Gravitation

INTRODUCTION

All of Isaac Newton's efforts in mechanics were focussed toward the explanation of the motions of the planets around the sun and of the moon round the earth. In 1666, Newton prompted by a simple observation (fall of an apple toward the earth) concluded that the force that caused an apple to fall to the ground and the force that kept the moon in its orbit around the earth were only different manifestation of one universal force called force of Gravitation. From the above assumptions, Newton made the hypothesis that every body in the universe exerts a gravitational force on every other body. This gravitational force is responsible for the motion of the planets around the sun, the motion of falling bodies towards earth, etc.

6.1 NEWTON'S LAW OF UNIVERSAL GRAVITATION

In order to explain the gravitational force Newton formulated the law of universal gravitation as under:

Newton began on the basis of approximation that the moon's orbit is circular, he then calculated centripetal acceleration of the moon, a_m, about the earth applying Huygen's formula for centripetal acceleration in the form

$$\vec{a}_c = -\frac{V^2}{r}\hat{r} \qquad 6.1(a)$$

Where $\hat{r}$ is a unit vector directed from the centre of the circle to the instantaneous location of the moving body. The minus sign in the equation specifies that the direction of $\vec{a}_c$ is inward (towards

the centre of the circle).

The magnitude of the centripetal acceleration is then given by

$$|\vec{a}_c| = a_c = \frac{V^2}{r} = \frac{4\pi^2}{T^2} r \qquad 6.1(b)$$

$$\because \quad V = \frac{2\pi r}{T}$$

Consequently, we can rewrite the above equation for the magnitude of the centripetal acceleration of the moon.

$$a_m = \frac{4\pi^2}{T^2} R_m \qquad 6.1(c)$$

where

$R_m = 3.84 \times 10^5$ km and represents the distance from the centre of the earth to the centre of the moon and called orbit radius of the moon.

$T = 27.3$ days $= 2.36 \times 10^6$ s and represents the time taken by the moon to complete one revolution around the earth.

Substituting the values of R_m and T in Eq. 6.1(c), the magnitude of the centripetal acceleration of the moon is found to be

$$a_m = 2.72 \times 10^{-3} \text{ ms}^{-2} \qquad 6.2$$

The magnitude of the centripetal acceleration of the moon given by Eq.6.2 provided the basis for the mathematical formulation of the law of universal gravitation. If the centripetal acceleration is a gravitational acceleration, the apple would also experience an acceleration of magnitude $a_m = 2.72 \times 10^{-3}$ ms^{-2}, provided the apple is placed at a distance of $R_m = 3.84 \times 10^8$ m from the centre of the earth.

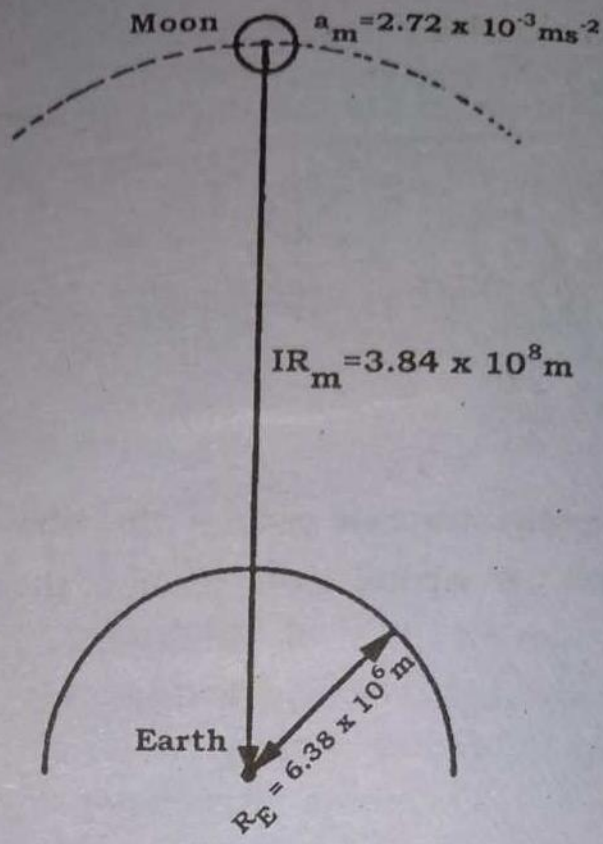

Fig: 6.1 Gravitational acceleration of apple decreases when it is moved away from the earth. Moon and apple have same acceleration when at the same distance.

