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GRAVITATION REVISION-MODULE

02

In this Chapter...

- Gravitation
- Kepler's Laws of Planetary Motion
- Free Fall
- Mass
- Weight

It has been observed that an object dropped from a height falls towards the earth. Newton generalised this idea and said that not only the earth but every object in the universe attracts every other object. This force of attraction between two objects is called the **force of gravitation** or **gravitational force**.

In this chapter, we shall learn about gravitation and universal law of gravitation.

Gravitation

It is defined as the force of attraction between any two bodies in the universe. The earth attracts (or pulls) all objects lying on or near its surface towards its centre.

The force with which the earth pulls the objects towards its centre is called the **gravitational force of the earth** or **gravity of the earth**.

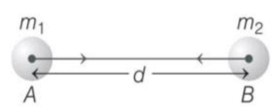
The Universal Law of Gravitation

It was given by Isaac Newton. According to this law,

"The attractive force between any two objects in the universe is directly proportional to the product of their masses and inversely proportional to the square of distance between them".

The direction of the force is along the line joining the centres of two objects.

Consider two bodies **A** and **B** having masses $\mathbf{m_1}$ and $\mathbf{m_2}$, whose centres are at a distance **d** from each other.



The gravitational force between two bodies is directed along the line joining their centres

Then, the force between two bodies is directly proportional to the product of their masses, i.e.

$$F \propto m_1 m_2 \quad \text{...(i)}$$

and the force between two bodies is inversely proportional to the square of the distance between them, i.e.

$$F \propto \frac{1}{d^2} \quad \text{...(ii)}$$

Combining Eqs. (i) and (ii), we get

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

or

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

where, $\mathbf{G = 6.67 \times 10^{-11} N\text{-}m^2/kg^2}$ is called the **universal gravitational constant.**

Its value does not depend on the medium between the two bodies and the masses of the bodies or the distance between them. Suppose the masses of two bodies are 1 kg each and the distance **d** between them is 1 m, then

$$F = G \quad (\because m_1 = m_2 = 1 \text{ kg and } d = 1 \text{ m})$$

Hence, the universal gravitational constant is defined as the gravitational force between two bodies of unit masses and separated by a unit distance from each other placed anywhere in space.

The SI unit of *G* is $\text{N-m}^2/\text{kg}^2$. The value of **G** was found out by Henry Cavendish (1731-1810) by using a sensitive balance.

Importance of Universal Law of Gravitation

The universal law of gravitation successfully explained several phenomena are given below

- The force that binds us to the earth.
- The motion of the moon around the earth.
- The motion of planets around the sun.
- The occurrence tides is due to the gravitational force of attraction of moon.
- The flow of water in rivers is also due to gravitational force of the earth on water.

Motion of Moon around Earth and Centripetal Force

The force that keeps a body moving along the circular path is acting towards the centre is called **centripetal** (centre seeking) **force**. The motion of the moon around the earth is due to the centripetal force.

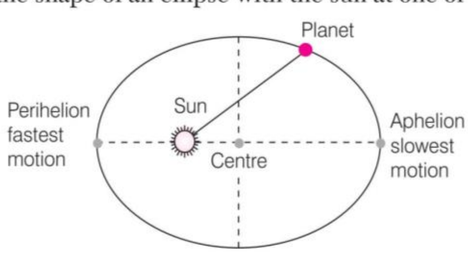
The centripetal force is provided by the gravitational force of attraction of the earth. If there were no such force, then the moon would pursue a uniform straight line motion.

Kepler's Laws of Planetary Motion

Johannes Kepler proposed three laws of planetary motion in 16th century. The three laws are given as below

Kepler's First Law

It states that the path of any planet in an orbit around the sun follows the shape of an ellipse with the sun at one of the foci.



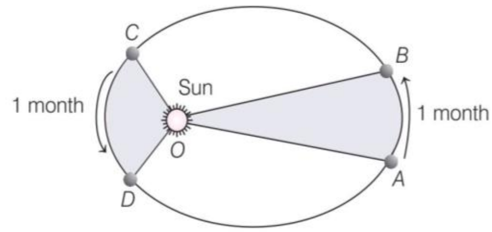
An ellipse showing Kepler's first law

The point in the orbit of a planet nearest to the sun is called **perihelion** and the point farthest from the sun is called **aphelion**.

Kepler's Second Law

It states that an imaginary line from the sun to the planet sweeps out equal areas in equal intervals of time.

Thus, if the time of travelling of a planet from *A* to *B* and from *C* to *D* is same, then the areas *AOB* and *COD* are equal.



Areas showing Kepler's second law

Kepler's Third Law

It states that the cube of the mean distance of a planet from the sun is directly proportional to the square of its orbital period *T*. It is expressed as

$$r^3 \propto T^2, \quad r^3 = k \times T^2$$

$$\boxed{k = \frac{r^3}{T^2}}$$

where, **T** = time period of the planet (around the sun),

r = radius as mean distance of the planet from the sun

and **k** = Kepler constant.

Free Fall

When objects fall towards the earth under the influence of earth's gravitational force alone, then these are called **freely falling objects** and such a motion is called **free fall.**

Acceleration due to Gravity (*g*)

Whenever an object falls towards the earth, an acceleration is involved. This acceleration is due to the earth's gravitational pull and is called acceleration due to gravity. It is denoted by **g**.

The SI unit of *g* is the same as that of acceleration, i.e. m/s^2.

Let mass of the earth be *M* and an object falling freely towards it be *m*. The distance between centres of the earth and the object is *R*.

From Newton's law of gravitation,

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

Also, from second law of motion, force exerted on an object,

$$F = ma$$

Since, **a** = **g** (i.e. acceleration due to gravity)

$$F = mg \quad \ldots(ii)$$

Equating RHS of Eqs. (i) and (ii), we get

$$mg = \frac{GMm}{R^2} \quad \text{or} \quad \boxed{g = \frac{GM}{R^2}} \quad \ldots(iii)$$

From the formula, it is clear that acceleration due to gravity does not depend on the mass of a falling object. It depends only on the mass of the earth or celestial bodies.

As distance of an object from the centre of the celestial body increases, the value of g decreases.

Earth is flattened at poles. Thus, radius of the earth is less at poles than at equator. Hence, the value of g is less at equator than at poles.

Calculation of the Value of g

To calculate the value of g, we should put the values of G, M and R in the Eq. (iii), $\mathbf{g = GM/R^2}$.

$\because$ Mass of the earth, $M = 6 \times 10^{24}$ kg

Radius of the earth, $R = 6.4 \times 10^6$ m

Universal gravitational constant, $G = 6.67 \times 10^{-11}\ \text{N-m}^2/\text{kg}^2$

$$g = \frac{GM}{R^2} = \frac{6.67 \times 10^{-11} \times 6 \times 10^{24}}{(6.4 \times 10^6)^2} = 9.8\ \text{m/s}^2$$

$$\boxed{g = 9.8\ \text{m/s}^2}$$

Equations of Motion for Free Fall

The three equations of motion which we have derived earlier is for bodies under uniform acceleration. In case of motion of bodies under free fall, there is a uniform acceleration, i.e. acceleration due to gravity (g) acting downward.

So, the three equations of motion can be applied for the motion of bodies under free fall as follows

General equations of motion	Equations for body under free fall	
$v = u + at$	$v = u + gt$	$(\because a = g)$
$s = ut + \frac{1}{2}at^2$	$h = ut + \frac{1}{2}gt^2$	$(\because a = g)$
$v^2 = u^2 + 2as$	$v^2 = u^2 + 2gh$	$(\because a = g)$

where, h is the height from which the object falls, t is the time of fall, u is the initial velocity and v is the final velocity when the body accelerates at g.

In solving numerical problems, we should remember the following points

- If an object falls vertically downwards, then acceleration due to gravity is taken as **positive,** since its velocity increases while falling.
- If an object is thrown vertically upwards, then acceleration due to gravity is taken as **negative,** since its velocity decreases as it moves upwards.

Mass

Mass is the total content of the body which measures the inertia of a body. It is a scalar quantity and its SI unit is kilogram. In other words, mass is the quantity of matter contained in a body.

Irrespective of the position of the body in the universe, mass always remains constant everywhere. The mass of the body cannot be zero.

Weight

The weight of an object is the force with which it is attracted towards the earth.

Weight of an object, $\mathbf{w = mg}$

where, $\mathbf{m}$ = mass and $\mathbf{g}$ = acceleration due to gravity

or $$w = \frac{GMm}{R^2}$$

Here, $\mathbf{M}$ = mass of the earth
and $\mathbf{R}$ = radius of the earth.

