Motion

Rest and Motion

We use the word ‘rest’ very often. For example, when someone is doing no work or lying on the bed, we often say that the person is resting. This means that the person is not moving. Scientifically as well, the word ‘rest’ has a similar meaning.

Scientifically, we say an object is at **rest** when the position of the object **does not change** with **time**, with respect to its **surroundings.**

Similarly, **motion** is defined as the change of position of an object with **time**, with respect to its **surroundings**.

What do we mean by **with respect to the surroundings**?

We know that a moving train is in motion because its position changes with time. Now, consider a person sitting in the train. For someone standing on the platform, the person sitting in the train is in motion. But for the co-passengers, the person is at rest as the position of the person does not change with time.

Therefore, we need to consider the surroundings or the point of observation while describing the state of motion of an object. The surroundings is called reference frame.

What the above discussion shows us is that rest and motion are relative. They can be different for different observers. If someone views the Earth from the universe, then all the things on the Earth (such as houses, trees, a moving train, etc.) are in motion for that person.

But for a person on the Earth’s surface, things such as houses, trees, etc., are at rest. So, when we say that an object is at rest, what we really mean is that the object is at rest with respect to its surroundings.

Types of Motion

So, you have already learned that all the objects around us can be classified as either **moving** or **stationary**. This classification of object is based on whether they change their position with time or not. If an object changes its position with time, then it is called moving object.

Here, we will discuss different types of motion of moving objects and the basis of their classification.

Classification of motion:

The motion of objects can be classified depending on the way they move. Let us learn more about the aspects of these types of motion.

i) Translatory motion:

In this motion, the object moves in a line such that each point of the object covers equal distance in equal time. It is further classified into two types:

a) Rectilinear motion:

Let us first look at examples of some moving objects.

Now, we can define rectilinear motion.

An object is said to have rectilinear motion if it moves from one point to another in a straight line.

Another very common example of rectilinear motion is the motion of a moving car on a straight road.

Try to find more examples of rectilinear motion.

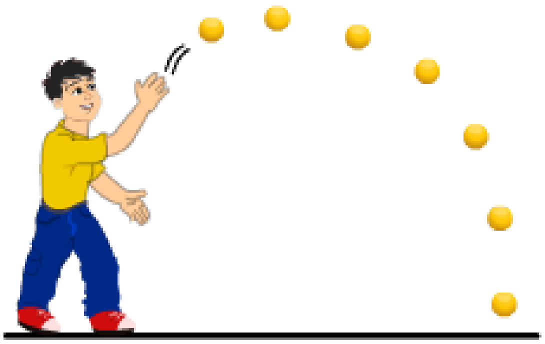
Can you compare the different motion given in the figure?

The motion of a convoy is uniform as the speed of all the vehicles is same throughout. This type of motion in which no change in speed of the object is observed is known as **uniform rectilinear motion.**

While the motion of launching rocket is not uniform as the speed of rocket goes on increasing as it goes higher. This type of motion in which the change in speed with which the object moves is observed is known as **non-uniform rectilinear motion.**

b) Curvilinear motion:

An object moving in a curve path is said to posses curvilinear motion.

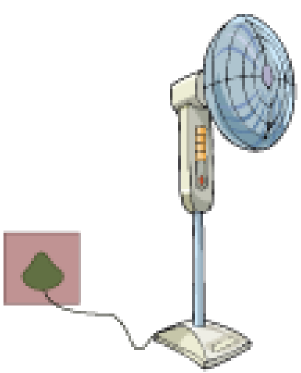


ii)

Circular motion:

An object is said to possess circular motion if it moves from one point to another in such a way that its distance from a fixed point always remains constant.

You have already seen an example of circular motion in the animation. Another simple example of this type of motion is the movement of the blades of a fan. During their motion, the blades move from one point to another, but the distance between them and the head of the fan remains the same.



List some objects in your house that possess circular motion.

iii)

Periodic motion:

An object is said to possess periodic motion if it moves in such a way that it repeats its motion after a certain interval of time.

Other examples of periodic motion are the motion of a swing, the motion of a guitar string, the motion of the head of a drum, etc.

List these objects in a table along with their types of motion. Does any visible part of the sewing machine have a periodic motion?

All oscillatory motions can be termed as periodic motions but all periodic motion can not be termed as oscillatory motion.

For example movement of the pendulum is an oscillatory motion as well as periodic, while rotation of the earth is a periodic motion but not oscillatory.