We know that near the surface of the earth an object falling freely experiences an acceleration of 9.8 ms^{-2} the value of a_m is then approximately equal to $1/(60)^2$ that of the acceleration due to gravity $g = 9.8\ ms^{-2}$ at the surface of the earth.

that is,

$$\frac{a_m}{g} = \frac{1}{(60)^2} \qquad 6.3$$

From Fig. 6.1, we see

$$\frac{R_E^2}{R_m^2} = \frac{(6.38 \times 10^3\ km)^2}{(3.84 \times 10^5\ km)^2} = \frac{1}{(60)^2} \qquad 6.4$$

It appears that

$$\frac{a_m}{g} = \frac{R_E^2}{R_m^2} \qquad 6.5$$

Where R_E is the distance from the centre of the earth to its surface i.e the radius of the earth as shown in Fig. (6.1). Comparison of the gravitational acceleration of the apple falling from the tree with the gravitational acceleration of the moon (if centripetal acceleration is the gravitational acceleration) falling in its orbit suggests that the acceleration of the moon because of the gravitational force exerted on the moon by the earth, depends inversely as the square of the distance from the centre of the earth to the centre of the moon. To make the law a truly universal law of gravitation it must apply to any pair of bodies A and B and not just to the earth and the apple, or the earth and the moon.

The magnitude $F_{\text{on A by B}}$ of the gravitational force $\vec{F}_{\text{on A by B}}$ exerted on body A due to the presence of the body B is given in the form

$$F_{\text{on A by B}} \propto \frac{1}{(r_{\text{From B to A}})^2} \qquad 6.6$$

Where $\vec{r}_{\text{From B to A}}$ describes the position of body A with respect to another body B as shown in Fig. 6.2

The magnitude, $F_{\text{on A by B}}$, of the gravitational force $\vec{F}_{\text{on A by B}}$ must also be proportional to the mass m_A of the body on which it is acting.

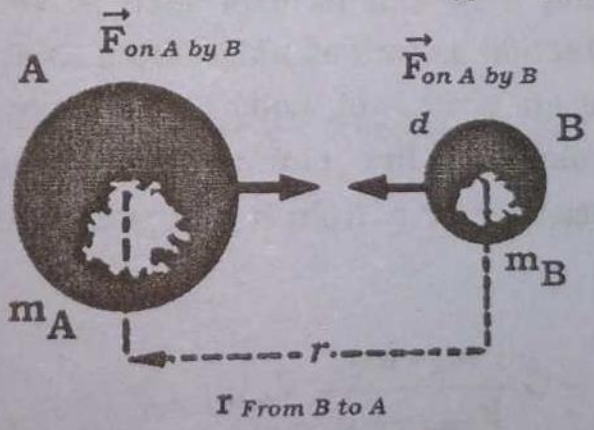

Fig: 6.2 gravitational force between m_A and m_B

therefore

$$F_{\text{on A by B}} \propto m_A \qquad 6.7$$

As the bodies A and B are chosen arbitrarily, there must be a force $\vec{F}_{\text{on B by A}}$ due to the presence of the body A. therefore,

$$F_{\text{on B by A}} \propto m_B \qquad 6.8$$

where m_B is the mass of body B.

According to the third law of motion, the magnitudes of two forces are equal, i.e

$$F_{\text{on A by B}} = F_{\text{on B by A}}$$

The proportionality Eq. 6.7 can therefore be written as

$$F_{\text{on A by B}} \propto m_A$$

when proportionalities are taken together

$$F_{\text{on A by B}} \propto m_A m_B \qquad 6.9$$

Combining Eq. 6.6 & Eq. 6.9, we get

$$F_{\text{on A by B}} \propto m_A\, m_B \,/\, (r_{\text{from B to A}})^2$$

When written in form of an equation

$$F_{\text{on A by B}} = G \frac{m_A m_B}{(r_{\text{from B to A}})^2} \qquad 6.10$$

Eq. 6.10 gives the magnitude of the gravitational force and G is a universal gravitational constant ($G = 6.673 \times 10^{-11}$ N- m^2/kg^2)

The equation 6.10 can be expressed in vector form which then gives the direction as well as magnitude. As shown in Fig. 6.2. The force exerted on body A by body B is always directed toward body B and acts along the line joining their centres and vice versa. As the displacement vector $\vec{r}$ from B to A is directed from the body B to A, we have

$$\vec{F}_{\text{on A by B}} = -G \frac{m_A \cdot m_B}{(r_{\text{from B to A}})^2} \hat{r}_{\text{from B to A}} \qquad 6.11(a)$$

The negative sign shows that the gravitational force is attractive.