Important points regarding weight are as given below

- Weight is a vector quantity, it acts in vertically downward direction and its SI unit is newton (N). Weight of 1 kg mass is 9.8 N. (i.e. 1 kg-wt = **9.8 N**)
- Weight of an object is not constant, it changes from place-to-place.
- In the space, where $\mathbf{g = 0}$, so weight of an object is zero.
- At the centre of the earth, weight becomes zero. This is due to the fact that on going down to the earth value of g decreases and at the centre of the earth, $\mathbf{g = 0}$.

Note • It is clear that, weight of an object will change on a planet other than the earth.

• Spring balance is used to measure the weight of a body and pan balance is used to measure the mass of a body.

Weight of an Object on the Moon

Let the mass of an object be **m** and its weight on the moon be w_m. Suppose the mass of the moon is M_m and its radius be R_m. According to universal law of gravitation, the weight of an object on the moon will be

$$w_m = G\frac{M_m \times m}{R_m^2} \quad \text{...(i)}$$

Let the weight of the same object on the earth be w_e, the mass of the earth be M_e and the radius of the earth be R_e.

$$\frac{w_m}{w_e} = \frac{\dfrac{GM_m m}{R_m^2}}{\dfrac{GM_e m}{R_e^2}} = \frac{M_m}{M_e} \times \frac{R_e^2}{R_m^2}$$

Now, $M_m = 5.98 \times 10^{24}$ kg; $M_e = 7.36 \times 10^{22}$ kg

$R_m = 1.74 \times 10^6$ m; $R_e = 6.37 \times 10^6$ m

$$\therefore \quad \frac{w_m}{w_e} = \frac{5.98 \times 10^{24}}{7.36 \times 10^{22}} \times \frac{(6.37 \times 10^6)^2}{(1.74 \times 10^6)^2} \approx \frac{1}{6}$$

Thus, the weight of an object on the moon is one-sixth of its weight on the earth.

Solved Examples

Example 1. Find the gravitational force between earth and an object of 2 kg mass placed on its surface. (Take, mass of the earth, $m_e = 6 \times 10^{24}$ kg and radius of the earth, $R = 6.4 \times 10^6$ m)

Sol. Given, mass of the earth, $m_e = 6 \times 10^{24}$ kg

Mass of an object, $m_o = 2$ kg

Distance between earth and an object, i.e. radius of the earth, $R = 6.4 \times 10^6$ m

From universal law of gravitation,

$$F = G\frac{m_e m_o}{R^2}$$

$$\therefore \quad F = \frac{6.67 \times 10^{-11} \times 6 \times 10^{24} \times 2}{(6.4 \times 10^6)^2} = 19.5 \text{ N}$$

Example 2. The mass of the mars is 6.39×10^{23} kg and that of the jupiter is 1.89×10^{27} kg. If the distance between mars and jupiter is 7.49×10^5 m, calculate the force exerted by the jupiter on the mars. (Take, $G = 6.7 \times 10^{-11}$ N-m^{2}kg^{-2})

Sol. Given, mass of the mars, $M_m = 6.39 \times 10^{23}$ kg

Mass of the jupiter, $M_j = 1.89 \times 10^{27}$ kg

Distance between the mars and jupiter,

$$d = 7.49 \times 10^5 \text{ m}$$

Gravitational constant, $G = 6.7 \times 10^{-11}$ N-m^2/kg^2

The force exerted by the jupiter on the mars,

$$F = G\frac{M_m \times M_j}{d^2}$$

$$= \frac{6.7 \times 10^{-11} \times 6.39 \times 10^{23} \times 1.89 \times 10^{27}}{(7.49 \times 10^5)^2}$$

$$= 1.44 \times 10^{29} \text{ N}$$

Thus, the force exerted by the jupiter on the mars is 1.44×10^{29} N.

Example 3. A car falls off a ledge and drops to the ground in 0.6 s. The value of g is 10 m/s^2 (for simplifying the calculation).

(i) What is its speed on striking the ground?

(ii) What is its average speed during the 0.6 s?

(iii) How high is the ledge from the ground?

Sol. Given, initial velocity, $u = 0$,

Acceleration due to gravity, $g = 10$ m/s^2,

Time, $t = 0.6$ s

(i) Speed, $v = u + gt$

$$v = 0 + 10 \times 0.6$$

$$v = 6 \text{ m/s}$$

(ii) Average speed $= \frac{u + v}{2} = \left(\frac{0 + 6}{2}\right) = 3.0$ m/s

(iii) Distance travelled, $h = ut + \frac{1}{2}gt^2$

$$h = 0 + \frac{1}{2} \times 10 \times (0.6)^2$$

$$= 5 \times 0.36 = 1.80 \text{ m}$$

Example 4. An object is thrown vertically upwards and rises to a height of 13.07 m.

Calculate

(i) the velocity with which the object was thrown upwards and

(ii) the time taken by the object to reach the highest point.

Sol. Given, distance travelled, $h = 13.07$ m

Final velocity, $v = 0$

Acceleration due to gravity $g = -9.8$ m/s^2 (upward motion)

(i) $v^2 = u^2 + 2gh \Rightarrow 0 = u^2 + 2 \times (-9.8) \times 13.07$

$$u^2 = 256 \Rightarrow u = 16 \text{ m/s}$$

(ii) $v = u + at \Rightarrow 0 = 16 - 9.8 \times t \Rightarrow t = 1.63$ s

Example 5. A ball is thrown vertically upwards with a velocity of 25 m/s. If g is 10 m/s^2, then calculate

(i) height it reaches and (ii) time taken to return back.

Sol. Given, initial velocity, $u = 25$ m/s and final velocity, $v = 0$.

If a body is thrown upwards, then its velocity becomes zero at the highest point, where it reaches, acceleration due to gravity, $g = -10$ m/s^2

(i) $\therefore$ Height, $h = \frac{v^2 - u^2}{2g}$

$$= \frac{0 - (25)^2}{2(-10)} = \frac{-625}{-20} = 31.25 \text{ m}$$

(ii) $\therefore$ Time, $t = \frac{v - u}{g} = \frac{0 - 25}{-10} = 2.5$s

Time taken to return back,

T = Time of ascent + Time of descent $= 2t$

Time taken to return back, $T = 2 \times 2.5 = 5$ s

Example 6. Mass of an object is 12 kg. Calculate
(i) its weight on the earth and (ii) its weight on the moon.

Sol. Given, mass of an object, $m = 12$ kg

(i) Acceleration due to gravity on earth, $g_e = 9.8\ m/s^2$

Weight on the earth, $w_e = mg_e = 12 \times 9.8 = 117.6$ N

(ii) Acceleration due to gravity on moon, $g_m = \frac{g_e}{6}$

$$g_m = \frac{9.8}{6}\ m/s^2$$

Weight on the moon, $w_m = mg_m = 12 \times \frac{9.8}{6} = 9.8 \times 2 = 19.6$ N

Example 7. A man weighs 600 N on the earth. What is his mass, if g is $10\ m/s^2$? On the moon, his weight would be 100 N. What is the acceleration due to gravity on the moon?

Sol. Given, weight of man on the earth, $w_e = 600$ N

Acceleration due to gravity on the earth, $g_e = 10\ m/s^2$

Weight of man on the moon, $w_m = 100$ N

As we know, mass of the man, $m = \frac{w_e}{g_e} = \frac{600}{10} = 60$ kg

$$\Rightarrow \quad g_e = \frac{w_e}{m}$$

Similarly, for the moon, $g_m = \frac{w_m}{m} = \frac{100}{60} = 1.66\ m/s^2$

Thus, acceleration due to gravity on the moon is $1.66\ m/s^2$, i.e. $g_m = \frac{g_e}{6}$.

Example 8. A particle weighs 120 N on the surface of the earth. At what height above the earth's surface will its weight be 30 N? (Take, radius of the earth = 6400 km)

Sol. Given, weight of particle on the surface of earth, $w = 120$ N

Weight of particle at height **h** above the earth's surface,
$w_1 = 30$ N

The weight of a particle on the surface of the earth,

$$w = mg = \frac{mGM}{R^2} \qquad \left(\because g = \frac{GM}{R^2}\right)$$

Let w_1 be the weight of a particle at height h above the earth's surface.