Therefore, the type of motion in which the object moves to and fro repeatedly about a mean or a fixed position is known as **oscillatory motion.**

Vibratory motion is a kind of oscillatory motion in which a part of body always remains fixed and the rest part moves to and fro about the fixed position. Also, in vibratory motion, the shape and size of the body changes.

The motion which does not repeat itself after regular interval of time is called non-periodic motion.

iv) Rotational motion:

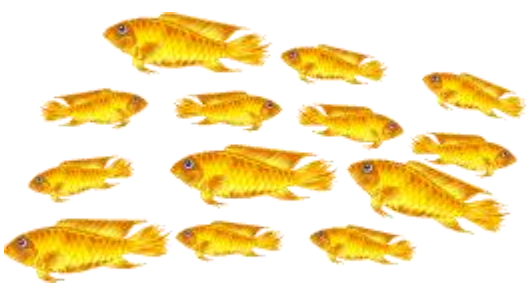
An object is said to possess rotational motion if it whirls around a fixed axis that passes through it.

Do not get confused with a circular motion. For better understanding, let us see an example.

The hands of a wall clock move about the fixed center. Hence, a clock’s hands have rotational motion. But remember, the tips of the hands of the clock have circular motion.

viii) Random Motion

If the object changes its direction and speed continuously without following a particular pattern then it is said to possess **random motion.**

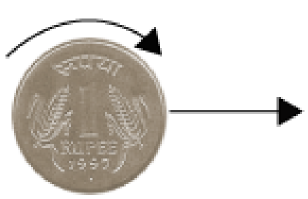


For example, movements of fish, butterfly etc. shows random motion as they do not follow a particular direction.

Some moving objects have more than one type of motion. Let us see.

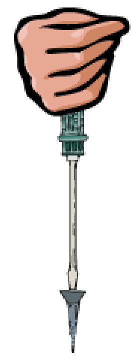
Combination of different types of motion

- **Rolling coin**



A coin rolling on a floor moves forward by rotating about an axis perpendicular to the surface of the coin. It shows the properties of both linear and rotational motion.

- **Screw motion**

When you tighten or loosen a screw with the help of a screwdriver, you rotate it clockwise or anticlockwise. As a result, the screw moves straight inwards or outwards, respectively. Hence, you can easily say that screw motion is linear as well as rotational.	

Which type of motion does a moving top have?

Do you want one more example of the combination of motion?

Here it is.

Speed

Sourabh and Apurva go to school on their bicycles. Sourabh covers 200 m in 4 minutes and Apurva covers the same distance in 5 minutes. **Who cycles faster?**

In this section, we will discuss the concept of speed and how it is used in solving various problems in our daily life.

Speed

The slowness or fastness of an object can be related with the help of their speeds. **The speed of a moving object is defined as the distance covered by it in unit time.** For example, if a car covers a distance of 25 km in one hour, then it is said that the car is moving with a speed of 25 km per hour. The speed of a vehicle can be measured by dividing the total distance covered by it by the total time it takes to cover that distance.

$$\text{Speed} = \frac{\text{Total distance covered } (d)}{\text{Total time taken } (t)}$$

You may have observed many times that the speed of your school bus keeps changing its motion along a straight path because of heavy traffic, traffic signals, etc. This is an example of **non-uniform motion**. In this type of motion, a vehicle’s speed keeps changing with time. In this case, the speed can be determined in terms of its "**average**" speed. Average speed is determined by dividing the total distance covered by the total time taken.

In the case of **uniform motion**, a vehicle moves with constant speed along a straight path. Hence, its average speed is the same as its actual speed.

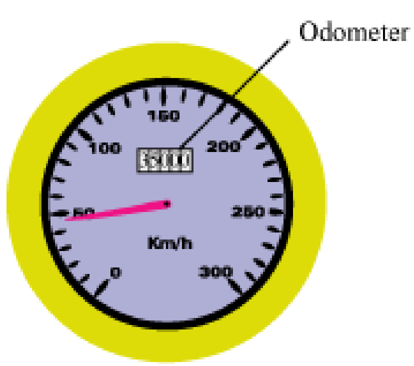
- An object that takes the minimum amount of time to cover a given distance is the one moving with the highest speed, whereas an object that takes the maximum amount of time to cover the same distance is the one moving with the slowest speed.