Similarly, the force exerted by body A on body B is given by

$$\vec{F}_{\text{on B by A}} = -G \frac{m_B\, m_A}{(r_{\text{from A to B}})^2} \hat{r}_{\text{from A to B}} \qquad 6.11(b)$$

Comparing Eq. 6. 11 (a) with Eq. 6.11 (b) we note that

$(r_{\text{from B to A}})^2 = (r_{\text{from A to B}})^2$

and

$\hat{r}_{\text{from B to A}} = -\hat{r}_{\text{from A to B}}$

Consequently we have

$$\vec{F}_{\text{on A by B}} = -\vec{F}_{\text{on B by A}}$$

as shown in Fig. (6.2)

These two gravitational forces constitute an action - reaction pair in accordance with Newton's third law.

We may substitute shorthand notation for the subscripts such that

(i) $\vec{F}_{\text{from A to B}} = \vec{F}_{AB}$

(ii) $\vec{F}_{\text{from A to B}} = \vec{F}_{BA}$

(iii) $\vec{r}_{\text{from A to B}} = \vec{r}_{BA}$

(iv) $\vec{r}_{\text{from A to B}} = \vec{r}_{AB}$

consequently, we rewrite Eq. 6.10, Eq. 6.11 (a) and Eq. 6.11 (b) in the form

$$F_{AB} = G \frac{m_A m_B}{r_{BA}^2} \qquad 6.12(a)$$

$$\vec{F}_{AB} = -G \frac{m_A m_B}{r_{BA}^2} \hat{r}_{BA} \qquad 6.12(b)$$

$$\vec{F}_{BA} = -G \frac{m_B m_A}{r_{AB}^2} \hat{r}_{AB} \qquad 6.12(c)$$

The Eq. (6.11) and Eq. (6.12) define Newton's universal law of gravitation. It is truly a universal law, since it describes the gravitational interaction between pairs of objects wherever we ob-

serve them through out the universe. The law states that

"Every body in the universe attracts every other body with a force which is directly proportional to the product of their masses, and inversely proportional to the square of the distance between them and directed along the line joining their centres".

The value of the gravitational constant, G, was determined experimentally. The first accurate measurement was made by Lord Cavendish in 1798. Later in ninteenth century significant improvement were made by Poynting and Boys. The present accepted value of the universal gravitational constant G was obtained by P.R.Heyl and P. Chizano Wski at the U.S National Bureau of standards, i.e

$$G = 6.673 \times 10^{-11} \ N \ m^2/kg^2$$

Example: 6.1

Compute the gravitational force of attraction between two balls each weighing 5kg, when placed at a distance of 0.33 m apart.

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

$$= \frac{6.673 \times 10^{-11} \ N \ m^2/kg^2 \times 5kg \times 5kg}{(0.33m)^2}$$

$$= 1.5 \times 10^{-8} \ N$$

6.2 MASS AND AVERAGE DENSITY OF EARTH

Mass of the earth can be determined by using the Newton's law of universal gravitation. Consider an object of mass M placed near the surface of the earth. If M_E is the mass of the earth and R_E its radius, then the magnitude of the gravitational force with which the earth attracts the object towards its centre, is given by

$$F = G \frac{MM_E}{R_E^2} \qquad 6.13$$

The force on the object is also given by the mass M of the object multiplied by the acceleration due to gravity which is equal to its weight W. (Second law of motion)

Hence $F = W = Mg$ 6.14

Where g is acceleration due to gravity. Thus from Eq. 6.13 and Eq. 6.14 we get

$$G \frac{MM_E}{R_E^2} = Mg$$

Solving for M_E we get

$$M_E = \frac{R_E^2 g}{G} \qquad 6.15$$

Since $R_E = 6.38 \times 10^6$ m, $g = 9.8 ms^{-2}$ and $G = 6.67 \times 10^{-11}$ N-m^2 kg^{-2}

Therefore

$$M_E = \frac{9.8 (ms^{-2}) \times (6.38 \times 10^6 m)^2}{6.67 \times 10^{-11} (N\text{-}m^2 kg^{-2})}$$

$$= 5.98 \times 10^{24} kg$$

The average density or mass per unit volume, ρ, of the Earth is given by

$$\rho = \frac{M_E}{V} \qquad 6.16$$

Where V is the volume of the earth

$$V = \frac{4}{3} \pi R_E^3 \qquad 6.17$$

Substituting for M_E and V in Eq. 6.16 we can obtain the average density of the earth which is $5.5 \times 10^3 kg/m^3$

EXAMPLE: 6.2

Calculate the mass of sun, when earth is orbiting around it.