So,
$$\frac{w}{w_1} = \frac{G\frac{M}{R^2}}{G\frac{M}{(R+h)^2}} = \frac{(R+h)^2}{R^2}$$

Substituting given values, we get

$$\Rightarrow \quad \frac{120}{30} = \left(\frac{R+h}{R}\right)^2$$

$$\Rightarrow \quad 4 = \left(\frac{R+h}{R}\right)^2$$

$$\Rightarrow \quad 2 = \frac{R+h}{R}$$

$$\Rightarrow \quad 2R = R + h$$

$$\Rightarrow \quad R = h$$

$\therefore$ Height of the particle, h = Radius of the earth

$$\Rightarrow \quad h = 6400 \text{ km}$$

Chapter Practice

PART 1

Objective Questions

• Multiple Choice Questions

1. The value of G was first determined experimentally by

(a) Newton (b) Henry Cavendish
(c) Galileo (d) Kepler

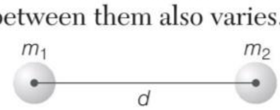
2. Law of gravitation gives the gravitational force between **(NCERT Exemplar)**

(a) the earth and a point mass only
(b) the earth and the sun only
(c) any two bodies having some mass
(d) two charged bodies only

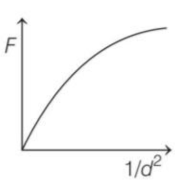
3. The value of quantity G in the law of gravitation

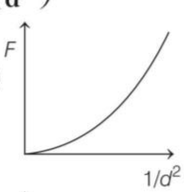
(a) depends on mass of the earth only **(NCERT Exemplar)**
(b) depends on radius of earth only
(c) depends on both mass and radius of the earth
(d) is independent of mass and radius of the earth

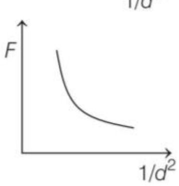
4. According to Newton's law of gravitation, if the distance between the masses is varied, the force of attraction between them also varies.

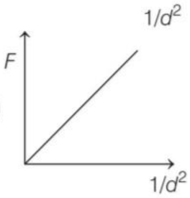


Which of the following graphs best represents the variation between F and $\left(\frac{1}{d^2}\right)$?

(a)


(b)


(c)


(d)


5. Which of the following is not true for universal law of gravitation?

(a) It is the gravitational force between the sun and the earth, which makes the earth move around the sun.
(b) The tides formed in sea are because of gravitational pull exerted by the sun and the moon on the surface of water.
(c) It is the gravitational pull of the earth which keeps us and other bodies firmly on the ground.
(d) The gravitational force exerted by sun on earth is larger than that exerted by earth on sun.

6. The value of gravitational acceleration g is

(a) highest at poles (b) highest at equator
(c) lowest at poles (d) lowest at equator

7. An apple falls towards the earth because the earth attracts it and the apple also attracts the earth by same force. Why do we not see the earth rising towards the apple?

(a) Acceleration of the earth is very large when compared to that of apple.
(b) Acceleration of the earth is equal to that of apple.
(c) Acceleration of the earth is neither high nor too low.
(d) Acceleration of the earth is very small when compared to that of apple.

8. A car falls off a ledge and drops to the ground in 0.9 s. If the value of **g** is 10 m/s^2, then speed of car on striking the ground is

(a) 6 m/s (b) 8 m/s (c) 9 m/s (d) 18 m/s

9. An object is thrown vertically upwards and rises to a height of 20 m, then the velocity with which the object was thrown upwards is (Take, $\mathbf{g} = \mathbf{10}$ m/s^2)

(a) 15 m/s (b) 25 m/s
(c) 10 m/s (d) 20 m/s

10. The value of acceleration due to gravity at the Mount Everest is

(a) g (b) $> g$ (c) $< g$ (d) zero

11. The atmosphere is held to the earth by

(a) earth's magnetic field
(b) earth's rotation
(c) gravity
(d) earth's electric field

12. The magnitude of weight of a body at the centre of earth is
(a) zero
(b) equal to mass of the body
(c) greater than g
(d) less than g

13. Two objects of different masses falling freely near the surface of moon would **(NCERT Exemplar)**
(a) have same velocities at any instant
(b) have different accelerations
(c) experience forces of same magnitude
(d) undergo a change in their inertia

14. When you put an object on a spring balance .... will be measured.
(a) mass (b) acceleration (c) force (d) weight

15. Match the following Columns.

Column I	Column II
A. Escape velocity	1. $1.67\ \text{ms}^{-2}$
B. Gravitational constant, **G**	2. $9.8\ \text{ms}^{-2}$
C. Acceleration due to gravity of earth, g_{earth}	3. $6.67\times 10^{11}\ \text{N-m}^2\text{kg}^{-2}$
D. Acceleration due to gravity of moon, g_{moon}	4. 11.2 km/s

Codes

	A	B	C	D
(a)	4	3	2	1
(b)	1	2	3	4
(c)	2	1	3	4
(d)	4	3	1	2

• Assertion-Reasoning MCQs

Direction (Q. Nos. 16-20) Each of these questions contains two statements Assertion (A) and Reason (R). Each of these questions also has four alternative choices, any one of which is the correct answer. You have to select one of the codes (a), (b), (c) and (d) given below.
(a) Both A and R are true and R is the correct explanation of A
(b) Both A and R are true, but R is not the correct explanation of A
(c) A is true, but R is false
(d) A is false, but R is true

16. Assertion Gravitational force between two masses in air is F. If they are immersed in water, force will remain F.
Reason Gravitational force does not depend on the medium between the masses.

17. Assertion The measurement of G by Cavendish's experiment, combined with the knowledge of g and R_E enables one to estimate M_E.
Reason By Newton's second law, the value of **g** is given by the relation, $g = \dfrac{GM_E}{R_E^2}$

18. Assertion The moon revolves around the earth due to gravitational force between moon and earth.
Reason Gravitational force between moon and earth is calculated by Newton's law of gravitation.

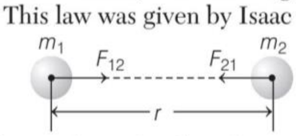
19. Assertion An object is weightless when it is in free fall and this phenomenon is called weightlessness.
Reason In free fall, there is no upward force acting on the object.

20. Assertion At the centre of earth, a body has no centre of gravity.
Reason This is because, $g = 0$ at the centre of earth.

• Case Based MCQs

21. Read the following and answer the questions from (i) to (v) given below

Universal Law of Gravitation
Each mass particle of universe attracts the other mass particle. The force of attraction between two particles because of their masses, is called the gravitational force of attraction. This law was given by Isaac Newton.



In figure shown above, let there be two particles of masses m_1 and m_2 at a separation r. According to this law, the force of attraction acting between them is dependent on both the masses and also on the distance of separation.

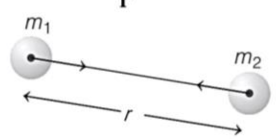
(i) The force of attraction between two unit point masses separated by a unit distance is called **(NCERT Exemplar)**
(a) gravitational potential
(b) acceleration due to gravity
(c) gravitational field
(d) universal gravitational constant

(ii) In the relation $F = Gm_1m_2/r^2$, the quantity **G** **(NCERT Exemplar)**
(a) depends on the value of g at the place of observation
(b) is used only when the earth is one of the two masses
(c) is greatest at the surface of the earth
(d) is universal constant of nature

(iii) If mass of a planet is 2% of mass of earth, then the ratio of gravitational pull of earth on the planet and that of planet on earth will be
(a) **1 : 20** (b) **2 : 5** (c) **1 : 1** (d) **1 : 50**

(iv) Two equal point masses are separated by a distance d_1. The force of gravitation acting between them is F_1. If the separation is decreased to d_2, then the new force of gravitation F_2 is given by
(a) $F_2 = F_1$
(b) $F_2 = F_1\left(\dfrac{d_1}{d_2}\right)^2$
(c) $F_2 = F_1\left(\dfrac{d_2}{d_1}\right)^2$
(d) $F_2 = F_1\left(\dfrac{d_1}{d_2}\right)$

(v) According to Newton's law of gravitation, the magnitude of the force **F** on point masses $\mathbf{m_1}$ and $\mathbf{m_2}$ is given by $|\mathbf{F}| = \dfrac{\mathbf{Gm_1m_2}}{\mathbf{r^2}}$



Which of the following statement(s) about this equation is/are correct?

I. This equation is not directly applicable for the gravitational force between extended object (like the earth) and a point mass.

