GRAVITATION

PL - 9

INTRODUCTION

Besides developing the three laws of motion, Sir lssac Newton also examined the motion of the heavenly bodes - the planets and the moon. Newton recognized that a force of some kind must be acting on the planets to keep them in nearly circular orbits, otherwise their paths would be straight lines. A falling apple is attracted by the earth by the apple attracts the earth as well (Newton's third law of motion). Extending this idea, Newton proposed that every body in this universe attracts every other body. This led to the discovery of the famous law of universal gravitation i.e. each object in this universe attracts every other object. Note that gravitational force is attractive. Newton concluded that it was the gravitational force that acted between the sun and each of the planets to keep them in their orbits. In this chapter, we shall discuss the role of gravitational force of the earth of the objects, on or nor the surface of the earth.

(a) Gravitation or Gravitational Force :

It was Newton, who said that every object in this universe attracts every other object with a certain force. The force with which two objects attract each other is called the force of gravitation. The force of gravitation acts even if the two objects are not connected by the any means. If, however, the masses of the objects are small, the force of gravitation between them is small and cannot be detected easily.

The force of attraction between any two particles in the universe is called gravitation or gravitational force.

NEWTON'S LAW OF GRAVITATION

The magnitudes and the direction of the gravitational force between two particles are given by the universal law of gravitation, which was formulated by Newton.

Universal law of gravitation :

The gravitational force of attraction between two particles is directly proportional to the product of the masses of the particles and is inversely proportional to the square of the distance between the particles. The direction of the force is along the line joining the two particles.

Mathematical derivation :

Let A and B be two particles of mass m_1 and m_2 respectively. Let the distance AB = r. By the law of gravitation, the particle A attracts the particle B with a force F such that,

$F \propto m_1 m_2$ (for a given pair of particles)

and $F \propto \frac{1}{r^2}$ (for given separation between the particles)

So $F \propto \frac{m_1 m_2}{r^2}$

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

Here G is a constant known as the universal constant of gravitation.

(a) Universal Gravitational Constant :

(i) Introduction :

Force of gravitation between two bodies of mass m_1 and m_2 kept with distance r between their centres, is given by :

$$F = \frac{Gm_1 m_2}{r^2}$$

where constant of proportionality G is called universal gravitational constant (U.G.C.).

(ii) Definition :

In relation $F = \frac{Gm_1 m_2}{r^2}$

If $m_1 = m_2 = 1$, $r = 1$, then $F = G$ Hence, universal gravitational constant may be defined as the force of attraction between two bodies of unit mass each, when kept with their centres a unit distance apart.

(iii) Units of G:

$$F = \frac{Gm_1 m_2}{r^2}$$

We have, $G = \frac{Fr^2}{m_1 m_2}$

In S.I. $G = \frac{Nm^2}{kgkg} = Nm^2 kg^{-2}$

In C.G.S. $G = \frac{dyne\ cm^2}{g.g.} = dyne\ cm^2\ g^{-2}$

(iv) Values of G :

In S.I. $G = 6.67 \times 10^{-11}\ Nm^2\ kg^2$

In C.G.S. $G = 6.67 \times 10^{-8}$ dyne cm^2 g^{-2}

(b) Important Characteristics of Gravitational Force :

(i) Gravitational force between two bodies form an action and reaction pair i.e., the forces are equal in magnitude but opposite in direction.

(ii) Gravitational force is a central force i.e., it acts along the line joining the centres of the two interacting bodies.

(iii) Gravitational force between two bodies is independent of the nature of the intervening medium.

(iv) Gravitational force between two bodies does not depend upon the presence of other bodies.

(v) Gravitational force is negligible in case of light bodies but becomes appreciable in case of massive bodies like starts and planets.

(vi) Gravitational force is a long range force i.e., gravitational force between two bodies is effective even if their distance of separation is very large. For example, gravitational force between the sun and the earth is of the order of 10^{22} N, although distance between them is 1.5×10^8 km.

(vii) Gravitational force is a conservative force.

(c) Experimental Support for the Law of Gravitation :

(i) All the planets including the earth, rotate around the sun due to gravitational force between the sun and the planet.

(ii) Tides are formed in oceans due to gravitational force between the moon and the earth.

(iii) It is the gravitational force between the planet and its satellite which makes the satellite to move around the planet.

(iv) The atmosphere of the earth is due to the gravitational force of the earth.

NEWTON'S THRID LAW OF MOTION AND GRAVITATION

Newton's third law of motion says that : If an object exerts a force on another object, then the second object exerts an equal and opposite force on the first object. The Newton's third law of motion also holds good for the force on the earth in the opposite direction. Thus, even a falling object attracts the earth towards itself. When an object, say a stone, is dropped from a height, it gets accelerated and falls towards the earth and we say that the stone comes down due to the gravitational force of attraction exerted by the earth. Now, the stone also exerts and equal and opposite force on the earth, then why don't we see the earth rising up towards the stone.