Let M be the mass of the sun and m be the mass of the earth

orbiting around the sun. Let R be the distance between the centres of the earth and the sun and is called orbit radius of earth.

The magnitude of the force of attraction between the sun and the earth is given by Eq 6.10.

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

The centripetal acceleration of the earth

$$a_c = \frac{4\pi^2 R}{T^2}$$

Where T is period of revolution of earth around sun. (365.30 days)

From Newton's second law of motion

$$F = ma = m \frac{4\pi^2 R}{T^2}$$

$\therefore$

$$G \frac{Mm}{R^2} = m \left(\frac{4\pi^2 R}{T^2}\right)$$

Hence

$$M = \frac{4\pi^2 R^3}{GT^2}$$

From astronomical data, we know.

$R = 1.49 \times 10^{11}$ m

$G = 6.673 \times 10^{-11}$ N-m^2 / kg^2.

$T = 365.3 \times 24 \times 60 \times 60$s

Substituting the values of R,T and G in the above relation, we get the mass of the sun.

$M = 1.99 \times 10^{30}$ kg.

6.3 VARIATION OF 'g' WITH ALTITUDE AND DEPTH

The force of gravity on a body varies slightly from place to place on the earth for two reasons. First, the shape of the earth, and secondly, its rotation. The earth is not a perfect sphere, but bulges at the equator. Therefore if a body is taken from a pole to the equator its distance from the centre of the earth will change Consequently, in accordance with Newton's law of gravitation, the gravitational pull on it will also vary.

(a) Now let us consider the variation of g when a body moves distance upward or downward from the earth's surface. Let g be the value of acceleration due to gravity at the surface of the earth and g′ at a height h above the surface of the earth. If the earth be considered as a sphere of homogeneous composition, then 'g' at any point above its surface will vary inversely as the square of the distance from that point to its centre. From Eq 6.15 we found that g is given by

$$g = \frac{M_E G}{R_E^2} \qquad 6.18$$

Similarly, the value of g′ at a distance $(R_E + h)$ as shown in Fig. 6.3 is given by

$$g' = \frac{M_E G}{(R_E + h)^2}$$

therefore

$$\frac{g}{g'} = \frac{(R_E + h)^2}{R_E^2}$$

$$= 1 + \frac{2h}{R_E} + \frac{h^2}{R_E^2} + \ldots \qquad 6.19$$

If 'h' is small as compared to R_E, the radius of earth, the quantity h^2/R_E^2 in the above equation will be negligibly small and we shall therefore have

$$g' = g\left(1 - \frac{2h}{R_E}\right) \qquad 6.20$$

From this equation we can conclude that the greater the value of h, the smaller is the value of g' or the value of g decreases with altitude.

Table 6.1

variation of 'g' with altitude at 45° latitude.

Altitude (metres)	g. (metre / sec^2)	Altitude (metres)	g. (metre / sec^2)
0	9.806	32×10^3	9.71
1000	9.803	100×10^3	9.60
4000	9.794	500×10^3	8.53
8000	9.782	1000×10^3	7.41
16000	9.757	3800×10^5	0.00271

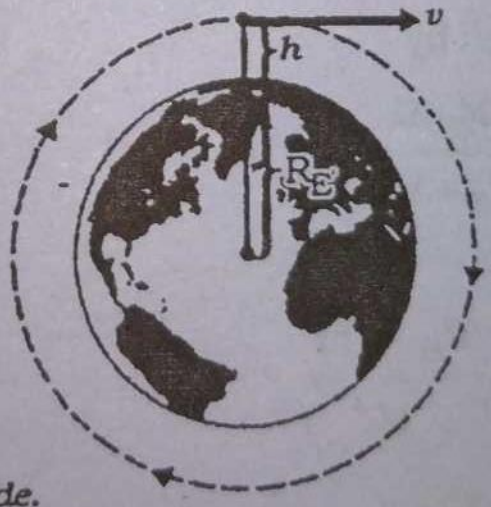

Fig. 6.3 Variation of 'g' with altitude.