The times taken by each cyclist to complete one round of a racing circuit are given in the table. **Who is the fastest cyclist?**	
Participant	**Time taken (in seconds)**
Rajesh	12
Manish	22
Sujoy	12
Anuj	10
Pawan	8
Gaurav	9
Samik	17
Biswas	16

Do You Know:

Maglev trains are one of the fastest trains in the world. They can move at an average speed of 450 km/h i.e., they can cover a distance of 450 km in just an hour!

Modern vehicles use **speedometers** that measure speed in units of km/h. They also include **odometers** that record the total distance travelled by vehicles in units of kilometre (km). A simple speedometer with an odometer is shown in the given figure.



Speedometer

Calculation of Speed

Atul takes 3 minutes to travel a distance of 300 m to reach his school. Can you determine his speed?

In this section, we will learn to solve problems related to speed.

We know that the speed of a body in motion is represented by the given relation.

$$\text{Speed} = \frac{\text{Distance covered}}{\text{Time taken}}$$

In the question given above, we have

Distance covered = 300 m

Time taken = 3 minutes = 180 s

Speed = $\frac{300\text{ m}}{180\text{ s}}$

$$= \frac{5}{3}$$
$$= 1.67\text{ m/s}$$

In the same way, the speed of a moving body can also be expressed in km/hr. However, that depends on the requirement of the situation.

The unit of speed is metre per second (m/s) or kilometre per hour (km/h).

Example: A school bus covers a distance of 5 km between a student’s house and the school in 30 minutes. What is the speed of the bus?

Solution:

The speed of the bus between the student’s house and the school can be determined by dividing the total distance covered by the total time taken by the bus.

$$\text{Speed} = \frac{\text{Total distance covered}}{\text{Total time taken}}$$

Since the total distance between the student's house and the school is 5 km and the time taken by the bus is 30 minutes,

$$\text{Speed} = \frac{5\text{ km}}{30\text{ minutes}}$$
$$(\because 1\,\text{h} = 60\,\text{minutes})$$
$$= \frac{5\,\text{km}}{0.5\,\text{h}}$$
$$= \frac{5\times 10}{5}$$
$$\text{Speed} = 10\,\text{km/h}$$

Hence, the speed of the bus between the student's house and the school is 10 km/h.

A train crosses a tunnel of length 100 m in 9 seconds. What is its speed in km/h?

To solve such a problem, one should know the concept of conversion between m/s and km/hr.

- **To convert km/hr into m/sec, we multiply the quantity with 5/18.**
- **To convert m/sec into km/hr, we multiply the quantity with 18/5.**

Hence,

Distance = 100 m

Time = 9 s

Speed = $\frac{100}{9}$ m/s

In terms of kilometre per hour, this speed can be written as

Speed = $\frac{100}{9} \times \frac{18}{5} = 40 \text{ km/h}$

= 40 km/h

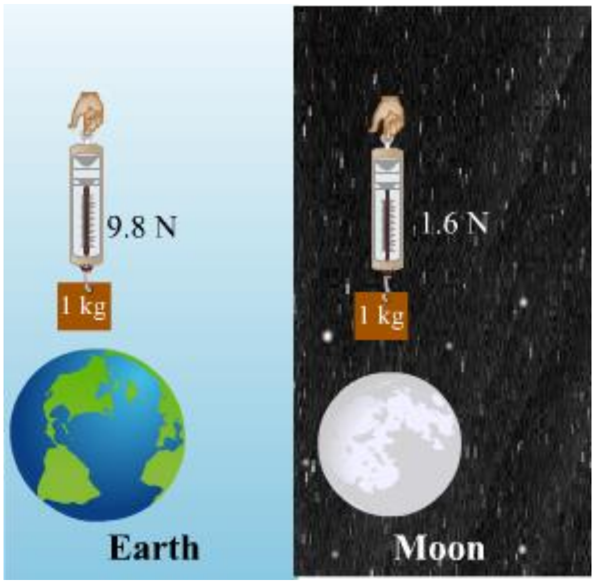
Now, try to do this yourself.

A car travels a distance of 105 km in 3 hours. Calculate its speed in m/s.

Mass and Weight

Mass and Weight: An Overview

Do you know that the mass of a body remains constant? And that the weight of the same body can vary from zero to any finite value, depending upon the celestial body on which it is kept? Have you heard about weightlessness? A body has weight because of gravity; the same body can experience weightlessness under the same gravity. Strange, isn't it?



Suppose a body of mass 1000 kg is placed on Earth's surface and then on the surface of the moon. The mass of the body will remain the same at both places, but it will have different weights (9800 N on Earth and 1600 N on the moon).