From Newton's second law of motion, we know that :

Force = Mass × Acceleration

So, $\text{Acceleration} = \dfrac{\text{Force}}{\text{Mass}}$

or $a = \dfrac{F}{M}$

It is clear from this formula that the acceleration produced in a body is inversely proportional to the mass of the body. Now, the mass of a stone is very small, due to which the gravitational force produces a large acceleration in it. Due to large acceleration of stone, we can seen the stone falling towards the earth. The mass of earth it, however, very-very large. Due to the very large mass of the earth, the same gravitational force produces very-very small acceleration in the earth. Actually, the acceleration produced in the earth is so small that it cannot be observed. And hence we do not see the earth rising up towards the stone.

ILLUSTRATIONS

1. Two persons having mass 50kg each, are standing such that the centre of gravity are 1m apart. Calculate the force of gravitation and also calculate the force of gravity on each.

Sol. Given : $m_1 = m_2 = 50$kg.

$r = 1$m. , $G = 6.67 \times 10^{-11}$ N. m^2/kg^2

Force of gravitation $F = \frac{Gm_1m_2}{r^2}$

$$F = \frac{6.67\times10^{-11}\times50\times50}{(1)^2} = 1.67\times10^{-7}\text{ N.}$$

Force of gravity,

$F' = \frac{GMm}{r^2}$ Here r = R, radius of the earth

and $m_1 = M$ = mass of earth, $m_2 = m$ = mass of object

$$F' = \frac{6.67\times10^{-11}\times6\times10^{24}\times50}{\left(6.4\times10^6\right)^2} = 0.48\times10^3\text{ N} \quad \text{.... (ii)}$$

F′ is much greater than F so the persons will not move towards each other but each of them moves towards the earth.

ESTI MATION OF GRAVITATIONAL FORCE BETWEEN DIFFERENT OBJECTS

(a) Between Sun and Earth :

Mass of earth, $m_1 = 6 \times 10^{24}$ kg

Mass of the moon, $m_2 = 7.4 \times 10^{30}$ kg

Distance between the sun and the earth, $r = 1.5 \times 10^{11}$m

Gravitation force between the sun and the earth,

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

$$F = \frac{6.67\times10^{-11}\text{Nm}^2\text{kg}^{-2}\times6\times10^{24}\text{kg}\times2\times10^{30}\text{kg}}{\left(1.5\times10^{11}\text{m}\right)^2}$$

$F = 3.6 \times 10^{22}$ N

The gravitational force between the sun and the earth is very large (i.e. 3.6×10^{22} N). This force keeps the earth bound to the sun.

(b) Between Moon and Earth :

Mass of the earth, m1 = 6×10^{24} kg

Mass of the moon, m2 = 7.4×10^{22} kg

Distance between the earth and the moon, $r = 3.8 \times 10^8$ m

$\therefore$ Gravitational force between the earth and the moon,

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

$$F = \frac{6.67\times10^{-11}\,Nm^2kg^{-2}\times6\times10^{24}\,kg\times7.4\times10^{22}\,kg}{\left(3.8\times10^{8}\,m\right)^2}$$

$F = 2.05 \times 10^{20}$ N

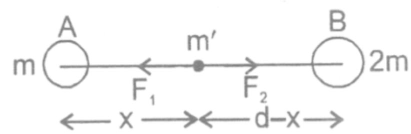
This large gravitational force keeps the moon to move around the earth. This large gravitational force is also responsible fort the ocean tides.

2. Two bodies A and B having mass m and 2m respectively are kept at a distance d apart. Where should a small particle be placed so that the net gravitational force on it due to the bodies A and B is zero ?

Sol. it is clear that the particle must be placed on the line AB, suppose it is at a distance x from A.

Let its mass is m′.

The force on m′ due to A,



$$F_1 = \frac{Gmm'}{x^2} \text{ towards A}$$

and that due to B is -

$$F_2 = \frac{G(2m)m'}{(d-x)^2} \text{ towards B.}$$

The net force will be zero if $F_1 = F_2$

Thus, $$\frac{Gmm'}{x^2} = \frac{G(2m)m'}{(d-x)^2}$$

of $(d - x)^2 = 2x^2$

$d - x = \pm\sqrt{2}\,x.$

$d = (1 \pm\sqrt{2})\,x$

$x = \dfrac{d}{\left(1+\sqrt{2}\right)}$ or $\dfrac{d}{\left(1-\sqrt{2}\right)}$

As x cannot be negative

So $x = \dfrac{d}{\left(1+\sqrt{2}\right)}$

FORCE OF GRAVITATION OF THE EARTH (GRAVITY)

Gravitation and gravity :

Attraction between two bodies having mass of same order, is called gravitation and the force is called gravitational force. Forces involved are very small and the attracting bodies do not move towards each other.