(b) Let g' be the acceleration due to gravity at a depth d below the surface of earth as shown in Fig 6.4. That is at a distance (R_E – d) from the centre of earth. From Eq 6.16, the mass of earth is given by.

$$M_E = \frac{4\pi}{3} R_E^3 \rho. \qquad 6.21$$

where ρ is the density of the earth supposed to be uniform everywhere.

The mass of the earth effective for attraction at a depth d from its surface is

$$M'_E = \frac{4\pi}{3} (R_E - d)^3 \rho \qquad 16.22$$

From Eq.6.18, the value of g at the surface is given by

$$g' = \frac{M_E G}{R_E^2} \qquad 6.23 (a)$$

Putting the value of M_E in the above equation we get

$$g' = \frac{\frac{4\pi}{3} R_E^3 \rho G}{R_E^2}$$

$$= \frac{4\pi}{3} R_E \rho G \qquad 6.23 (b)$$

At depth d the value of acceleration due to gravity is equal to

$$g' = \frac{M'_E G}{(R_E - d)^2} \qquad 6.24 (a)$$

Putting the value of M'_E in the above equation we get

$$g' = \frac{\frac{4\pi}{3} (R_E - d)^3 \rho G}{(R_E - d)^2}$$

$$= \frac{4\pi}{3} (R_E - d) \rho G \qquad 6.24 (b)$$

The ratio g' to g is given by dividing Eq. 6.24 (b) by Eq. 6.23 (b)

$$\frac{g'}{g} = \frac{R_E - d}{R_E}$$

$$= 1 - \frac{d}{R_E}$$

$$\therefore \quad g' = g\left(1 - \frac{d}{R_E}\right)$$

That is the value of g decreases with depth from surface of the earth. It also follows that at the centre of earth, when $d = R_E$, the value of g will be zero.

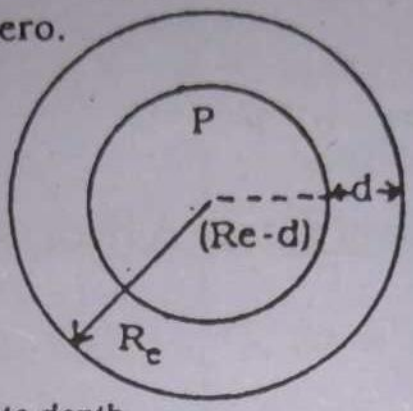

Fig. 6.4 Variation of 'g' due to depth.

It can be observed from both the cases that acceleration due to gravity decreases at a faster rate for a points above the surface of earth than for the same points below the surface of the earth.

The variation of 'g' in the earth's interior is shown in table 6.2

Table 6.2

Depth, km	g, (metre / sec^2)	Depth, km	g, (metre / sec^2)
0	9.82	1400	9.88
33	9.85	1600	9.86
100	9.89	1800	9.85
200	9.92	2000	9.86
300	9.95	2200	9.90
413	9.98	2400	9.98
600	10.01	2600	10.09
800	9.99	2800	10.26
1000	9.95	2900	10.37
1200	9.91	4000	8.00

6.4 WEIGHT

The weight of a body is the gravitational force exerted on it by the earth. Weight, being a force, is a vector quantity. The direction of this vector is the direction of the gravitational force that is toward the centre of the earth. The magnitude of the weight is expressed in the units of force, such as newton.

If an observer, stationed in a certain frame of references allows a body to fall, the body will fall with a certain acceleration. However, if we apply a suitable force, we can prevent it from accelerating. This force is a measure of the weight in the frame of reference of the observer. Thus we can define that weight of a body in a certain frame of reference is equal and opposite to the force required to prevent it from accelerating from rest in that frame of reference.

A force is measured by the acceleration, it imparts to a mass m. When a body of mass m is allowed to fall freely, its acceleration due to gravity is g and the force acting on it, is its weight W. According to Newton's second law of motion force is given by

$$F = ma$$

Replacing 'F' by 'W' and 'a' by 'g', in the above equation, we get

$$W = mg$$

The weight of a body is not a fixed quantity. It depends upon the location, as well as upon the motion of the frame of reference. The value of g i.e. the acceleration due to gravity, varies from place to place. Thus the weight of the body also varies from place to place, but its mass will remain the same, provided the velocity of the body is negligibly small as compared to the velocity of light.