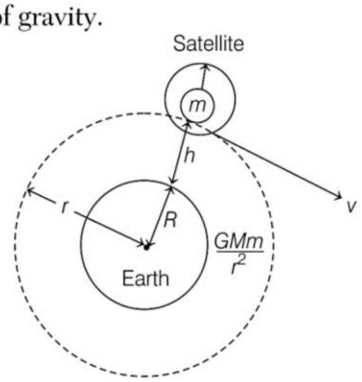
II. This equation can be directly applied for gravitational force between an extended object and a point mass.

III. This equation can be applied to find the gravitational force between an extended object and a point mass.

(a) Only I (b) Both I and II
(c) Only II (d) Both II and III

22. Read the following and answer the questions from (i) to (v) given below

Weightlessness in a Satellite
A satellite which does not produce its own gravity moves around the earth in a circular orbit under the action of gravity.



The acceleration of satellite is $\dfrac{\mathbf{GM}}{\mathbf{r^2}}$ towards the centre of the earth as shown in figure. If a body of mass **m** is placed on the surface inside a satellite moving around the earth, then forces applied on the body are the gravitational pull of earth and the reaction force by the surface. Using, Newton's law, the reaction force exerted on the surface becomes zero.

(i) Astronauts inside spaceship feel
(a) zero weight (b) more acceleration
(c) less weight (d) None of these

(ii) In the weightlessness state, bodies have
(a) no weight, no inertia (b) weight and inertia
(c) no weight, but possess inertia
(d) weight, but don't possess inertia

(iii) The mass of an astronaut in a space satellite, if at earth's surface the astronaut weighs 250 N is
(a) 20 kg (b) 5 kg (c) 25 kg (d) 30 kg

(iv) An astronaut experiences weightlessness in a space satellite. It is because
(a) gravitational force is large at that location in space
(b) gravitational force is small at that location in space
(c) astronaut experiences no gravity
(d) gravitational force is infinitely large at that location in space

(v) A person sitting in a chair inside the satellite feels weightlessness as
(a) the earth does not attract the objects in a satellite
(b) the normal force by the chair on the person balances the earth's attraction
(c) the normal force is zero
(d) the person in the satellite is not accelerated

PART 2

Subjective Questions

• Short Answer Type Questions

1. State the universal law of gravitation. **(NCERT)**

2. Write the formula for magnitude of gravitational force between the earth and an object on the surface of the earth. **(NCERT)**

3. How does the force of gravitation between two objects change, when distance between them is reduced to half?

4. What is the importance of universal law of gravitation?

5. If the distance between masses of two objects is increased by five times, by what factor would the mass of one of them have to be changed to maintain the same gravitational force? Would there be an increase or a decrease in the same?

6. Calculate the force of gravitation between the earth and the sun. The average distance between the two is $\mathbf{1.5 \times 10^{11}}$ m. (Take, the mass of the earth $= \mathbf{6 \times 10^{24}}$ kg and of the sun $= \mathbf{2 \times 10^{30}}$ kg). **(NCERT)**

7. What is the magnitude of the gravitational force between the earth and a 1 kg object on its surface? (Take, mass of the earth $= \mathbf{6 \times 10^{24}}$ kg and radius of the earth $= \mathbf{6.4 \times 10^6}$ m) **(NCERT)**

8. The earth and the moon are attracted to each other by gravitational force. Does the earth attract the moon with a force that is greater than or smaller than or equal to the force with which the moon attracts the earth? Why? **(NCERT)**

9. How does the force of attraction between the two bodies depend upon their masses and distance between them? A student thought that two bricks tied together would fall faster than a single one under the action of gravity. Do you agree with his hypothesis or not? Comment. **(NCERT Exemplar)**

10. A body weighs 25 kg on the surface of the earth. If the mass of the earth is 6×10^{24} kg, then the radius of the earth is 6.4×10^{6} m and the gravitational constant is 6.67×10^{-11} N-m^2/kg^2.

Calculate

(i) the mutual force of attraction between the body and the earth.

(ii) the acceleration produced in the body.

(iii) the acceleration produced in the earth.

11. Two bodies of masses 3 kg and 12 kg are placed at a distance 12 m. A third body of mass 0.5 kg is to be placed at such a point that the force acting on this body is zero. Find the position of that point.

12. What do you mean by free fall? **(NCERT)**

13. What do you mean by acceleration due to gravity? **(NCERT)**

14. Gravitational force acts on all objects in proportion to their masses. Why a heavy object does not fall faster than a light object? **(NCERT)**

15. A stone is released from the top of a tower of height 19.6 m. Calculate its final velocity just before touching the ground. **(NCERT)**

16. On the earth, a stone is thrown from a height in a direction parallel to the earth's surface while another stone is simultaneously dropped from the same height. Which stone would reach the ground first and why? **(NCERT Exemplar)**

17. A ball is thrown with some speed u m/s. Show that under the free fall, it will fall on the ground with same speed.

18. Identical packets are dropped from two aeroplanes, one above the equator and the other above the north pole, both at height **h**. Assuming all conditions are identical, will those packets take same time to reach the surface of earth? Justify your answer. **(NCERT Exemplar)**

19. A firecracker is fired and it rises to a height of 1000 m. Find the

(i) velocity by which it was released and

(ii) time taken by it to reach the highest point. (Take, $g = 9.8$ m/s^2)

20. What is the difference between the mass of an object and its weight?

21. Why is the weight of an object on the moon (1/6)th of its weight on the earth? **(NCERT)**

22. The weight of any person on the moon is about $\frac{1}{6}$ times that on the earth. He can lift a mass of 15 kg on the earth. What will be the maximum mass which can be lifted by the same force applied by the person on the moon? **(NCERT Exemplar)**

23. Gravitational force on the surface of the moon is only $(1/6)$th as strong as gravitational force on the earth. What is the weight (in N) of a 10 kg object on the moon and on the earth? **(NCERT)**

24. Amit buys few grams of gold at the poles as per the instruction of one of his friends. He hands over the same, when he meets him at the equator. Will the friend agree with the weight of gold bought? If not, why?

• Long Answer Type Questions

25. (i) Write the formula to find the magnitude of gravitational force between the earth and an object on the earth's surface.

(ii) Derive how does the value of gravitational force **F** between two objects change, when

(a) distance between them is reduced to half.

(b) mass of an object is increased four times.

26. (i) At some moment, two giant planets jupiter and saturn of the solar system are in the same line as seen from the earth. Find the total gravitational force due to them on a person of mass 50 kg on the earth. Could the force due to the planets be important?

(Take, mass of the jupiter $= 2 \times 10^{27}$ kg,

Mass of the saturn $= 6 \times 10^{26}$ kg,

Distance of jupiter from the earth $= 6.3 \times 10^{11}$ m,

Distance of saturn from the earth $= 1.28 \times 10^{12}$ m,

Gravitational constant, $G = 6.67 \times 10^{-11}$ N-m^2/kg^2

and acceleration due to gravity on the earth $= 9.8$ m/s^2.

(ii) A bag of sugar weighs w at a certain place on the equator. If this bag is taken to Antarctica, then will it weigh the same or more or less? Give a reason for your answer.

27. (i) Prove that, if the earth attracts two bodies placed at the same distance from the centre of the earth with equal force, then their masses will be the same.

(ii) Mathematically express the acceleration due to gravity in terms of mass of the earth and radius of the earth.

(iii) Why is G called a universal constant?

28. A ball thrown up vertically returns to the thrower after 6 s, find

(i) the velocity with which it was thrown up,

(ii) the maximum height it reaches and

(iii) its position after 4 s.

29. A stone is dropped from the edge of a roof.

(i) How long does it take to fall 4.9 m?

(ii) How fast does it move at the end of that fall?

(iii) How fast does it move at the end of 7.9 m?

(iv) What is its acceleration after 1 s and after 2 s?

30. Two objects of masses $\mathbf{m_1}$ and $\mathbf{m_2}$ having the same size are dropped simultaneously from heights $\mathbf{h_1}$ and $\mathbf{h_2}$, respectively. Find out the ratio of time they would take in reaching the ground.

Will this ratio remain the same if (i) one of the objects is hollow and the another one is solid and (ii) both of them are hollow, size remaining the same in each case? Give reason. **(NCERT Exemplar)**

31. The radius of the earth at the poles is 6357 km and the radius at the equator is 6378 km. Calculate the percentage change in the weight of a body, when it is taken from the equator to the poles.

32. (i) A person weighs 110.84 N on the moon, whose acceleration due to gravity is (1/6)th of that the earth. If the value of g on the earth is 9.8 m/s^2, then calculate

(a) g on the moon,

(b) mass of person on the moon and

(c) weight of person on the earth.