Attraction between a planet (earth) or its satellite and a body, having masses of widely different order is called gravity and the force is called force of gravity. Forces involved are large and body moves towards the planet.

Thus, gravity becomes a special case of gravitation in which small bodies move towards huge planets. Then force of gravity

$$F = \frac{GMm}{r^2}$$

EXERCISE

OBJECTIVE DPP - 9.1

1. When an apple falls from a tree :

(A) only earth attracts the apple
(B) only apple attracts the earth
(C) both the earth and the apple attract each other
(D) none attracts each other

2. Force of attraction between two bodies does not depend upon :

(A) the shape of bodies
(B) the distance between their centres
(C) the magnitude of their masses
(D) the gravitational constant

3. When the medium between two bodies changes, force of gravitation between them :

(A) will increase
(B) will decrease
(C) will change according to the environment
(D) remains same

4. S.I. unit of G is :

(A) $Nm^2\ kg^{-2}$
(B) $Nm\ kg^{-2}$
(C) $N\ kg^2\ m^{-2}$
(D) $Nkg\ m^{-2}$

5. The value of universal gravitational constant :

(A) changes with change of place
(B) does not change from place to place
(C) becomes more at night
(D) becomes more during the day

6. The value of G in S.I. unit is :

(A) 6.67×10^{-9}
(B) 6.67×10^{-10}
(C) 6.67×10^{-11}
(D) 6.67×10^{-12}

7. The gravitational force between two bodies varies with distance r as :

(A) $\frac{1}{r}$
(B) $\frac{1}{r^2}$
(C) r
(D) r^2

8. The value of G in year 1900 was $6.673 \times 10^{-11}\ Nm^2\ kg^{-2}$. They value of G in the year 2007 will be :

(A) $6.673 \times 10^{-9}\ Nm^2\ kg^{-2}$
(B) $6.673 \times 10^{-10}\ N\ m^2\ kg^2$
(C) $6.673 \times 10^{-2}\ Nm^2\ kg^{-2}$
(D) $6.673 \times 10^{-11}\ Nm^2\ kg^{-2}$

9. Value of G on surface of earth is $6.673 \times 10^{-11}\ Nm^2\ kg^{-2}$, then value of G on surface of Jupiter is :

(A) $12 \times 6.673 \times 10^{-11}\ Nm^2\ kg^{-2}$
(B) $\frac{6.673}{12} \times 10^{-10}\ Nm^2\ kg^{-2}$

(C) 6.673×10^{-11} $Nm^2 kg^{-2}$ (D) $\frac{6.673}{6} \times 10^{-11}$ $N m^2 kg^{-2}$

10. The earth attracts the moon with a gravitational force of 10^{20}N. Then the moon attracts the earth with a gravitational force of :

(A) 10^{-20}N (B) 10^2 N (C) 10^{20} N (D) 10^{10} N

11. The orbits of planets around the sun are :

(A) circular (B) parabolic (C) elliptical (D) straight

12. Law of gravitation is applicable for :

(A) heavy bodies only (B) medium sized bodies only

(C) small sized bodies only (D) bodies of any size

13. The universal law of gravitation was proposed by :

(A) Copemicus (B) Newton (C) Galileo (D) Archimedes

14. Choose the correct statement :

(A) All bodies repel each other in the universe. (B) Our earth does not behave like a magnet.

(C) Acceleration due to gravity is 8.9 ms^{-2}. (D) All bodies fall at the same rate in vacuum.

SUBJECTIVE DPP - 9.2

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1. What is the unit of gravitational constant ?

2. Which force is responsible for the earth revolving round the sun ?

3. What type of force is involved in the formation of tides in the sea ?

4. Write mathematical expression for gravitational force between two bodies of masses m_1 and m_2 separated by a distance r. All quantities are in S.I. units.

5. State the universal law of gravitation.

6. Two masses 50 kg and 100 kg are separated by a distance of 10 m. What is the gravitational force of attraction between them ? G = $6.67 \times 10^{-11} \frac{Nm^2}{kg^2}$

7. State two applications of universal law of gravitation.

8. What happens to the forces between two objects, it :

(i) The mass of the one object is doubled ?

(ii) The distance between the objects is doubled ?

(iii) The masses of both objects are doubled ?

9. (i) Name the scientist who gave the universal law of gravitation.