6.5 WEIGHTLESSNESS IN SATELLITES

In connection with space exploration, one often encounters

about the weightlessness. It is well known fact that astronauts experience weightlessness when their space craft is orbiting around the earth. In such circumstances, the earth's gravitational pull is just balanced by the centripetal force resulting into weightlessness.

In order to understand the weightlessness in satellites, let us consider a simple case of the weight of a body in an elevator. Sup-

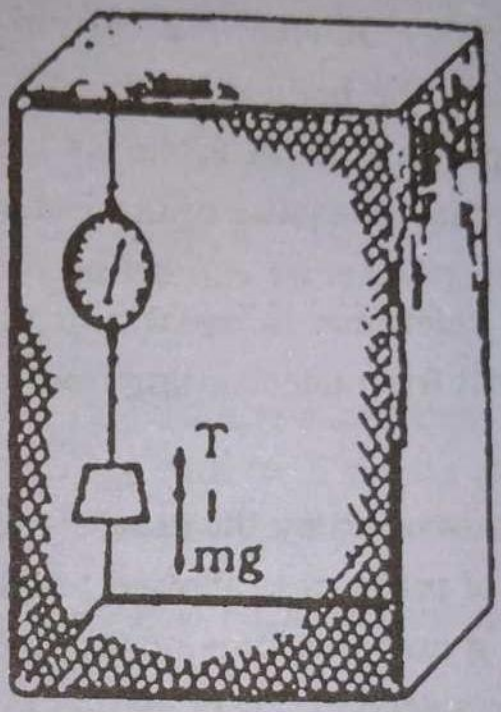

Fig:6.5 A body suspended in an elevator.

pose that a block is suspended from a spring balance by means of a thread attached to the ceiling of the elevator. Fig 6.5

(a) When the elevator is at rest, the force along the thread is equal and opposite to the force of gravity experienced by the block and this represents true weight of the block, i.e. $\vec{F} = m\vec{g}$

(b) When the elevator is ascending with an acceleration $\vec{a}$ relative to the earth, then the equation of motion will be

$$\vec{F}_w - m\vec{g} = m\vec{a} \qquad 6.25(a)$$

$$\vec{F}_w = m\vec{g} + m\vec{a} \qquad 6.25(b)$$

Eq 6.25 (b) gives apparent weight of block which is greater than true weight and the body feels "heavier".

(c) When the elevator is descending with the same accelera-

tion $\vec{a}$, the equation of motion will be

$$m\vec{g} - \vec{F}_w = m\vec{a}$$

$$\vec{F}_w = m\vec{g} - m\vec{a} \qquad 6.26\ (a)$$

6.26 (b)

The Eq. 6.26 (b) gives apparent weight of block which is less than the true weight and the body appears "lighter"

(d) Suppose, if the cable supporting the elevator breaks, the elevator will fall down with an acceleration equal to g. The net force will be

$$\vec{F}_w = m\vec{g} - m\vec{g} \quad [\therefore \vec{a} = \vec{g}]$$

or

$$\vec{F}_w = 0 \qquad 6.27$$

Consequently, the spring balance will read zero and the man in the elevator will find that the block has no weight besides the fact that the force of gravity still acts upon the block and its weight $\vec{w}$ is given by $m\vec{g}$. This is referred as the state of "weightlessness".

Our discussion of apparent weight can also be applied to the phenomenon of "weightlessness" in satellites. Bodies in an orbiting satellite are not weightless; the earth's gravitational attraction continues to act on them just as though they were at rest relative to the earth. But a space vehicle in orbit has an acceleration $a_\perp$ towards the earth's centre equal to the value of the acceleration due to gravity $\vec{g}$ at its orbit radius. The apparent weight $\vec{F}_w$ is given by.

$$\vec{F}_w = m\vec{g} - m\vec{a}_\perp$$

but in this case $\vec{g} = \vec{a}_\perp$

So $\vec{F}_w = 0$

It is in this sense that an astronaut or other body in the space craft is said to be "weightless" or in a state of "Zero g". The

earth's gravity acts on both the spacecraft and the bodies in it, giving each the same acceleration. Thus a body released in side the space craft does not fall relative to it. and it appears to be weightless.

