
   (A) 6W (B) W/6
   (C) W/4 (D) W/8
5. **As compared to the weight on the surface of earth, our weight on mountains will be: *(U.B)***
   (A) Equal (B) Greater
   (C) Less (D) None of above
6. **Value of g on the surface of the Mercury is (ms^{-2}) *(K.B)***
   (A) 10 (B) 9.8
   (C) 1.62 (D) 3.7
7. **Value of g on the surface of the Moon is (ms^{-2}) *(K.B)***
   (A) 10 (B) 9.8
   (C) 1.62 (D) 3.7

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8. **Value of g on the surface of the Mars is (ms^{-2}) *(K.B)***
(A) 10 (B) 9.8
(C) 3.73 (D) 3.7

9. **Value of g on the surface of the sun: *(K.B)***
(A) 3.7 ms^{-2} (B) 274.2ms^{-2}
(C) 8.87 ms^{-2} (D) 25.94 ms^{-2}

10. **Value of g on the surface of the Jupiter: *(K.B)***
(A) 3.7 ms^{-2} (B) 274.2ms^{-2}
(C) 8.87 ms^{-2} (D) 25.94 ms^{-2}

11. **Value of g on the surface of the Venus: *(K.B)***
(A) 3.7 ms^{-2} (B) 274.2ms^{-2}
(C) 8.87 ms^{-2} (D) 25.94 ms^{-2}

12. **Value of g on the surface of the Earth: *(K.B)***
(A) 3.7 ms^{-2} (B) 274.2ms^{-2}
(C) 9.8 ms^{-2} (D) 25.94 ms^{-2}

5.4 ARTIFICIAL SATELLITE

LONG QUESTIONS

Q.1. What are artificial satellites? Define orbital velocities and what do you know about communication satellites? *(K.B+A.B+U.B)* **(LHR 2013)**

Ans: **SATELLITES**

Definition:
"An object that **revolves** around a **planet** is called a satellite**"**.

Natural Satellite of Earth:
The moon revolves around the Earth so moon is the natural satellite of Earth.

Orbit:
A satellite travels round the Earth in a curved path called an orbit. Gravitational pull (in other words, the satellite's weight) provides the centripetal force needed. When a satellite is put into orbit, its speed is carefully chosen so that its path does not take it further out into space or back to Earth. Heavy satellites need the same speed as light ones. If the mass is doubled, twice as much centripetal force is required, but that is supplied by the double gravitational pull of the Earth.

Orbital Velocity:
It is the velocity of the satellite with which it moves around the earth at specific height.

Artificial Satellites:
Scientists have sent many objects into space. Some of these revolve around the Earth. These are called artificial satellites.

Example:
First artificial satellite Sputnik 1 was launched by Soviet Union in 4th October 1957. Later on large numbers of artificial satellites have been launched in different orbits around the Earth. They take different time to complete their one revolution around the Earth depending upon their distance **h** from the Earth.

Purpose of Artificial Satellites:
Most of the artificial satellites orbiting around the Earth are used for communication purposes. Artificial satellites carry instruments or passengers to perform experiments in the space.

Communication Satellites:

Communication satellites take 24 hours to complete their one revolution around the Earth. As Earth also completes one rotation about its axis in 24 hours, hence, these communication satellites appear to be stationary with respect to Earth. It is due to this reason that the orbit of such satellites is called **geostationary orbit**. Dish antennas sending and receiving the signals from them have fixed direction depending upon their location on the Earth.

Q.2. Explain the motion of an artificial satellite and derive the formula for orbital velocity of an artificial satellite. ***(K.B+A.B+U.B)***

Ans: **MOTION OF ARTIFICIAL SATELLITE**

Introduction:

A satellite requires centripetal force that keeps it to move around the Earth. The **gravitational force of attraction** between the satellite and the Earth provides the necessary **centripetal force.**

Mathematical Derivation:

Suppose a satellite of **mass** m is revolving around the Earth at an **altitude** 'h' in an orbit of **radius** r_o with **orbital velocity** $\mathbf{v_o}$ as shown in the figure:

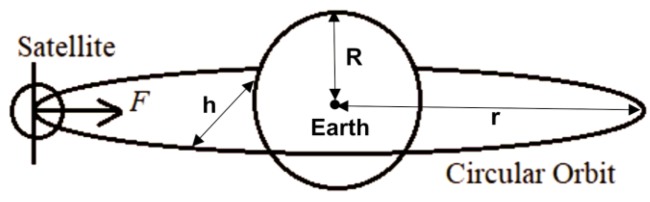

Figure: **A Satellite is Orbiting around the Earth at a height h above the Surface of the Earth**

The necessary centripetal force $\mathbf{F_c}$ required to keep the satellite moving is given by,

$$F_c = \frac{mv_o^2}{r_o} \dots (1)$$

This centripetal force is provided to the satellite by the gravitational force of attraction between the Earth and satellite and is equal to the weight of the satellite $w'(mg_h)$. Thus,

$$F_c = w' = mg_h \dots (2)$$

By comparing equation (1) and equation (2), we get

Or $$mg_h = \frac{mv_o^2}{r_o}$$

Or $$v_o^2 = g_h r_o$$

Or $$v_o = \sqrt{g_h r_o}$$

As $$r_o = R + h$$

$\therefore$ $$v_o = \sqrt{g_h (R + h)} \dots (3)$$

This equation represents the orbital velocity, which a satellite must possess when launched in an orbit of radius $r_o = R + h$ around the Earth. An approximation can be made for a satellite revolving close to the Earth such that $R >> h$.

$$R + h \approx R$$

And $$g_h \approx g$$

So $$v_o = \sqrt{gR}$$

We know

Gravitational Acceleration=g = $10ms^{-2}$
Radius of the Earth=R = 6.4×10^6 m

By putting values

$$v_o = \sqrt{10 \times 6.4 \times 10^6} = 8000ms^{-1} \text{ or } 8kms^{-1}$$

Conclusion:

A Satellite revolving around very close to the Earth has speed nearly 8 kms^{-1} or 29000 kmh^{-1}.

5.4 SHORT QUESTIONS

Q.1. Define orbital velocity. *(K.B)* **(GRW 2012)**

Ans: **ORBITAL VELOCITY**

It is the velocity of the satellite with which it moves around the earth at specific height.

Expression:

Expression for orbital velocity is given below:

$$v_o = \sqrt{g_h(R+h)}$$

Value:

A Satellite revolving around very close to the Earth has speed nearly 8 kms^{-1} or 29000 kmh^{-1}.

Q.2. What do you know about Global Positioning System (GPS)? *(K.B)* **(GRW 2014)**

Ans: **GLOBAL POSITIONING SYSTEM**

Global Positioning System (GPS) is a satellite navigation system. It helps us to find the exact position of an object anywhere on the land, on the sea or in the air. GPS consists of 24 Earth satellites. These satellites revolve around the Earth twice a day with a speed of 3.87 kms^{-1}.

Q.3. What do you know about geostationary satellites? *(K.B)*

Ans: **GEOSTATIONARY SATELLITE**

Geostationary satellites are the satellites whose velocity relative to earth is zero. These satellites remain stationary with respect to the earth at the height of 42,300 km from the surface of the earth. These are used for global TV transmissions and other telecommunication purposes.

Q.4. Moon revolves around the earth, from where it gets necessary centripetal force? *(K.B)*

Ans: **CENTRIPETAL FORCE ON THE MOON**

The gravitational force between the earth and the moon provides the necessary centripetal force to moon for revolving around the earth.

5.4 MULTIPLE CHOICE QUESTIONS

1. Distance of moon from Earth is? *(K.B)* **(GRW 2013, 2014)**

(A) 38, 000 km (B) 3, 80, 000 km
(C) 3, 000, 000 km (D) 30, 000 km

2. Moon completes its revolution around the Earth in: *(K.B)*

(A) 30 days (B) 27.3 days
(C) 31 days (D) 365 days

3. Speed of GPS satellite is:

(A) 7.9 kms^{-1} (B) 3.87 kms^{-1}
(C) 5.6 kms^{-1} (D) 5.0 kms^{-1}

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4. The force which pulls the object towards the center of circle is known as: *(K.B)*
(A) Frictional (B) Coulomb
(C) Centripetal (D) Gravitational