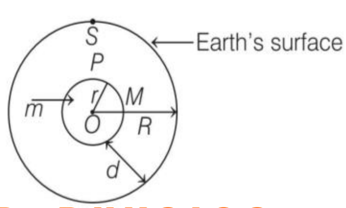
(ii) How does the value of g on the earth is related to the mass of the earth and its radius? Derive it.

• Case Based Questions

33. Read the following and answer the questions from (i) to (v) given below

Consider the earth to be made up of concentric shells and a point mass **m** situated at a distance **r** from the centre.

The point P lies outside the sphere of radius **r** and point **P** lies inside, if the shell's radius is greater than **r**. The smaller sphere exerts a force on a mass **m** at **P**, as if its mass $\mathbf{m_r}$ is concentrated at the centre.



Variation in acceleration due to gravity

I.	At the surface of earth	$g = \frac{GM}{R^2}$
II.	Effect of altitude	$g_h = \frac{g}{\left(1+\frac{h}{R}\right)^2}$
III.	Effect of depth	$g_d = g\left(1-\frac{d}{R}\right)$

where,

$\mathbf{g}$ = acceleration due to gravity,

$\mathbf{g_h}$ = acceleration due to gravity at height **h** above the surface of earth,

$\mathbf{g_d}$ = acceleration due to gravity at depth **d**,

M = mass of earth = $\mathbf{6 \times 10^{24}}$ kg

and **R** = radius of earth = $\mathbf{6.4 \times 10^6}$ m.

(i) From the given table, what conclusion can you derive?

(ii) Calculate the value of **g** using formula I, given in table.

(iii) What is the value of acceleration due to gravity at point **O** (in given figure)?

(iv) As we increase the value of **h** in formula II given in table, what will be the effect on acceleration due to gravity of earth?

(v) If a person starts digging and reaches at a depth $\frac{R}{2}$ from the surface, then find the value of acceleration due to gravity at a depth $\frac{R}{2}$.

34. Read the following and answer the questions from (i) to (v) given below

The universe has many forces that include our daily pushes and pulls. We are always pushing or pulling something, even if we stand still on the ground. But it truns out that in physics, there are only four fundamental forces are present from which everything else is derived. These are the strong force, the weak force, the electromagnetic force and the gravitational force. The gravitational force is a force that attracts any two objects which has some mass.

(i) When do we use the term force of gravity rather than force of gravitation?

(ii) Which force brings tides in the ocean?

(iii) Which force keeps the moon in a uniform circular motion around the earth?

(iv) Two objects kept in a room do not move towards each other as per the universal law of gravitation. Why?

(v) The earth is acted upon by gravitation of the sun even, then it does not fall into the sun. Why?

EXPLANATIONS

Objective Questions

1. (*b*) Henry Cavendish was the scientist who first determined the value of *G* experimentally.

2. (*c*) Law of gravitation is applicable to all bodies having some mass and is given by $\mathbf{F}=\frac{\mathbf{Gm_1m_2}}{\mathbf{r^2}}$

   where, $\mathbf{F}$ = force of attraction between the two bodies,
   $\mathbf{m_1}$ **and** $\mathbf{m_2}$ = masses of two bodies,
   $\mathbf{G}$ = gravitational constant
   and $\mathbf{r}$ = distance between the two bodies.

3. (*d*) **G** is the constant of proportionality and is called the universal gravitational constant. It is independent of mass and radius of the earth.

4. (*d*) According to Newton's law of gravitation,
$$F=\frac{Gm_1m_2}{d^2}$$
$$\Rightarrow \quad F\propto\frac{1}{d^2}$$
   Force between them directly depends on $\frac{1}{d^2}$, so, it will represent a straight line in the graph.

5. (*d*) According to Newton's law of gravitation, any two bodies in the universe attract each other with a force. i.e. force is directly proportional to the product of their masses and inversely proportional to square of distance between them.

   As, $$F\propto\frac{m_1m_2}{r^2}$$
$$\Rightarrow \quad F\propto\frac{1}{r^2}$$
   where $\mathbf{m_1}$, $\mathbf{m_2}$ are masses and **r** is the distance.
   Hence, gravitational force exerted by earth is exactly equal to that exerted by earth on sun.

6. (*a*) Gravitational acceleration *g* is given by $\mathbf{g}=\frac{\mathbf{Gm_e}}{\mathbf{R_e^2}}$

   where, **G** is gravitational constant, $\mathbf{m_e}$ is mass of earth and $\mathbf{R_e}$ is radius of earth.

   Since, radius of earth at equator is greater than poles, hence value of *g* at poles is greater than equator.

7. (*d*) As we know, acceleration $(\mathbf{a})=\frac{\text{force (f)}}{\text{mass (m)}}$ such that,

   acceleration is inversely proportional to the mass of the object. Since, the mass of earth is very large as compared to that of the apple.

   Therefore, acceleration of the earth is very small when compared to that of the apple.

8. (*c*) Initial velocity, $\mathbf{u}=\mathbf{0}$
   Acceleration due to gravity, $\mathbf{g}=10\ \text{m/s}^2$
   ∵ If v be the speed of car on striking the ground, then
$$v=u+gt$$
$$=0+10\times0.9=9\ \text{m/s}$$

9. (*d*) Given, height, $\mathbf{h}=\mathbf{20}$ m and $\mathbf{g}=\mathbf{10}\ \text{m/s}^2$
   At highest point, final velocity, $\mathbf{v}=\mathbf{0}$
   ∴ From equation of motion,
$$v^2=u^2-2gh$$
$$0=u^2-2\times10\times20$$
   Initial velocity, $\quad u=\sqrt{400}=20\ \text{m/s}$
   Thus, object was thrown upwards with velocity 20 m/s.

10. (*c*) We know that when, we go above the surface of earth, the value of acceleration due to gravity will decrease. Hence, the value of acceleration due to gravity at the Mount Everest is less than *g*.

11. (*c*) The atmosphere is held to the earth by gravity.

12. (*a*) The value of gravitational acceleration *g* at the centre is zero, hence weight, $\mathbf{w}=\mathbf{mg}=\mathbf{m}\times\mathbf{0}=\mathbf{0}$.

13. (*a*) Objects of different masses falling freely near the surface of the moon would have the same velocities at any instant because they will have same acceleration due to gravity.

14. (*d*) A spring balance measures the weight of an object by opposing the force of gravity acting with the force of an extended spring.

15. (*a*) (A) → (4); Escape velocity on earth is given by
$$v_{escape}=\sqrt{\frac{2GM}{r}}=11.2\ \text{km/s}$$
   (B) → (3); Value of gravitational constant,
$$G=6.67\times10^{11}\ \text{N-m}^2\ \text{kg}^{-2}$$
   (C) → (2); Acceleration due to gravity of earth,
$$g_{earth}=9.8\ \text{ms}^{-2}$$
   (D) → (1); Acceleration due to gravity on the moon is $(1/6)$th that of earth, $g_m=\frac{g_e}{6}=\frac{10}{6}\ \text{ms}^{-2}=1.67\ \text{ms}^{-2}$
   Hence, (A) → (4), (B) → (3), (C) → (2), (D) → (1)

16. (*a*) Gravitational force is given by
$$F=\frac{GMm}{r^2}$$
   where **M**, **m** are masses of bodies and **F** is force of gravitation between two bodies and depends on universal gravitational constant **G**.
   The value of **G** remains constant and does not depend upon medium.
   So, the gravitational force in both mediums (air and water) would be equal.
   Thus, both A and R are true and R is the correct explanation of A.

17. (*a*) Henry-Cavendish experiment helped to determine the value of G ($\mathbf{G}=\mathbf{6.67}\times\mathbf{10^{-11}}\ \text{N-m}^2\ \text{kg}^{-2}$)
   From the value of *g* (acceleration due to gravity on the surface of the earth) and $\mathbf{R_E}$ (radius of the earth) using the relation $\mathbf{g}=\frac{\mathbf{GM_E}}{\mathbf{R_E^2}}$ the mass of the earth ($\mathbf{M_E}$) can be estimated

$$\Rightarrow \quad M_E = \frac{gR_E^2}{G}$$

where, $g = 9.8\ ms^{-2}$

$R_E = 6400 \times 10^3\ m$

and $G = 6.67 \times 10^{-11}\ N\text{-}m^2/kg$

Thus, A and R are true and R is the correct explanation of A.