(ii) Define universal Gravitational constant.

(iii) What is the value of G in S.I. unit ?

10. Newton's law of gravitation states that every object exerts a gravitational force of attraction on every other object. If this is true, then why don't we notice such forces, when the two objects in a room move towards each other due to the force ?

GRAVITATION

PL - 10

BODIES FALLING NER THE SURFACE OF THE EARTH

(a) Galileo's Observations on Falling Bodies :

The speed of falling body increases as it comes down. This means that the body accelerates, when i t falls freely. Suppose we drop a coin and a feather from the same height simultaneously. Which will reach the ground first ? The answer is obvious, the coin will reach earlier than lighter feather or we can say that the heavier objects comes down more faster than lighter ones but such a generalization is not correct. If we take two slid balls of different masses, say, one of 1 kg and the other of 2kg, and drop them from the same height, we will find that they reach the ground almost simultaneously.

It is said that Galileo dropped two stones of different masses from the Leaning Tower of Pisa (in Italy) and founded that they reached the ground simultaneously. Galileo argued that the air resist on object traveling through it. If the material is dense and its surface area is small, the resistance due to air is quite small compared to the force of gravity. Thus one can neglect the effect of air resistance while studying falling stones, metallic blocks, coins etc. But the effect of air resistance is very important for small pieces of paper, feather, leaves etc. each of which ahs a large surface area and low density. When a coin and a feather fall through air, air offers greater resistance to the motion of the feather and les resistance to the motion of the coin, According to Galileo's argument, if air is totally removed, the coin and the feather will fall simultaneously.

Newton was born in the year Galileo died. Galileo died not have access to the equations for gravitational attraction and the acceleration resulting from a force. Still, he correctly predicted something from his observations that was contrary to everyday experience.

Galileo's prediction was tested by the British scientist Robert Boyle. He kept a coin and a feather in a long glass tube and evacuated the air from inside the tube by using a vacuum pump. When the tube was inverted, the coin and the feather fell together.

(b) Acceleration due to Gravity :

if we drop a ball from a height, its speed increases as time passes. If we throw a ball upwards, its speed decreases till it reached the highest point. If we throw the ball at an angle to the vertical, its direction of motion changes. In all these cases, the velocity of the ball changes, i.e., the all is accelerated, whenever an object moves near the surface of the earth with no other object pushing or pulling it, it is accelerated. This acceleration is caused due to the force of gravity and is called the acceleration due to gravity. Consider an object of mass m moving freely near the earth's surface. Neglecting air resistance, the only force on it, is due to gravity. The force has magnitude :

$$F = \frac{GM_6 m}{R_e^2} \qquad ....(i)$$

where M = mass of the earth, m = mass of the object, and R_e = radius of the earth.

As the earth's radius R_s (6400 km) is large as compared to distance of the object from the earth's surface. We use R_e in Equation (i) to denote the distance of the object from the centre of the earth. As the force given by equation (i), is the resultant force on the object, its acceleration is

$$a = \frac{F}{m} = \frac{GM_e}{R_e^2}$$

Note that this acceleration does not depends on the mass of the object. Thus we have the following

:

if gravity is the only acting force (meaning that air resistance is neglected), all objects move with the same acceleration near the earth's surface. This acceleration is called the acceleration due to gravity, whose magnitude 'g' is given by

$$g = \frac{GM_e}{R_e^2}$$

$$g = \frac{\left(6.67\times10^{-11}\ \frac{Nm^2}{kg^2}\right)\times\left(6\times10^{24}\ kg\right)}{\left(6.4\times10^{6}\ m\right)^2} = 9.8\,ms^{-2}$$

The direction of this acceleration is towards the centre of the earth, i.e., in the vertically downward direction. The acceleration has the same value, both in magnitude (9.8 m/s^2) and direction (towards centre of earth), whether the particle falls, moves up or moves at some angle with the vertical. In all these cases, we say that the particle moves freely under gravity.

(c) Value of 'g' on the Surface of the Moon :

$g = \frac{GM}{R^2}$ where M is the mass of a heavenly body like earth and R is its radius. As all heavenly bodies (like planets, the sun and the moon) are of different masses and different radii, so the value of g is different on different heavenly bodies.

We know, $$g_{moon} = \frac{GM_m}{R_m^2} \qquad .....(i)$$

M_m (mass of the moon) = 7.4 × 10^{22} kg

R_m (radius of the moon) = 1.75 × 10^6 m

G = 6.673 × 10^{-11} Nm^2 kg^{-2}

Then, from equation (i), $$g_{moon} = \frac{6.673\times10^{-11}\,Nm^2\,kg^{-2}\times7.47\times10^{22}\ kg}{\left(1.75\times10^{6}\ m\right)^2}$$

$$g_{moon} = 1.63\,ms^{-2}$$

Now, $$\frac{g_{moon}}{g_{earth}} = \frac{1.663\,ms^{-2}}{9.8\,ms^{-2}} = \frac{1}{6}$$

or $$g_{moon} = \frac{1}{6} g_{earth}$$

Thus acceleration due to gravity on the surface of moon is $\frac{1}{6}$ times the acceleration due to gravity on the surface of the earth.