6.6 ARTIFICIAL GRAVITY

In the preceding section, we have seen that all orbiting space crafts along with astronaut and other objects are in the state of free fall, and consequently will be in the state of weightlessness. Weightlessness in space crafts or satellites is highly inconvenient to an astronaut in many ways. For example, he cannot pour liquid into a cup, neither can he drink from it. If the space craft is a space laboratory intended to stay in space for a long period of time, the weightlessness may be a severe handicap to the astronaut in performing experiments. In order to overcome this problem an artificial gravity can be created in the space craft, by spinning it around its own axis. Fig 6.6

So that normal force of gravity can be supplied to the occupants in the spacecraft.

Consider a spacecraft consisting of two chambers connected by a tunnel of length 20 metres. Let us see how many revolutions per second must the space craft make in order to supply artificial gravity for the astronauts. Let T be the time for one revolution and υ be the frequency of rotation, than $\upsilon_t = 1$

The magnitude of centripetal acceleration in this case is given by

$$a_c = \frac{4\pi^2 R}{T^2} = 4\pi^2 \upsilon^2 R$$

where R represents the half of the tunnel length i.e

$$R = \frac{20m}{2} = 10m.$$

$$\therefore v = \frac{1}{2\pi}\sqrt{\frac{a_c}{R}}$$

When a body falls freely $a_c = g$:

$$\therefore v = \frac{1}{2\pi}\sqrt{\frac{g}{R}}$$

$$\therefore v = \frac{1}{2\pi}\sqrt{\frac{9.8ms^{-2}}{10m}}$$

$$= 0.158 \text{ rev/s}$$

$v = 9.5$ revolutions/minute

Thus the astronaut should feel comfortable in space craft spinning at 9.5 revolution/minute at a distance of 10m away from the axis of rotation as shown in Fig. (6.6).

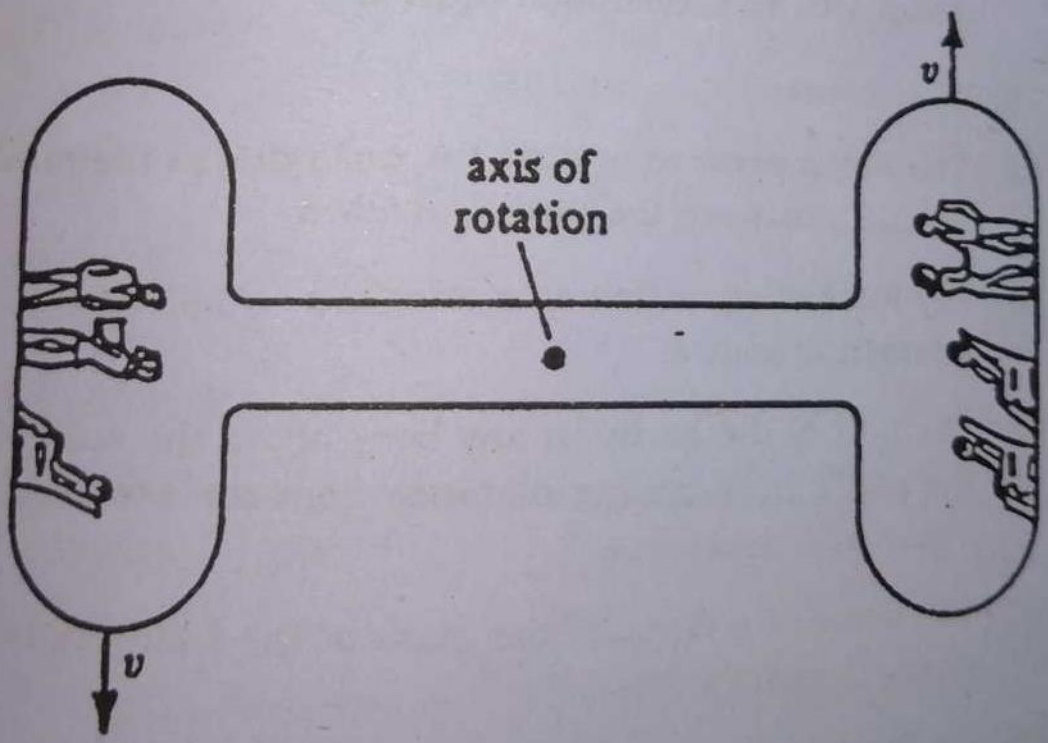

Fig: 6.6 *Rotating spaceship supplies "artificial" gravity for the passengers. Their apparent weight is the sume as on earth.*

OBJECTIVE TYPE QUESTIONS

1 Whether true or false, if false correct the following:

a. Every body in the universe repels every other body with a force which is inversely proportional to the product of their masses.

b. The force of gravitational attraction is directly proportional to the square of the distance between two bodies.

c. The force with which the earth repels a body on its surface towards its centre is equal to its weight.

d. The value of g increases with the increase of the distance of the body from the centre of earth.

e. Gravitational force is of a very large order of about 6.67×10^{-11} Nm^2/kg^2.

f. If the cable carrying the elevator breaks, the elevator will go up with an acceleration equal to g.