18. (*b*) Moon revolves around the sun and centripetal force is obtained from gravitational force between moon and earth.

i.e. Gravitational force = Centripetal force

Thus, both A and R are true but R is not the correct explanation of A.

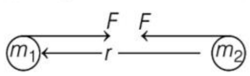
19. (*a*) An object is weightless when it is in free fall as during free fall, there is no upward force acting on the body and this phenomenon is called weightlessness.

Thus, A and R are true and R is the correct explanation of A.

20. (*a*) At the centre of earth, acceleration due to gravity, $g = 0$, i.e. a body has no weight and hence no centre of gravity.

Thus, both A and R are true and R is the correct explanation of A.

21. (i) (*d*) We know that, the gravitational force, $F = G\frac{m_1 m_2}{r^2}$



where, F = force between masses,

m_1 and m_2 = mass of the body,

G = gravitational constant,

and r = distance between two masses.

Given, $m_1 = 1$ unit, $m_2 = 1$ unit and $r = 1$ unit, we get

$$F = G\frac{1 \times 1}{(1)^2}$$

$$\Rightarrow \quad F = G$$

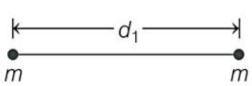
Therefore, the force of attraction between two unit point masses separated by a unit distance is called universal gravitational constant.

(ii) (*d*) The quantity **G** is universal constant of nature. It is applied to all the body present in universe. It is constant of proportionality in Newton's universal law of gravitation.

The accepted value of **G** is $6.67 \times 10^{-11}\ N\text{-}m^2kg^{-2}$.

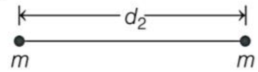
(iii) (*c*) The gravitational forces are mutually equal and opposite, hence the ratio of gravitational pull of the earth on the planet and that of planet on the earth will be **1 : 1**.

(iv) (*b*) From Newton's law of gravitation, the two equal point masses are separated by a distance d_1 are shown below



$$\text{Gravitational force, } F_1 = \frac{Gm \cdot m}{d_1^2} = \frac{Gm^2}{d_1^2} \quad \text{...(i)}$$

Similarly,



$$F_2 = \frac{Gm^2}{d_2^2} \quad \text{...(ii)}$$

On dividing Eq. (i) by Eq. (ii), we get

$$\frac{F_1}{F_2} = \left(\frac{d_2}{d_1}\right)^2$$

$$\therefore \quad F_2 = F_1\left(\frac{d_1}{d_2}\right)^2$$

(v) (*a*) For the gravitational force between an extended object (like the earth) and a point mass, the Newton's universal law of gravitation is not directly applicable.

So, statement I is correct but II and III are incorrect.

22. (i) (*a*) They feel zero weight because there is no external force present in the space.

(ii) (*c*) The weight of a body is the force with which it gets attracted towards centre of earth, but inertia is a property of mass. A body can have inertia but no weight.

(iii) (*c*) Inside the satellite, the astronaut feels weightlessness. So, mass of astronaut can be calculated using weight at the surface of earth

$$mg = 250\ N$$

$$\Rightarrow \quad m = \frac{250}{10}$$

$$\Rightarrow \quad m = 25\ kg$$

(iv) (*c*) The main reason behind weightlessness inside a space satellite is that the astronaut experiences no gravity.

(v) (*c*) Since, the person sitting in a chair inside the satellite is essentially in free-fall along the satellite. So, he does not experience any reaction force.

Subjective Questions

1. The universal law of gravitation states that, "The force of attraction between any two objects is directly proportional to the product of their masses and inversely proportional to the square of the distance between them". This law is applicable on any two objects anywhere in the universe.

2. The formula for magnitude of gravitational force between the earth and an object on the surface of the earth is given by

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

where, M = mass of the earth,

m = mass of an object,

G = gravitational constant

$= 6.67 \times 10^{-11}\ N\text{-}m^2/kg^2$

and R = distance between centres of the earth and an object.

3. Force of gravitation between two objects is given by

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

If distance is reduced to half, i.e. $\mathbf{r}' = \mathbf{r}/2$, then new force of gravitation,

$$F' = \frac{Gm_1 m_2}{r'^2} = \frac{Gm_1 m_2}{(r/2)^2} = 4 \times \frac{Gm_1 m_2}{r^2} = 4F$$

i.e. The force of gravitation becomes 4 times that of the original value.

4. The universal law of gravitation successfully explained several phenomena given as below
- (i) The force that binds us to the earth.
- (ii) The motion of the moon around the earth.
- (iii) The motion of planets around the sun.
- (iv) The tides due to the moon and the sun.
- (v) The flow of water in rivers is also due to gravitational force of the earth on water.

5. According to universal law of gravitation, $F = \frac{Gm_1 m_2}{r^2}$

So, if the distance between the two objects is increased five times, then to make the force between them same mass of one object should be increased 25 times.

6. The force of gravitation between the earth and the sun is given by

$$F = \frac{GM_s M_e}{r^2} \quad \ldots(i)$$

where, $G = 6.67 \times 10^{-11}$ N-m²/kg²,

Mass of the sun, $M_s = 2 \times 10^{30}$ kg,

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

and average distance between the earth and the sun,

$$r = 1.5 \times 10^{11} \text{ m.}$$

From Eq. (i) we get

$$F = \frac{6.67 \times 10^{-11} \times 2 \times 10^{30} \times 6 \times 10^{24}}{(1.5 \times 10^{11})^2}$$

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

Thus, the force between earth and sun is 3.6×10^{22}**N**.

7. Gravitational force between the earth and an object is given by $F = \frac{GMm}{R^2}$.

where, gravitational constant, $G = 6.67 \times 10^{-11}$N-m²/kg²,

mass of the earth, $M = 6 \times 10^{24}$ kg,

radius of the earth, $R = 6.4 \times 10^6$ m

and mass of an object $m = 1$ kg.

$$\therefore \quad F = \frac{6.67 \times 10^{-11} \times 6 \times 10^{24} \times 1}{(6.4 \times 10^6)^2}$$

$$= 9.77 \approx 9.8 \text{ N}$$

Thus, magnitude of gravitational force between the earth and 1 kg object is 9.8 N.

8. When two objects attract each other, then gravitational force of attraction applied by first object on the second object is same as the force applied by the second object on the first object. So, both earth and moon attract each other by the same gravitational force of attraction.

9. The force of attraction between two bodies of masses m_1 and m_2 and separated by distance r is given by Newton's universal law of gravitation.

i.e., $F = \frac{m_1 m_2}{r^2}$, where G is the universal constant in nature.

All bodies fall with the same acceleration due to gravity whatever their masses have, i.e.

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

where, M = mass of earth and R = radius of earth.

And from equation it is clear that, acceleration due to gravity (i.e. g) depends only on mass of the earth and the radius of the earth.

So, two bricks tied together will not fall faster than a single brick under the action of gravity. Hence the hypothesis is not correct.

10. Given, mass of earth, $M_e = 6 \times 10^{24}$ kg,

Body weighs, $m = 25$ kg,

Radius of earth, $R_e = 6.4 \times 10^6$ m

and gravitational constant,

$$G = 6.67 \times 10^{-11} \text{N-m}^2/\text{kg}^2$$

(i) Mutual force, $F = G\frac{M_e}{R_e^2}m$

$$= \frac{6.67 \times 10^{-11} \times 6 \times 10^{24} \times 25}{(6.4 \times 10^6)^2} = 244 \text{ N}$$

(ii) Acceleration produced in the body,

$$a = \frac{F}{m} = \frac{244}{25} = 9.8 \text{ m/s}^2$$

(iii) Acceleration produced in the earth,

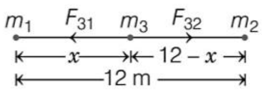
$$a = \frac{F}{M_e} = \frac{244}{6 \times 10^{24}}$$

$$= 4.06 \times 10^{-23} \text{ m/s}^2$$

11. Given, mass of first body, $m_1 = 3$ kg

and mass of second body, $m_2 = 12$ kg

Let the mass of third body, $m_3 = 0.5$ kg be placed at a distance of x from m_1 as shown in figure.



Then, force acting on m_3 due to m_1 is equal and opposite to the force acting on m_3 due to m_2.

$$\therefore \quad F_{31} = F_{32}$$

$$\frac{Gm_3 m_1}{x^2} = \frac{Gm_3 m_2}{(12-x)^2} \Rightarrow \frac{3}{x^2} = \frac{12}{(12-x)^2}$$

$$\Rightarrow \left(\frac{12-x}{x}\right)^2 = \frac{12}{3} = 4 \quad \Rightarrow \frac{12-x}{x} = 2$$

$$\Rightarrow 12 - x = 2x \quad \Rightarrow 12 = 3x$$

$$\Rightarrow x = 4 \text{ m}$$

The position of required point is at a distance 4 m from the mass 3 kg.