5. A satellite is revolving around the earth in a circular orbit. If the radius of the orbit is increased from R to 2R. What will be its velocity? *(U.B+A.B)*
(A) $\sqrt{2}v$ (B) v^2
(C) v/2 (D) $\frac{v}{\sqrt{2}}$

6. An artificial satellite keeps on revolving around the earth in different orbits with uniform speed due to the? *(K.B)*
(A) Gravitational force (B) Frictional force
(C) Coulomb force (D) Electromagnetic force

7. Relative velocity of Geostationary satellite with respect to earth is: *(K.B)*
(A) 7.9 kms^{-1} (B) 11.2 kms^{-1}
(C) 9.8 ms^{-1} (D) Zero

8. For making the rocket to revolve around the earth it must be sent velocity of: *(K.B)*
(GRW 2013, LHR 2015)
(A) 8 ms^{-1} (B) 8 kms^{-1}
(C) 9.8 ms^{-1} (D) 11.2 kms^{-1}

9. Height of the Geostationary satellite above the surface of earth is: *(K.B)*
(A) 1000 km (B) 3600 km
(C) 36000 km (D) 42300 km

MCQ'S ANSWER KEY (TOPIC WISE)

5.1 THE FORCE OF GRAVITATION

1	2	3	4	5	6	7	8	9	10
B	B	B	D	B	D	A	A	C	B

5.2 MASS OF EARTH

1	2	3	4
C	D	B	A

5.3 VARIATION OF g WITH ALTITUDE

1	2	3	4	5	6	7	8	9	10	11	12
C	D	C	B	C	D	C	C	B	D	C	C

5.4 ARTIFICIAL SATELLITE

1	2	3	4	5	6	7	8	9
B	B	B	C	A	A	D	B	D

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TEXT BOOK EXERCISE

MULTIPLE CHOICE QUESTIONS

5.1 Encircle the correct answer from the given choices.

i. Earth's gravitational force of attraction vanishes at: *(K.B)* **(LHR 2017)**

(a) 6400 km (b) Infinity
(c) 42300 km (d) 1000 km

ii. Value of g increases with the: *(K.B)*

(a) increase in mass of body (b) increase in altitude
(c) decrease in altitude (d) none of the above

iii. The value of g at a height one Earth's radius above the surface of Earth is: *(K.B)*

(a) 2 g (b) 1/2 g
(c) 1/3 g (d) 1/4 g

iv. The value of g on moon's surface is 1.6 ms^{-2}. What will be the weight of a 100 kg body on the surface of the moon? *(A.B)*

(a) 100 N (b) 160 N
(c) 1000 N (d) 1600 N

v. The altitude of geostationary orbits in which communications satellites are launched above the surface of Earth is: *(K.B)*

(a) 850 km (b) 1000 km
(c) 6400 km (d) 42300 km

vi. The orbital speed of a low orbit satellite is: *(K.B)*

(a) zero (b) 8 ms^{-1}
(c) 800 ms^{-1} (d) 8000 ms^{-1}

ANSWER KEY

i	ii	iii	iv	v	vi
B	C	D	B	D	D

5.2. What is meant by force of gravitation? *(K.B)* **(LHR 2011, 2015, 2016, GRW 2015)**

Ans: **FORCE OF GRAVITATION**

Definition:

In the universe, there exists a force between the bodies due to which everybody of the universe attracts every other body. This force is known as force of gravitation.

Discovery:

In 1665 Newton discovered this force when an apple fell on him with this he also discovered the cause that makes planets to revolve around the Sun and the moon around the Earth.

5.3. Do you attract the earth or the Earth attracts you? Which one is attracting with a larger force? You or Earth? *(K.B)*

Ans: **WE ATTRACT THE EARTH**

We attract the earth and Earth attracts us. The both forces are same. We attract the earth with same force as earth attract earths, because the force of gravity is a mutual force and it depends on the product of mass of earth and mass of us.

5.4. What is a field force? *(K.B)*

Ans: *Given on Page* # 183

5.5. Why earlier scientists could not guess about the gravitational force? *(K.B)*

Ans: **EARLIER SCIENTISTS**

The early scientists could not guess about the gravitational force due to lack of observations, sensitive instruments and lack of knowledge. Also it is a very weak force and its presence cannot be detected until mass of one body in much greater than mass of other body.