The mass of an object is defined as the amount of matter present in it.

It is the measure of the inertia possessed by an object. It is one of the three fundamental physical quantities, the other two being length and time. The mass of an object is usually represented by the small letter '*m*'. Its SI unit is kilogram (kg).

The mass of an object is a conserved quantity. It can be neither created nor destroyed during physical or chemical changes. During a physical or chemical process, the total mass of the objects involved remains constant.

Did You Know?

You might know the famous mass–energy equation given by Albert Einstein.

$E = mc^2$

This equation expresses the amount of energy created when mass (m) is lost in a process. The letter ‘c’ represents the speed of light in vacuum and is numerically equal to 3×10^8 m/s. Let us consider that somehow we are able to completely convert 1 g (= 0.001 kg) of mass into energy. The resultant energy is given as:

$E = 0.001 \times (3 \times 10^8)^2$

$\Rightarrow E = 10^{-3} \times 9 \times 10^{16}$

$\Rightarrow E = 9 \times 10^{13}$ J

This energy is enough to meet the electricity needs of India for more than a year!!

A body contains the same quantity of matter whether it is on Earth, on Mars or in outer space. So, if the mass of an object is 10 kg on Earth, then it will have the same mass on Mars, on the moon and even in outer space. The mass of an object can never be zero.

Weight

The weight of an object is the force of gravity on the object and may be defined as the product of its mass and acceleration due to gravity.

We know that:

Force = Mass × Acceleration

The acceleration produced by Earth’s force of attraction is known as acceleration due to gravity and is denoted by the letter ‘g’. Thus, the downward force acting on a body is given by:

Force = $m \times g$

Where, m is the mass of the body

By definition, Earth’s force of attraction on a body is known as the weight of the body. Hence, on writing ‘Weight’ (W) in place of ‘Force’ in the above equation, we get:

Weight, $W = m \times g$

Where, m = Mass of the body

g = Acceleration due to gravity

Weight has the same SI unit as force, i.e., newton (N).

Now, let us calculate the weight of an object having a mass of 1 kg on Earth's surface.

We know that acceleration due to gravity on Earth's surface is 9.8 m/s^2.

Therefore, weight of the object = $m \times g$ = 1 kg × 9.8 m/s^2 = 9.8 N

Know More

Weight has magnitude as well as direction. The weight of a body acts in vertically downward direction and is given by mg. Since the value of 'g' (acceleration due to gravity) changes from place to place, the weight of a body also changes from place to place, i.e., the weight of a body is not constant. In interplanetary space, acceleration due to gravity is negligible. Thus, the weight of a body is zero in interplanetary space, and because of this, one experiences weightlessness.

Acceleration due to gravity increases at the poles. As a result, the weight of an object increases at the poles. Acceleration due to gravity decreases at higher altitudes. As a result, the weight of an object decreases at higher altitudes. Acceleration due to gravity decreases under Earth's surface. As a result, the weight of an object decreases under Earth's surface and becomes zero at Earth's centre.

The weight of an object on Earth is the force with which Earth attracts the object toward itself. Similarly, the weight of an object on the moon is the force with which the moon attracts the object toward itself.

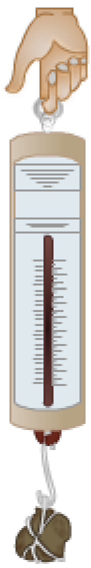
Differences Between Mass and Weight

S. No.	Mass	Weight
1.	Mass is the amount of matter contained in a body.	Weight is the force exerted on a body due to the gravitational pull of another body such as Earth, the sun and the moon.
2.	Mass is an intrinsic property of a body.	Weight is an extrinsic property of a body.
3.	Mass is the measure of inertia.	Weight is the measure of force.
4.	The mass of a body remains the same everywhere in the universe.	The weight of a body depends on the local acceleration due to gravity where it is placed.

5.	The mass of a body cannot be zero.	The weight of a body can be zero.
6.	The SI unit of mass is kilogram (kg).	Since weight is a force, its SI unit is newton (N).
7.	The mass of a body can be measured using a beam balance and a pan balance.	The weight of a body can be measured using a spring balance and a weighing machine.

Differences Between Mass and Weight

Spring Balance and Beam Balance



While commonly used for measuring the mass of a body, what a spring balance actually measures is the weight of the body (or the force acting in the downward direction).

It can be used locally to measure mass when calibrated correctly according to the value of acceleration due to gravity at the given place.