MASS OF EARTH AND MEAN DENSITY OF EARTH

(a) Mass of the Earth :

The mass of the earth can be calculated by using Newton's law of gravitation. Consider a body of mass m lying on the surface of the earth, then force of gravity acting on the body is given by

$$F = \frac{GMm}{R^2} \quad .....(i)$$

where, M = mass of the earth

R = radius of the earth

Also, F = mg ....(ii)

From (i) and (ii), we have $mg = \frac{GMm}{R^2}$ or $M = \frac{gR^2}{G}$

Now g= 9.8 ms^{-2}, R = 6400 km = 6.4×10^5 m

$G = 6.67 \times 10^{-11}$ $Nm^2\,kg^{-2}$

$$M = \frac{9.8 \times \left(6.4 \times 10^6\right)^2}{6.67 \times 10^{-11}} = 5.98 \times 10^{24} \text{ kg}$$

Thus, the order of the mass of earth is 10^{25} kg

(b) Mean Density of Earth :

We know, $g = \frac{GM}{R^2}$

Let ρ be the means density of the earth. Since earth is assumed to be a homogeneous sphere of radius R, therefore, mass of the earth is given by

$$M = \text{Volume} \times \text{density} = \frac{4}{3}\pi R^3 \rho$$

Substituting this value in equation (i), we get

$$g = \frac{G}{R^2} \times \frac{4}{3}\pi R^3 \rho = \frac{4}{3}\pi G R \rho$$

$$\therefore \rho = \frac{3g}{4\pi GR}$$

Since, $g = 9.8\ ms^{-2}$, $G = 6.67 \times 10^{-11}\ N\ m^2\ kg^{-2}$, $R = 6400\ km = 6.4 \times 10^6\ m$

$$\therefore \quad \rho = \frac{3 \times 9.8}{4 \times 3.142 \times 6.67 \times 10^{-11} \times 6.4 \times 10^6} \quad \text{or} \quad \rho = 5478.4\ kgm^{-3}$$

$$\frac{\text{Density of earth}}{\text{Density of water}} = \frac{5478.4\ kg\ m^{-3}}{1000 kg\ m^{-3}} \simeq 5.5$$

Thus, density of earth is about 5.5 times the density of water.

EQUATIONS OF MOTION FOR FREELY FALLING OBJECT

Since the freely falling bodies fall with uniformly accelerated motion, the three equations of motioning derived earlier for bodies under uniform acceleration can be applied to the motion of freely falling bodies. For freely falling bodies, the acceleration due to gravity is 'g' so we replace the acceleration 'a' of the equations by 'g' and since the vertical distance of the freely falling bodies is known as height 'h', we replace the distance 's' in our equations by the height 'h'. This gives us the following modified equations for the motion of freely falling bodies.

General equations of motion		**Equations of motion for freely falling bodies**
(i) $v = u + at$	changes to	$v = u + gt$
(ii) $s = ut + \frac{1}{2}at^2$	changes to	$h = ut + \frac{1}{2}gt^2$
(iii) $v^2 = u^2 + 2as$	changes to	$v^2 = u^2 + 2gh$

We shall use these modified equations to solve numerical problems. Before we do that, we should remember the following important points for the motion of freely falling bodies.

(i) When a body is dropped freely from a height, its initial velocity 'u' becomes zero.

(ii) When a body is thrown vertically upwards, its final velocity 'v' becomes zero.

(iii) The time taken by a body to rise to the highest point is equal to the time it takes to fall from the same height.

(iv) The distance traveled by a freely falling body is directly proportional to the square of time of fall.

(a) Sign Conventions :

(i) g is taken as positive when it is acting in the same direction as that of motion and g is taken as negative

when it is opposing the motion.

(ii) Distance measured upward from the point of projection is taken as positive, while distance measured downward from the point of projection is taken as negative.

(iii) Velocity measured away from the surface of earth (i.e. in upward direction) is taken as positive, while velocity measured towards the surface of the earth is taken as negative.