5.6. How can you say that gravitational force is a field force? *(K.B)*

Ans: **FIELD FORCE**

The force that acts on a body with in certain region whether the body is in contact or not is called field force. The gravitational force exists around the Earth and is acting on the bodies whether the bodies are in contact with the Earth or not. So, we can say that gravitational force is a field force i.e. Gravitational force is a non-contact force.

Example:

The velocity of a body, thrown up, goes on decreasing while on returns its velocity goes on increasing. This is due to the gravitational pull of the Earth acting on the body whether the body is in contact with the Earth or not. Such a force is called the field force. It is assumed that a gravitational field exists all around the Earth. This field is directed towards the centre of the Earth. The gravitational field becomes weaker and weaker as we go farther and farther away from the Earth.

5.7. Explain what is meant by gravitational field strength? *(K.B)* **(LHR 2013)**

Ans: *Given on Page # 183*

5.8. Why law of gravitation is important to us? *(A.B)*

Ans: **IMPORTANCE OF LAW OF GRAVITATION**

Law of gravitation is important to us because it is used to:

- Calculate force of attraction between two masses.
- Calculate the mass of Earth.
- Understand working of satellites etc.

5.9. Explain the law of gravitation? *(K.B+A.B+U.B)*

Ans: (See Topic 5.1, Long Question-1)

5.10. How the mass of Earth can be determined? *(K.B+A.B+U.B)*

Ans: (See Topic 5.2, Long Question-1)

5.11. Can you determine the mass of our moon? If yes, then what you need to know? *(K.B+A.B+U.B)*

Ans: **MASS OF THE MOON**

Yes we can determine the mass of the moon by same method used to measure the mass of the Earth with the help of law of gravitation. The formula is:

$$M_m = \frac{g_m R_m^2}{G}$$

From the about relation it shows that we require,

g_m = gravitational acceleration on the surface of moon

R_m = Radius of moon

G = Gravitational constant

5.12. Why does the value of g vary from place to place? ***(A.B+U.B)*** **(GRW 2015, LHR 2016)**

Ans: **<u>g VARIES FROM PLACE TO PLACE</u>**

We know that (On the surface of the Earth)

$$g = \frac{GMe}{R^2}$$

And (At height h from the surface of the Earth)

$$g_h = \frac{GMe}{(R+h)^2}$$

The above relations show that value of 'g' is inversely proportional to the square of distance of body from the centre of earth. It means value of g depends on altitude. As different places are at different altitudes so value of g varies from place to place.

5.13. Explain how the value of g varies with altitude. ***(K.B+A.B+U.B)***

Ans: (See Topic 5.3, Long Question-1)

5.14. What are artificial satellites? ***(K.B)***

Ans:

5.15. How Newton's law of gravitation helps in understanding the motion of satellites. ***(K.B)***

Ans: **<u>UNDERSTANDING THE MOTION OF SATELLITE</u>**

When a satellite moves around the earth in a nearly circular path, the gravitational force of attraction between earth and satellite provides the necessary centripetal force for its motion. This gravitational force can be found by using Newton's law of gravitation and finally we can find orbital speed of satellites by using following formula that has been derived by using Law of gravitation.

$$v_o = \sqrt{g_h\left(R+h\right)}$$

5.16. On what factors the orbital speed of a satellite depends? ***(K.B)*** **(GRW 2015, LHR 2016)**

Ans: **<u>DEPENDANCE OF ORBITAL SPEED</u>**

As we know that

$$v_o = \sqrt{g_h\,(R+h)}$$

So, we can say that orbital speed depends upon:

- The gravitational acceleration.
- Distance between the center of earth and the satellite.

5.17. Why communication satellites are stationed at geostationary orbits? ***(K.B+U.B)*** **(GRW 2013, 14,17)**

Ans: **<u>GEOSTATIONARY ORBIT</u>**

Communication satellites are stationed at geostationary orbits because in these orbits the relative velocity of artificial satellites becomes zero with respect to the Earth. Hence satellites in geostationary orbits remain all the time in front of the targeted part of the Earth so we have not to change that direction of dish antenna again and again.

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NUMERICAL PROBLEMS U.B + A.B

5.1. Find the gravitational force of attraction between two spheres each of mass 1000 kg. The distance between the centers of the spheres is 0.5m.