A spring balance shows different readings on different planets because of the differing values of acceleration due to gravity.

In a spring balance,

$mg = kx$

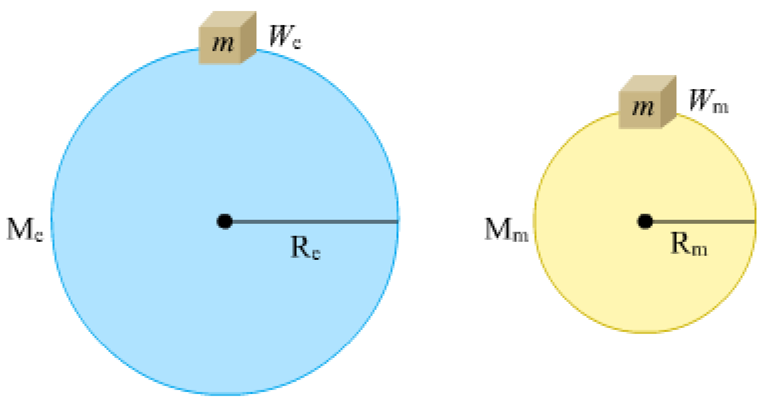
Where, x is the extension produced in the spring and k is the spring constant.

$\therefore x = mg/k$

So, for differing values of *g*, *x* also has different values.

A beam balance is also used for measuring the mass of a body. It does so by comparing the mass of the body with a given standard mass.

Weight of an Object on the Moon



Suppose an object having a mass *m* and weight W_e on Earth, is brought to the surface of the moon.

So, we have:

Mass of the object = *m*

Weight of the object on Earth = W_e

Let us take:

Mass of Earth = M_e

Radius of Earth = R_e

Weight of the object on the moon = W_m

Mass of the moon = M_m

Radius of the moon = R_m

Since the mass of the object remains the same everywhere in the universe, it will be the same on both Earth and the moon.

Newton's law of gravitation gives the weight of the object on the moon as:

$$W_{\mathrm{m}} = G\frac{M_{\mathrm{m}} \times m}{R_{\mathrm{m}}^2} \quad \ldots . (\mathrm{i})$$

Its weight on Earth is given as:

$$W_{\mathrm{e}} = G\frac{M_{\mathrm{e}} \times m}{R_{\mathrm{e}}^2} \quad \ldots . (\mathrm{ii})$$

The values of the mass and radius of Earth and the moon are given in the following table.

	Mass	**Radius**
Earth	5.98×10^{24} kg	6.37×10^{6} m
Moon	7.36×10^{22} kg	1.74×10^{6} m

Hence, equation (ii) gives the weight of the object on Earth as:

$$W_e = G \times \frac{5.98 \times 10^{24} \times m}{\left(6.37 \times 10^{6}\right)^2}$$

$W_e = 1.4737 \times 10^{11}\, m$ G… (iii)

Equation (i) gives its weight on the moon as:

$$W_m = \frac{G \times 7.36 \times 10^{22} \times m}{\left(1.74 \times 10^{6}\right)^2}$$

$W_m = 2.4309 \times 10^{10}\, m$ G… (iv)

On dividing equation (iv) by equation (iii), we obtain:

$$\frac{W_m}{W_e} = \frac{2.4309 \times 10^{10} mG}{1.4737 \times 10^{11} mG}$$

$$\frac{W_m}{W_e} = \frac{1}{6}$$

$$\boxed{\frac{\text{Weight of the object on the moon}}{\text{Weight of the object on Earth}} = \frac{1}{6}}$$

From the above result, we can infer that:

- The weight of an object on the moon is one-sixth of its weight on Earth.
- The acceleration due to gravity on the moon is one-sixth of the acceleration due to gravity on Earth.

Solved Examples

Easy

Example 1:

A toy has a mass of 1 kg. Its weight is measured at the equator and at the North Pole using a spring balance. Where do you think the toy would weigh more?

Solution:

Acceleration due to gravity is more at the North Pole than at the equator. Thus, an object weighs more at the North Pole than at the equator. Hence, the toy will weigh more at the North Pole.

Example 2:

A block of mass 10 kg is taken to the moon. If the acceleration due to gravity on the moon is 1.63 m/s^2, then what is the weight of the block on the moon?