OBJECTICE DPP - 10.1

1. The value of acceleration due to gravity (g) on earth's surface is :

(A) 6.67×10^{-11} Nm^2 kg^{-2} (B) 8.9 m/s^2

(C) 9.8 m/s^2 (D) none of these

2. The acceleration due to gravity :

(A) has he same value everywhere is space (B) has the same value everywhere on the earth

(C) varies with the latitude on the earth (D) is greater on moon because it has smaller diameter

3. When a space ship is at a distance of two earths radius from the centre of the earth, the gravitational acceleration is :

(A) 19.6 ms^{-2} (B) 9.8 ms^{-2} (C) 4.9 m/s^2 (D) 2.45 ms^2

4. If planet existed whose mass and radius were both half of the earth, the acceleration due to gravity at the surface would be :

(A) 19.6 m/s^2 (B) 9.8 m/s^2 (C) 4.9 ms^{-1} (C) 2.45 m/s^2

5. A stone is dropped from the top a tower. Its velocity after it has fallen 20 m is [Take g = 10 ms^{-2}]

(A) 5 ms^{-1} (B) 10 ms^{-1}

(C) 15 ms^{-1} (D) 20 ms^{-1}

6. A ball is thrown vertically upwards. The acceleration due to gravity :

(A) is the direction opposite to the direction of its motion

(B) is in the same direction as the direction of its motion

(C) increases as it comes down

(D) become zero at the higher point.

7. The acceleration due to gravity on the moon's surface is :

(A) approximately equal to that near the earth's surface

(B) approximately six times that near the earth's surface

(C) approximately one-sixth of that near the earth's surface

(D) slightly greater than that near the earth's surface

8. The force acting on a ball due to earth has a magnitude F_b and that acting on the earth due to the ball has a magnitude F_e Then :

(A) $F_b = F_e$ (B) $F_b > F_e$ (C) $F_b < F_e$ (D) $F_e = 0$

9. Force of gravitation between two bodies of mass 1 kg each kept at a distance of 1m is :

(A) 6.67 N (B) 6.67×10^{-9} N (C) 6.67×10^{-11} N (D) 6.67×10^{-7} N

10. The force of gravitation between the bodies does not depend on :

(A) their separation

(B) the product of their masses

(C) the sum of their masses

(D) the gravitational constant

11. The ratio of the value of g on the surface of moon to that on the earth's surface is :

(A) 6 (B) $\sqrt{6}$ (C) $\frac{1}{6}$ (D) $\frac{1}{\sqrt{6}}$

12. Order of magnitude of G is S.I. unit is :

(A) 10^{-11} (B) 10^{11} (C) 10^{-7} (D) 10^{7}

13. The S.I. unit of g is :

(A) m^2/s (B) m/s^2 (C) s/m^2 (D) m/s

14. If the distance between two masses be doubled then the force between them will become :

(A) $\frac{1}{4}$ times (B) 4 times (C) $\frac{1}{2}$ times (D) 2 times

15. The type of force which exists between charged bodies is :

(A) only gravitational

(B) neither gravitational nor electrical

(C) only electrical

(D) both electrical and gravitational

SUBJECTIVE DPP - 10.2

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1. What is the value of g on the surface on moon ?

2. What is average density of the earth ?

3. What is mass of he earth ?

4. What is unit of g is C.G.S. and S.I. system ?

5. The earth's gravitational force causes and acceleration of 5 ms^{-2} on a 1 kg mass somewhere in the space. How much will be the acceleration of 3 kg mass at that place ?

6. In what sense does the moon fall towards the earth ? Why does not it actually fall on earth's surface

7. What is the acceleration due to gravity at height $\frac{R}{5}$ from the surface of earth (radius R) ?

8. Using Newton's universal law of gravitation and second law of motion, find the mathematical expression for acceleration due to gravity on the surface on any planet.

9. Derive a relation for acceleration due to gravity. How its value vary with :

(i) mass of the planet (ii) Size of the planet ?

MASS AND WEIGHT

(a) Mass :

Definition :

Quantity of matter possessed by a body, is called the mass of the body. It is represented by the symbol m. It is a clear quantity.

Nature :

A body with more mass, needs a greater effort (force) to move it from rest or stopping it from motion. The body exhibits inertia. Thus, mass offers inertia. This mass is called inertial mass (m_1).

A body never has a zero mass.

Measurement of mass :

Mass of a body is measured by a beam balance by comparing the mass with bodies of known mass.

At one place, bodies of same mass have same pull of gravity on them.

A beam balance works on the principle of moments (Bodies of equal masses, having equal weights, have equal and opposite moments about fulcrum of the balance, when suspended at equal distances from the fulcrum, and made the beam horizontal).

(b) Weight :

Definition :

The force with which a body is attracted towards the centre of the earth, is called the weight of the body. It is represented by the symbol W.

It is a vector quantity having direction towards the centre of the earth.