Solution:

Given Data:

Mass of each sphere = $m_1 = m_2 = 1000$ kg
Distance between their centers = d = 0.5 m
Gravitational constant = G = 6.673×10^{-11} Nm^2kg^{-2}

To Find:

Gravitational force between the spheres = F = ?

Calculations:

From the law of gravitation, we have

$$F = \frac{G\, m_1 m_2}{d^2}$$

By putting the values, we have

$$F = \frac{6.67\times10^{-11}\times1000\times1000}{(0.5)^2}$$

$$F = \frac{6.67\times10^{-5}}{0.25}$$

$F = 26.68 \times 10^{-5}$

$F = 2.67 \times 10^{-4}$ N

Result:

Hence, the gravitational force between the spheres will be 2.67×10^{-4} N.

5.2. The gravitational force between two identical lead spheres kept at 1 m apart is 0.006673 N. Find their masses.

Solution:

Given Data:

Gravitational force between lead spheres = F = 0.006673 N
Distance between centers of lead spheres = r = 1 m
Gravitational constant = 6.67×10^{-11} Nm^2kg^{-2}

To Find:

Mass of each lead spheres = $m_1 = m_2$ = ?

Calculations:

From law of gravitation, we have

$$F = G\,\frac{m_1\times m_2}{r^2}$$

OR $m_1 \times m_2 = \frac{F\times r^2}{G}$

By putting the values, we have

$$m_1 \times m_2 = \frac{0.006673 \times (1)^2}{6.67 \times 10^{-11}}$$

As $m_1 \times m_2 = 0.001000 \times 10^{11}$

$$m_1 \times m_2 = 1.00 \times 10^8$$

$$m_1 = m_2 = m$$

So $m^2 = 1.00 \times 10^8$

Taking square root on both sides

$$m = 1.00 \times 10^4 \text{kg} = 10,000\text{kg}$$

So $m_2 = 1.00 \times 10^4$ kg = 10,000kg

Result:

Hence, the Mass of each lead spheres will be 1 x 10^4 kg or 10,000kg.

5.3. Find the acceleration due to gravity on the surface of the Mars. The mass of Mars is 6.42 x 10^{23} kg and its radius is 3370 km.

Solution:

Given Data:

Mass of the mars = M = 6.42 x 10^{23} kg
Radius of mars = R = 3370 km = 3370 x 10^3 m = 3.37 x 10^6 m

To Find

Gravitational acceleration = g = ?

Calculations:

As we know that

$$g = G\frac{M}{R^2}$$

By putting the values, we have

$$g = \frac{6.67 \times 10^{-11} \times 6.42 \times 10^{23}}{(3.77 \times 10^6)^2}$$

$$g = \frac{42.8214 \times 10^{12}}{11.3569 \times 10^{12}}$$

$$g = 3.77\text{ms}^{-2}$$

Result:

Hence, the gravitational acceleration on the surface of the Mars will be 3.77 ms^{-2}.

5.4. The acceleration due to gravity on the surface of moon is 1.62 ms^{-2}. The radius of moon is 1740 km. Find the mass of moon?

Solution:

Given Data:

Gravitational acceleration on Moon = g_m = 1.62 ms^{-2}
Radius of moon = R_m = 1740 km = 1740 x 10^3 m = 1.74 x 10^6 m
Gravitational constant = G = 6.67 x 10^{-11} N m^2 kg^{-2}

To Find:

Mass of the moon = M = ?

Calculations:

As we know that

$$M = \frac{g_m R_m^2}{G}$$

By putting the values, we have

$$M = \frac{1.62\times(1.74\times10^{6})^2}{6.67\times10^{-11}}$$

$$M = \frac{1.62\times3.0276\times10^{12}}{6.67\times10^{-11}}$$

$$M = \frac{4.90\times10^{12}}{6.67\times10^{-11}}$$

$$M = 0.735\times10^{23}$$

$$M = 7.35\times10^{22}\text{kg}$$

Result:

Hence, the mass of the moon is 7.35 x 10^{22} kg.

5.5. Calculate the value of g at a height of 3600 km above the surface of the Earth.

Solution:

Given Data:

Height above the surface of Earth = h = 3600 km = 3600 x 10^3 = 3.6 x 10^6 m
Gravitational constant = G = 6.67 x 10^{-11} N m^2 kg^{-2}
Mass of Earth = Me = 6 x 10^{24} kg

To Find:

Gravitational acceleration = g = ?