12. The falling of a body from a height towards the earth under the gravitational force of the earth is called free fall.

Hence, the motion of a particle falling down or going up under the action of gravity means the body is under free fall.

13. According to Kepler's third law of planetary motion, $T^2 \propto r^3$

For objects on or near the surface of the earth,

$$mg = G\frac{M \times m}{R^2}$$

where, g = acceleration due to gravity,
M = mass of the earth,
m = mass of an object
and R = radius of the earth.

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

14. Acceleration due to gravity g is independent of mass of the falling object and is equal for all objects at a point. So, a heavy object falls with same acceleration as light object.

15. Given, height, $h = 19.6$ m

Initial velocity, $u = 0$ ($\because$ it starts from rest)

From the third equation of motion, $v^2 = u^2 + 2gh$

$$v^2 = 0 + 2 \times 9.8 \times 19.6 = 19.6 \times 19.6$$

$$\therefore \quad v = \sqrt{19.6 \times 19.6} = 19.6 \text{ m/s}$$

Final velocity of stone just before touching the ground is 19.6 m/s .

16. For both the stones,

initial velocity, $u = 0$

Acceleration in downward direction $= g$

Now, from second equation of motion,

$$h = ut + \frac{1}{2}gt^2 \quad \Rightarrow \quad h = 0 + \frac{1}{2}gt^2$$

$$\Rightarrow h = \frac{1}{2}gt^2 \quad \Rightarrow \quad t = \sqrt{\frac{2h}{g}}$$

Both stones will take the same time to reach the ground because the two stones fall from the same height.

17. When the ball is thrown upwards, then it will reach certain height h and starts falling. At maximum height h, the final velocity will be $v = 0$.

Maximum height reached by the ball,

$$v^2 - u^2 = 2gh \quad \text{(using equation)}$$

$$0 - u^2 = -2gh \quad (\because \text{ acceleration} = -g)$$

$$\Rightarrow \quad h = \frac{u^2}{2g} \quad \ldots(i)$$

In second case, when the ball starts to fall, then the initial velocity $u = 0$. It will accelerate due to gravity, i.e. $a = g$ and reach ground with speed (say v_2).

Using equation,

$$v_2^2 - u^2 = 2gh$$

$$\Rightarrow \quad v_2^2 - 0 = 2gh$$

$$v_2^2 = 2g\left(\frac{u^2}{2g}\right) = u^2 \quad \text{[from Eq. (i)]}$$

$$\Rightarrow \quad v_2 = u$$

Thus, the ball reaches the ground with same speed.

18. No, those packets do not take same time to reach the surface of earth. Because the value of g is different at poles and equator due to rotation of the earth.

So, value of g at equator is less than value of g at poles and we know that, $t = \sqrt{\frac{2h}{g}}$, i.e. $t \propto \frac{1}{g}$

Since, g is greater at the poles than at the equator. So, packet dropped above the north pole will reach first at the surface of the earth.

19. Given, height, $h = 1000$ m,

Final velocity, $v = 0$,

Acceleration due to gravity, $g = -9.8 \text{ m/s}^2$

(i) From the third equation of motion,

$$v^2 = u^2 + 2gh$$

$$\Rightarrow \quad 0 = u^2 - 2 \times 9.8 \times 1000$$

$$u = \sqrt{2 \times 9.8 \times 1000}$$

$$= \sqrt{19600} = 140 \text{ m/s}$$

Velocity by which firecracker is released = 140 m/s

(ii) From the first equation of motion,

$$v = u + gt$$

$$\Rightarrow \quad 0 = 140 - 9.8t$$

$$\Rightarrow \quad t = \frac{140}{9.8} = 14.28 \text{ s}$$

Time taken, $t = 14.28$ s

20. Difference between the mass of an object and its weight given as below

Mass	Weight
Quantity of matter contained in an object.	Force with which an object is attracted towards centre of the earth due to gravity.
Constant everywhere.	Changes from place-to-place.
It is a scalar quantity.	It is a vector quantity.
Its SI unit is kg.	Its SI unit is newton.
Mass is never zero.	Weight is zero at the centre of the earth or free space.

21. Weight of an object, $w = mg$

where, m = mass of an object
and g = acceleration due to gravity.

The mass of an object m remains constant at all the places. Acceleration due to gravity changes from place-to-place. So, we can say that the weight of an object depends on the acceleration due to gravity.

On the moon, the acceleration due to gravity is (1/6)th that of the earth, this is the reason why the weight of an object on the moon is (1/6)th its weight on the earth.

22. **On earth** Force applied by the man on earth, $F = m \times g$,

where m = mass.

On moon $g = \frac{g}{6}$, so by same force he can lift a mass of

$15 \times 6 = 90$ kg

This is because, the 90 kg of mass will appear only 15 kg on moon.

23. Given, mass of the object, $m = 10$ kg

Weight on the earth, $w = mg = 10 \times 9.8 = 98$ N

Weight on the moon $= \frac{1}{6}$ of the weight on the earth

$$= \frac{1}{6} \times 98 = 16.33 \text{ N}$$

24. No, his friend will not agree with the weight of gold.

$$w = mg \quad \ldots(i)$$

$$w = \frac{GMm}{R^2} \quad \ldots(ii)$$

From Eqs. (i) and (ii), we get

$$mg = \frac{GMm}{R^2}$$

$$g \propto \frac{1}{(\text{Distance of an object from centre of the earth})^2}$$

or $$g \propto \frac{1}{R^2}$$

The value of **g** is greater at poles than at the equator. Therefore, gold at equator weighs less than that at poles. Thus, Amit's friend will not agree with the weight of the gold bought.

25. (i) Formula to find the magnitude of gravitational force,

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

where, M = mass of the earth,
m = mass of the object,
R = radius of the earth
and **G** = universal gravitational constant $= 6.67 \times 10^{-11}$ N-m²/kg².

(ii) (a) Let gravitational force be **F**, when the distance between them is **R**,

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

Now, when the distance reduces to half,

$$F' = \frac{GMm}{\left(\frac{R}{2}\right)^2} = \frac{4GMm}{R^2}$$

...(ii)

On dividing Eq. (i) by Eq. (ii), we get

$$\frac{F}{F'} = \frac{GMm}{R^2} \times \frac{R^2}{4GMm}$$

$$F' = 4F$$

(b) When the mass becomes 4 times,

$$\frac{F}{F'} = \frac{GMm}{R^2} \times \frac{R^2}{4GMm}$$

$\Rightarrow$ $$F' = 4F$$

26. (i) Gravitational force acting on the 50 kg,

$$mg = 50 \times 9.8 = 490 \text{ N}$$

Gravitational force acting on the 50 kg mass due to jupiter,

$$F_{jupiter} = \frac{G \times M_{jupiter} \times M_{person}}{(\text{Distance of jupiter from the earth})^2}$$

$$F_{jupiter} = \frac{6.67 \times 10^{-11} \times 2 \times 10^{27} \times 50}{6.3 \times 10^{11} \times 6.3 \times 10^{11}}$$

$$F_{jupiter} = \frac{6.67 \times 2 \times 50 \times 10^{-11+27-22}}{6.3 \times 6.3}$$

$$F_{jupiter} = 1.68 \times 10^{-5} \text{ N}$$

Gravitational force acting on the 50 kg mass due to saturn,

$$F_{saturn} = \frac{G \times M_{saturn} \times M_{person}}{(\text{Distance of saturn from the earth})^2}$$

$$F_{saturn} = \frac{6.67 \times 10^{-11} \times 6 \times 10^{26} \times 50}{1.28 \times 10^{12} \times 1.28 \times 10^{12}}$$

$$F_{saturn} = \frac{6.67 \times 6 \times 50}{1.28 \times 1.28} \times 10^{-11+26-24}$$

$$F_{saturn} = 0.12 \times 10^{-5} \text{ N}$$

$\therefore$ Total gravitational force due to the jupiter and the saturn

$$= (1.68 \times 10^{-5} + 0.12 \times 10^{-5}) \text{ N}$$

$$= 1.8 \times 10^{-5} \text{ N}$$

Thus, the combined force due to the planets jupiter and saturn (1.8×10^{-5}) N is negligible as compared to the gravitational force due to the earth.