2 Fill in the blanks

(a) The moon revolves around the earth due to the presence of ..... between the earth and moon.

(b) The force of attraction acts along the .... joining the two interacting bodies.

(c) The pull of the earth on any body above the surface of the earth ..... as the distance from the centre of the the earth decreases.

(d) The value of g is .... of the mass of the falling body towards the earth.

(e) Artificial gravity can be supplied by .... the space craft so that normal force of gravity can be supplied to the passengers.

3 Select the appropriate answer.

(a) The sun exerts a force of attraction on the planets thus keeping them in their:

(i) axes (ii) radii (iii) orbits (iv) State of motion

(b) The force with which the earth attracts the other body towards its centre is given by:

(i) $F = \frac{M_E m}{R_E^2}$ (ii) $F = G\frac{M_E m}{R_E^2}$

(iii) $F = \frac{R_E^2 M_E m}{G}$

(c) Numerical value of G can also be estimated by knowing the :

(i) average density of earth (ii) circular motion

(iii) mass of earth.

(d) If we go away from the surface of the earth a distance equal to the radius of earth the value of g will become:

(i) one fourth (ii) one eighth (iii) one ninth

(e) Weight of a body is :

(i) vector (ii) scalar (iii) rotational quantity

QUESTIONS

1. State and explain the Newton's Universal Law of Gravitation.
2. Once value of G has been measured in the laboratory, how it can be used to determine the mass of the earth. Explain.
3. How one can determine the mass of Moon?
4. Explain how the value of g varies with a change in the altitude. What is the effect of depth on the value of g ?

5. Discuss the concept of weightlessness in the motion of space crafts.

6. Explain how artificial gravity is useful in space technology.

PROBLEMS

1. A 10 kg mass is at a distance of 1 m from a 100 kg mass. Find the gravitational force of attraction when
   (a) 10 kg mass exerts force on the 100 kg mass
   (b) 100 kg mass exerts force on the 10 kg mass

   (Ans. 6.67×10^{-8} N in both cases)

2. Compute gravitational acceleration at the surface of the planet Jupiter which has a diameter as 11 times as compared with that of the earth and a mass equal to 318 times that of earth.

   (Ans. 2.63 times that of earth)

3. The mass of the planet Jupiter is 1.9×10^{27} kg and that of the sun is 2.0×10^{30} kg. If the average distance between them is 7.8×10^{11} m, find the gravitational force of the sun on Jupiter.

   (Ans. 1.613 m7s^2: 69.8)

4. The radius of the moon is 27% of the earth's radius and its mass is 1.2% of the earth's mass. Find the acceleration due to gravity on the surface of the moon. How much will a 424N body weight there?

   (Ans. 1.613m/s^2 : 69.8 N)

5. What is the value of the gravitational acceleration at a distance of
   (i) earth's radius above the earth's surface?
   (ii) Twice earth's radius above the earth's surface.

   (Ans. 2.45 m/s^2, 1.09 m/s^2)

6. At what distance from the centre of the earth does the gravitational acceleration have one half the value that it has on the earth's surface?

(Ans. 1.41 earth's radius)

7. Compute the gravitational attraction between two college students of mass 80 and 50 kg respectively, 2m apart from each other. Is this force worth worrying about?

(Ans 6.67×10^{-8} N, Not at all)

8. Determine the gravitational attraction between the proton and the electron in a hydrogen atom, assuming that the electron describes a circular orbit with a radius of 0.53×10^{-10} m (mass of proton = 1.67×10^{-27} kg
mass of electron = 9.1×10^{-31} kg)

(Ans. 3.62×10^{-47} N)

9. A woman with a mass of 45 kg is standing on a scale in an elevator. The elevator accelerates upward with a constant acceleration of 1.2 m/s^2. What is the woman's weight as measured by her in the elevator.

(Ans: 495N)