Calculations"

As we know that

$$g_h = \frac{GM_e}{(R+h)^2}$$

By putting the values, we have

$$g_h = \frac{6.67\times10^{-11}\times6\times10^{24}}{(6.4\times10^{6}+3.6\times10^{6})^2}$$

$$g_h = \frac{40.02\times10^{13}}{(10\times10^{6})^2}$$

$$g_h = \frac{40.02\times10^{13}}{1\times10^{14}}$$

$$g_h = 40.02\times10^{-1}$$

$$g_h = 4.002\text{ms}^{-2}$$

$$g_h = 4.0\text{ms}^{-2}$$

Result:

Hence, gravitational acceleration at height 3600km above the surface of the Earth will be 4.0 ms^{-2}.

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5.6. Find the value of g due to the Earth at geostationary satellite. The radius of the geostationary orbit is 48700 km.

<u>Solution</u>:

<u>Given Data</u>:

Radius of geostationary satellite = R+h =48700 km=48700 x 10^3 m=4.87 x 10^7 m
Mass of earth = Me = 6 x 10^{24} kg
Gravitational constant = R = 6.67 x 10^{-11} N m^2 kg^{-2}

<u>To Find</u>:

Gravitational acceleration = g_h = ?

<u>Calculations</u>:

As we know that

$$g_h = \frac{GM_e}{(R+h)^2}$$

By putting the values, we have

$$g_h = \frac{6.67\times10^{-11}\times6\times10^{24}}{(4.87\times10^{7})^2}$$

$$g_h = \frac{40.02\times10^{13}}{23.72\times10^{14}}$$

$$g_h = 1.68\times10^{-1}$$

$$g_h = 0.168 \text{ ms}^{-2}$$

$$g_h = 0.17 \text{ ms}^{-2}$$

<u>Result</u>:

Hence, the value of g on geostationary orbit will be 0.17 ms^{-2}.

5.7. The value of g is 4.0 ms^{-2} at a distance of 10000 km from the centre of the Earth. Find the mass of the Earth.

<u>Solution</u>:

<u>Given Data</u>:

Gravitational acceleration = g_h = 4.0 ms^{-2}
Distance from centre of Earth = R+ h = 10000 km = 10000 km = 1 x 10^7 m
Gravitational constant = G = 6.67 x 10^{-11} N m^2 kg^{-2}

<u>To Find</u>:

Mass of earth = Me = ?

<u>Calculations</u>:

As we know that

$$g_h = \frac{GM_e}{(R+h)^2}$$

By putting the values, we have

$$M_e = \frac{g_h(R+h)^2}{G}$$

$$M_e = \frac{4\times(1.0\times10^{7})^2}{6.67\times10^{-11}}$$

$$M_e = \frac{4\times10^{14}}{6.67\times10^{-11}}$$

$M = 0.599 \times 10^{25}$

$M_e = 5.99 \times 10^{24}$

$M_e = 6 \times 10^{24}$ kg

Result:

Hence, the mass of Earth is 6×10^{24} kg.

5.8. At what altitude the value of g would become one fourth than on the surface of the Earth?

Solution:

Given Data:

Gravitational acceleration = g = 10 ms^{-2}

Gravitational acceleration at height = $g_h = \frac{g}{4}$

Gravitational constant = G = 6.67×10^{-11} Nm^2kg^{-2}

Mass of earth = Me = 6×10^{24} kg

To Find:

Height of the satellite = h = ?

Calculations:

As we know that

$$g_h = \frac{GM_e}{(R+h)^2}$$

$$\frac{g}{4} = \frac{GM_e}{(R+h)^2}$$

Again we know that

$$M_e = \frac{gR^2}{G}$$

or $GM_e = gR^2$

Putting he value of GM_e in equation

$$\frac{g}{4} = \frac{gR^2}{(R+h)^2}$$

or $$\frac{1}{4} = \frac{R^2}{(R+h)^2}$$

or $$(R+h)^2 = 4R^2$$

Taking square root on both sides

$$\sqrt{(R+h)^2} = \sqrt{4R^2}$$

R+h = 2R

h = 2R – R

h = R

Result:

Hence, required altitude will be equal to one earth's radius.