(ii) We know that, g at equator is less than g at poles (Antarctica). Thus, weight at equator is less than weight at pole (Antarctica). A bag of sugar weighs w at a certain place on the equator. If this bag is taken to Antarctica, then it will weigh more due to greater value of g.

27. (i) Let the two bodies have masses m_1 and m_2 and they are placed at the same distance **R** from the centre of the earth. According to the question, if the same force acts on both of them, then

$$F_1 = \frac{GMm_1}{R^2} \quad \ldots(i)$$

and $$F_2 = \frac{GMm_2}{R^2} \quad \ldots(ii)$$

As, $$F_1 = F_2$$

Hence, $$\frac{GMm_1}{R^2} = \frac{GMm_2}{R^2}$$

So, $m_1 = m_2$, their masses will be same.

(ii) Mathematically, $g = \frac{GM}{R^2}$

where, g = acceleration due to gravity,
G = universal gravitational constant,
M = mass of the earth
and R = radius of the earth.

(iii) **G** is known as the universal gravitational constant because its value remains same all the time everywhere in the universe, applicable to all bodies whether celestial or terrestrial.

28. Total time taken = **6** s

$\therefore$ Time taken to reach the maximum height, $t = \frac{6}{2} = 3$ s

($\because$ time of ascent = time of descent)

(i) From the first equation of motion, $v = u - gt$

(negative sign is taken due to upward motion)

$$0 = u - 9.8 \times 3 \quad (\because \text{at maximum height, } v = 0)$$

$$\Rightarrow \quad u = 29.4 \text{ m/s}$$

(ii) From the third equation of motion, $v^2 = u^2 - 2gh$

(negative sign is taken due to upward motion)

$$0 = (29.4)^2 - 2 \times 9.8 \times h$$

$$\Rightarrow \quad h = \frac{(29.4)^2}{2 \times 9.8} = 44.1 \text{ m}$$

Maximum height attained by the ball is **44.1 m**.

(iii) In initial 3 s, the ball will rise, then in next 3 s it falls toward the earth.

$\therefore$ The position after 4 s = Distance covered in 1 s in the downward motion

From the second equation of motion,

$$h = ut + \frac{1}{2}gt^2 = 0 + \frac{1}{2} \times 9.8 \times (1)^2 = 4.9 \text{ m}$$

i.e. The ball will be at 4.9 m below from the top of the tower or the height of ball from the ground will be at $(44.1 - 4.9) = 39.2$ m.

29. Given, initial velocity, $u = 0$

Acceleration, $a = 9.8 \text{ m/s}^2$

Distance, $s = 4.9$ m

(i) We have, $s = ut + \frac{1}{2}gt^2$

$$4.9 = 0 \times t + \frac{1}{2} \times 9.8 \times t^2$$

$$t^2 = \frac{9.8}{9.8} = 1$$

$$\Rightarrow \quad t = 1 \text{ s}$$

The stone takes 1 s to fall 4.9 m.

(ii) We have, $v^2 - u^2 = 2as$

$$v^2 - 0^2 = 2 \times 9.8 \times 4.9$$

$$\Rightarrow \quad v = \sqrt{96.04} = 9.8 \text{ m/s}$$

At the end of 4.9 m, stone will be moving at a speed of 9.8 m/s.

(iii) We have, $v^2 - u^2 = 2as$

$$v^2 - 0^2 = 2 \times 9.8 \times 7.9 \Rightarrow v = 12.44 \text{ m/s}$$

The stone will be moving with a speed of 12.44 m/s at the end of 7.9 m.

(iv) During the free fall, the acceleration produced in a body remains constant.

So, acceleration after 1 s = 9.8 m/s^2 and acceleration after 2 s = 9.8 m/s^2.

30. From second equation of motion,

$$h = ut + \frac{1}{2}gt^2 \quad \text{(for I object, } u = 0)$$

So, $$h = \frac{1}{2}gt^2$$

where, h = displacement, u = initial velocity, t = time and g = acceleration due to gravity.

$$\Rightarrow \quad gt^2 = 2h$$

$$\Rightarrow \quad t^2 = \frac{2h}{g}$$

i.e. $$t = \sqrt{\frac{2h}{g}}$$

$\therefore$ Time taken by first object of mass m_1,

$$t_1 = \sqrt{\frac{2h_1}{g}} \quad \text{(for II object, } u = 0)$$

Similarly, time taken by object of mass m_2,

$$t_2 = \sqrt{\frac{2h_2}{g}} \Rightarrow \frac{t_1}{t_2} = \sqrt{\frac{h_1}{h_2}}$$

(i) Acceleration due to gravity is independent of mass of falling body, so, the ratio remains the same.

(ii) If bodies are hollow, then also ratio remains the same. i.e. $t_1 : t_2 = \sqrt{h_1} : \sqrt{h_2}$.

31. Given, radius of the earth at the poles, $R_p = 6357$ km and radius of earth at the equator, $R_e = 6378$ km

Let acceleration due to gravity at equator,

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

and acceleration due to gravity at poles,

$$g_p = \frac{GM_e}{R_p^2}$$

The variation of acceleration due to gravity,

$$\Delta g = g_p - g_e = GM_e\left(\frac{1}{R_p^2} - \frac{1}{R_e^2}\right)$$

Percentage variation in g

$$= \frac{GM_e\left(\frac{1}{R_p^2} - \frac{1}{R_e^2}\right)}{\frac{GM_e}{R_e^2}} \times 100$$

$$= \frac{R_e^2 - R_p^2}{R_e^2 R_p^2} \times 100 \times R_e^2 = \frac{R_e^2 - R_p^2}{R_p^2} \times 100$$

$$= \frac{(6378)^2 - (6357)^2}{(6357)^2} \times 100 \approx 0.7\%$$

$\therefore$ % variation in the weight of a body = % change in g = 0.7%

32. (i) (a) g on the moon is given by

$$g' = \frac{g}{6} = \frac{9.8}{6} = 1.63 \text{ m/s}^2$$

(b) Given, a person weighs on the moon = 110.84 N

Mass of the person on the moon,

$$m = \frac{110.84}{1.63} = 68 \text{ kg}$$

(c) Weight of person on the earth = mg

$$= 68 \times 9.8 = 666.4 \text{ N-m}^2/\text{kg}^2$$

(ii) From Newton's law of gravitation,

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

here, **M** is mass of earth, object having mass **m** falling towards it and **R** is the distance between centres of earth & the object.

From second law of motion, force exerted on an object,

$$F = ma$$

Since, $a = g$ (i.e. acceleration due to gravity)

$$F = mg \quad \ldots(ii)$$

From Eqs. (i) and (ii), we get

$$mg = \frac{GMm}{R^2}$$

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

33. (i) Given table shows the variation in acceleration due to gravity at the surface of earth, at depth **d** below from the surface of earth and height **h** above from the surface of earth.

Acceleration due to gravity is different at different points on the earth.

(ii) Given, mass of the earth, $M = 6 \times 10^{24}$ kg

Radius of the earth, $R = 6.4 \times 10^6$ m

Universal gravitational constant,

$$G = 6.67 \times 10^{-11} \text{ N-m}^2/\text{kg}^2$$

$$\because \quad g = \frac{GM}{R^2}$$

$$= \frac{(6.67 \times 10^{-11})(6 \times 10^{24})}{(6.4 \times 10^6)^2}$$

$$= 9.8 \text{ m/s}^2$$

(iii) Point **O** is the centre of earth.

At centre **O** of the earth, $d = R$

From formula III given in table,

$$g_d = g\left(1 - \frac{d}{R}\right) = 0$$

Thus, at the centre of earth, acceleration due to gravity is zero.

(iv) The value of acceleration due to gravity decreases with increase in height above the surface of earth.

(v) At a depth of $d = \frac{R}{2}$ from centre of earth according to formula III given is table,

$$g_d = g\left(1 - \frac{d}{R}\right) = g\left(1 - \frac{R/2}{R}\right) = \frac{g}{2}$$

i.e. Acceleration due to gravity will be reduced to half.

34. (i) We use the term force of gravity rather than force of gravitation for the force of attraction between two bodies in which one body had infinitely large mass.

(ii) Gravitational force of the moon brings tides in the ocean.

(iii) Gravitational force between the moon and the earth keeps the moon in a uniform circular motion around the earth.

(iv) The size of the bodies is very small, therefore the force of attraction between them is very small. So, both objects do not move towards each other.

(v) The earth does not fall into the sun because the earth remains in its circular orbit due to the gravitational force acting on it.