Expression for weight :

If mass of a body = m

Acceleration due to gravity of the earth = g

Then from relation ,

Force = Mass × Acceleration   i.e., $W = mg$

This is the required expression.

Nature :

As $W = mg$, the weight of a body will vary from place to place due to variation in value of g. A body has zero weight at the centre of the earth (where $g = 0$).

Measurement of weight :

Weight of a body is measured by a spring balance.

(C) Difference between Mass and Weight :

Mass	Weight
1. Mass is quantity of matter possessed by a body?	1. Weight is the force with which a body is attracted towards the centre of the earth.
2. It is a scalar quantity.	2. It is a vector quantity.
3. Its S.I. units is kilogram (kg.)	3. Its S.I. unit is Newton (N).
4. Mass of a body remains constant at all places	4. Weight of the body changes from place to place.
5. Mass of a body is never zero.	5. Weight of a body becomes zero at the centre of the earth.
6. Mass of measured by a beam balance.	6. Weight is measured by a spring balance.

(d) Weight to object on Moon :

A body of mass m has weight, W = mg

For calculation

For earth $g_e = 9.8\ ms^{-2}$

For moon $g_m = 1.7\ ms^{-2}$

Hence,

For earth, $W_e = mg_e$

For moon $W_m = mg_m$

Ratio $\frac{W_m}{W_e} = \frac{mg_m}{mg_e} = \frac{g_m}{g_e} = \frac{1.7}{9.8} \approx \frac{1}{6}$

i.e. Weight ton moon = $\frac{1}{6}$th weight on earth.

kg. wt. is a unit of force:

From relation, W = mg

If m = 1kg W = 9.8 N

Hence a 1 kg body has weight of 9.8 N

It means that 9.8 N becomes equal to a force of 1 kilogram weight (kg. wt.)

(e) Variation in the weight of a body :

Weight of the body is given by,

W = mg

So the weight of a body depends upon (i) the mass of the body and (ii) value of acceleration due to gravity (g)at a place.

The mass of a body remains the same throughout the universe, but as the value of 'g' is different at different places. Hence, he weight of a body is different at different planes.

(i) The value of 'g' is more at poles and less at the equator. Therefore, weight of a body is more at the poles and less at the equator. In other words, a body weighs more at the poles and less at the equator.

(ii) The value of 'g' on the surfaces of different planet of the solar system is different, therefore, the weight of a body is different on different planet's

(iii) The value of 'g' decreases with height from the surface of the earth. Therefore, the weight of a body also decreases with height from the surface of the earth. That is why, the weight of a man is less on the peak of Mount Everest that the weight of the man at Delhi.

(iv) The value of 'g' decreases with depth from the surface of the earth. Therefore, the weight of a body decreases with depth from the surface of the earth.

(v) The value of 'g' at the centre of the earth is zero hence weight (=mg) of the body is zero at the centre of the earth.

DIFFERENCE BETWEEN 'g' AND 'G'

Acceleration due to gravity (g)	Universal gravitational constant (G)
1. The acceleration produced in a body falling freely under the action of gravitational pull of the earth is known as acceleration due to gravity.	1. The gravitational force between two bodies of unit masses separated by a unit distance is known as universal gravitational constant.
2. The value of 'g' is different at different points on the earth.	2. The value of 'G' is same at every point on the earth.
3. The value of 'g' decreases as we go higher from the surface of the earth or as we go deep into the earth.	3. The value of 'G' does not change with height and depth from the surface of the earth.
4. The value of 'g' at the centre of the earth is zero.	4. The value of 'G' is not zero at the centre of the earth or anywhere else.
5. The value of 'g' is different on the surface of different heavenly bodies like the sun, moon, and the planets.	5. The value of 'G' is same throughout the universe.
6. The value of 'g' on the surface of the earth is $9.8\ ms^{-2}$.	6. The value of $G = 6.673 \times 10^{-11}\ Nm^2\ kg^{-2}$ throughout the universe.

WEIGHTLESNESS

(a) Introduction :

When a man stands on weighing machine at rest, his weight compressed its spring downwards. Due to upward reaction, the pointer of the machine moves over the scale and the machine records the weight of the man.

But when the same machine starts falling down freely, there is no reaction and the pointer stays at zero recording a zero weight.

The man falling freely under the action of gravity has become weightless.

Definition :

Weightlessness may be defined as the state in which a body its weight due to free fall.