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5.9. A polar satellite in launched at 850 km above Earth. Find its orbital speed. **(LHR 2014)**

Solution:

Given Data:

Height of satellite = h = 850 km

= 850 × 1000

= 8.5×10^5m

Mass of earth = Me = 6×10^{24} kg

Gravitational constant = G = 6.673×10^{-11} Nm^2 kg^{-2}

To Find:

Orbital speed of satellite = V_o = ?

Calculations:

We know that

$$V_o\sqrt{g_h(R+h)}$$

Putting the value of g_h

$$V_o = \sqrt{\frac{GM_e}{(R+h)^2}(R+h)}$$

$$V_o = \sqrt{\frac{GM_e}{R+h}}$$

$$= \sqrt{\frac{(6.673\times10^{-11})(6\times10^{24})}{6.4\times10^6+8.5\times10^5}}$$

$$= \sqrt{\frac{4.0038\times10^{14}}{7250000}}$$

$$V_o = \sqrt{55224827.59}$$

$$V_o = 7431\text{ms}^{-1}$$

Result:

Hence, the orbital speed of Polar satellite will be 7431 ms^{-1}.

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5.10. A communication satellite is launched at 42000 km above Earth. Find its orbital speed.

Solution:

Given Data:

Height of satellite = h = 42000 km = 42000 x 10^3 m = 4.2 x 10^7 m

Mass of earth = Me = 6 x 10^{24} kg

Gravitational constant = G = 6.673 x 10^{-11} Nm^2kg^{-2}

To Find:

Orbital speed of satellite = V_o = ?

Calculations:

As we know that

$$v_o = \sqrt{g_h(R+h)}$$

Putting the value of g_h

$$V_o = \sqrt{\frac{GM_e}{(R+h)^2}(R+h)}$$

$$V_o = \sqrt{\frac{GM_e}{(R+h)}}$$

By putting the values, we have

$$v_o = \sqrt{\frac{(6.673\times10^{-11})(6\times10^{24})}{6.4\times10^6+4.2\times10^7}}$$

$$v_o = \sqrt{\frac{4.0038\times10^{14}}{48400000}}$$

$$v_o = \sqrt{8272314.05}$$

v_o = 2876 ms^{-1}

Result:

Hence, the orbital speed of communication satellite will be 2876 ms^{-1}.

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SELF TEST

Time: 40 min. **Marks: 25**

Q.1 Four possible answers (A), (B), (C) & (D) to each question are given, mark the correct answer. **(6×1=6)**

1. Who gave the idea of gravity?
(A) Galileo (B) Isaac Newton
(C) Einstein (D) Faraday

2. The orbital speed of a lower orbit satellite is:
(A) 0 (B) 8 ms^{-1}
(C) 8000 ms^{-1} (D) 800 ms^{-1}

3. Value of g on the surface of the Moon in ms^{-2} is:
(A) 10 (B) 9.8
(C) 1.62 (D) 3.7

4. Speed of Geostationary satellite is:
(A) 7.9 kms^{-1} (B) 3.87 kms^{-1}
(C) 5.6 kms^{-1} (D) 5.0 kms^{-1}

5. A satellite is revolving around the earth in a circular orbit. If the radius of the orbit is increased from R to 2R. What will be its velocity?
(A) $\sqrt{2}v$ (B) v^2
(C) v/2 (D) $\frac{v}{\sqrt{2}}$

6. Earth's gravitational force of attraction vanishes at:
(A) 6400 km (B) Infinity
(C) 42300 km (D) 1000 km

Q.2 Give short answers to following questions. **(5×2=10)**

i. How value of 'g' varies with altitude? What will be the value of 'g' at height h=3R above the surface earth?
ii. Can we measure mass of the Moon? If yes, which values are required?
iii. Why we do not have to change direction of dish antennae again and again?
iv. Moon revolves around the earth, from where it gets necessary centripetal force?
v. Does an apple attract the Earth towards it?

Q.3 Answer the following questions in detail. **(4+5=9)**

a) State and explain Newton's law of gravitation.
a) A polar satellite in launched at 850 km above Earth. Find its orbital speed.

<u>Note</u>:

Parents or guardians can conduct this test in their supervision in order to check the skill of students.

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