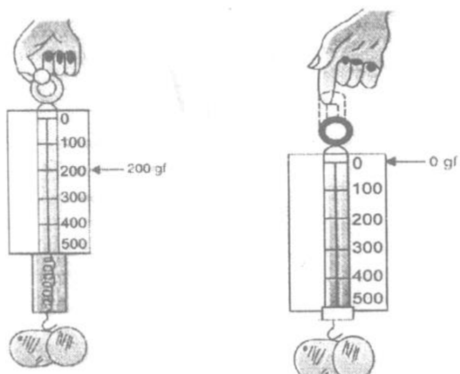
(d) Demonstration :

Let a stone piece be suspended from a spring balance suspended by a hand finger. The balance shows the actual weight of the stone.

When the balance is released from h and finger, the balance falls freely with the hanging stone piece. The balance shows a zero reading. This proves that the freely falling stone is weightless.

(i) The spring balance shows the weight of the stone.

(ii) Freely falling spring balance with the stone showing a zero reading.



Spring balance showing weight of a stone. (a)

Freely falling spring balance shows zero weight. (b)

(c) Weightlessness of an Astronaut in a Satellite (Space Ship):

A satellite is a freely falling body orbiting round the earth. It tries to reach the earth but its path being parallel to earth's surface. It does not reach the earth. Hence the satellite and all the bodies inside it become weightless.

It is due to this situation of weightlessness of astronauts that they are shown floating in spaceship in films on television.

EXERCISE

OBJECTIVE DPP - 11.1

1. The acceleration due to gravity is 9.8 m/s^2 :

(A) Much above the earth's surface (B) Near the earth's surface

(C) Deep inside the earth (D) At the centre of the earth

2. A particle is taken to a height R above the earth's surface, where R is the radius of the earth. The acceleration due to gravity there is :

(A) 2.45 m/s^2 (B) 4.9 m/s^2 (C) 9.8 m/s^2 (D) 19.6 m/s^2

3. When a body is thrown up, the force of gravity is :

(A) in upward direction (B) in downward direction

(C) zero (D) in horizontal direction

4. Mass of an object is :

(A) amount of matter present in the object (B) same as weight of an object

(C) measure of gravitational pull (D) none of these

5. The weight of an object is :

(A) the quantity of matter it contains

(B) refers to its inertia

(C) same as its mass but is expressed in different units

(D) the force with which it is attracted towards the earth

6. Weight of an object depends on:

(A) temperature of the place

(B) atmosphere of the place

(C) mass of an object

(D) none of these

7. The mass of body is measured to be 12 kg on the earth. Its mass on moon will be :

(A) 12 kg (B) 6 kg (C) 2 kg (D) 72 kg

8. A heavy stone falls :

(A) faster than a light stone

(B) slower than a light stone

(C) with same acceleration as light stone

(D) none of these

9. A stone is dropped from the roof of a building takes 4s to reach ground. The height of the building is :

(A) 19.6 m (B) 39.2 m (C) 156.8 m (D) 78.4 m

10. A ball is thrown up and attains a maximum height of 19.6 m. Its initial speed was :

(A) 9.8 ms^{-1} (B) 44.3 ms^{-1} (C) 19.6 ms^{-1} (D) 98 ms^{-1}

11. The value of g at pole is :

(A) greater than the value at the equator

(B) less than the value at the equator

(C) equal to the value of the equator

(D) none of these

12. Two bodies A and B of mass 500 g and 200 g respectively are dropped near the earth's surface. Let the acceleration of A and B be a_A and a_B respectively, then :

(A) $a_A = a_B$ (B) $a_A > a_B$ (C) $a_A < a_B$ (D) $a_A \neq a_B$

13. A body is thrown up with a velocity of 20 m/s. The maximum height attained by it is approximately :

(A) 80 m (B) 60 m (C) 40 m (D) 20 m

14. The weight of a body is 120 N on the earth. If it is taken to the moon, its weight will be about :

(A) 120 N (B) 60 N (C) 20 N (D) 720 N

15. Two iron and wooden balls identical in size are released from the same height in vacuum. The time taken by them to reach the ground are :

(A) not equal (B) exactly equal (C) regularly equal (D) zero

SUBJECTIVE DPP - 11.2

1. How does the acceleration due to gravity depends on the mass of planet ?

2. Is g vector or scalar ? Write is SI unit.

3. What is acceleration under free fall ?

4. What is the S.I. unit of mass ?

5. What is S.I. unit of weight ?

6. How many Newton's make 1 kg. wt. ?

7. Name of device to measure weight :

8. Which is greater : The force of attraction of earth for 1 kg of tin or the force of attraction of earth for 1 kg of lead.

9. The mass of the mass on the surface of earth is 100 kg. Does the weight on the surface of moon increase or decrease ? Explain.

10. A ball thrown up vertically returns to the thrower after 12 second. Find (Take g = 10 m/s) :

(i) velocity with which it was thrown up.

(ii) the maximum height it reaches.

(iii) its position after 4s