Solution:

Weight, $W = m$g

Where, m = Mass of the block = 10 kg

g = Acceleration due to gravity on the moon = 1.63 m/s^2

$\therefore W = 10 \times 1.63 = 16.3 \text{ N}$

Example 3:

A horizontal force of 10 N acts on a block weighing 9.8 N. What is the acceleration produced in the block? (Take g = 9.8 m/s^2)

Solution:

Weight of the block = Mass of the block × Acceleration due to gravity
Let the mass of the block be *m.*

⇒ 9.8 = *m* × 9.8
∴ *m* =1 kg

Accerleration produced in the block =

$$\frac{\text{Force acting on the block}}{\text{Mass of the block}} = \frac{10 \text{ N}}{1 \text{ kg}} = 10 \text{ m/s}^2$$

Medium

Example 4:

Why does the weight of an object change when we move from the poles to the equator?

Solution:

Earth's radius increases when we move from the poles to the equator. The value of acceleration due to gravity is **inversely proportional** to Earth's radius (*R*). So, as we move from the poles to the equator, the gravitational force decreases.

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

The equation makes it clear that as *R* increases, the value of *g* decreases.

Now, the weight of an object is the product of its mass and the gravitational force. So, the weight of the object will decrease as we move from the poles to the equator.

Hard

Example 5:

If a man's weight is 80 N on Earth's surface, then how far must he go from Earth's centre so as to weigh 40 N? (Take Earth's radius = 6400 km)

Solution:

Weight (*W*) of the man on Earth's surface = 80 N

The acceleration due to gravity g at height *h* above Earth's surface is given as:

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

Weight of the man at height *h* is:

$$W = mg = \frac{GMm}{(R+h)^2} = \frac{GMm}{\left(R\left(1+\frac{h}{R}\right)\right)^2}$$

$$\Rightarrow W = \frac{GMm}{R^2} \times \left(\frac{R}{R+h}\right)^2$$

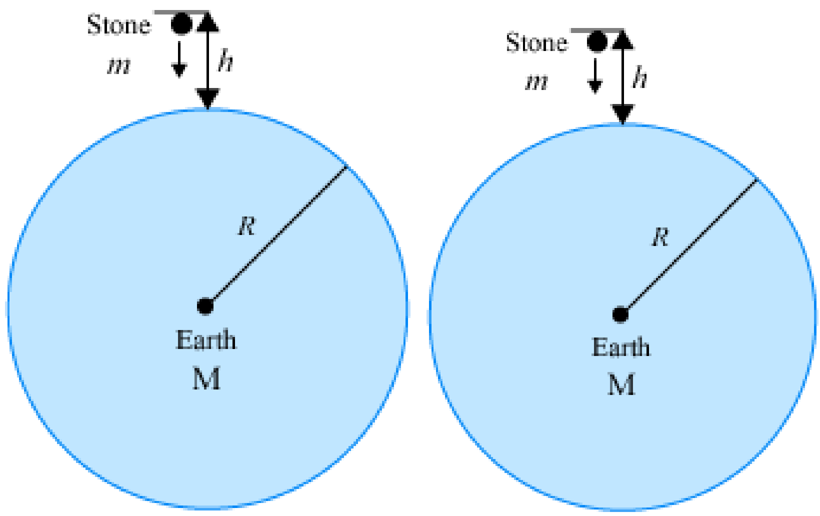
$$\Rightarrow W = mg\left(\frac{R}{R+h}\right)^2$$

$$\Rightarrow 40 = 80 \times \left(\frac{R}{R+h}\right)^2$$

On solving, we get:

$$h = \left(\sqrt{2} - 1\right)R = 0.414R$$

$$\text{So, } h = 2.65 \times 10^6 \text{ m}$$



Therefore, the man must go (R+h) = ($6.4 \times 10^6 + 2.65 \times 10^6 = 9.05 \times 10^6$) m far from Earth's centre so as to weigh 40 N.

Weightlessness

Weightlessness describes the situation wherein the weight of a body becomes zero.

The effective weight of the body at a place (or in a situation) is zero when the effective acceleration due to gravity at that point is zero.

Let us read about the situations wherein the weight of a body becomes zero.

Case I: When the body is taken to Earth's centre

The effective value of acceleration due to gravity at Earth's centre is zero.

Therefore, weight of the body at Earth's centre = $mg' = m \times 0 = 0$

Case II: When the body is revolving around Earth under the influence of the gravitational force

Earth's gravitational pull on the body (acting towards Earth's centre) is balanced by the centrifugal force on the body (acting away from Earth's centre). In consequence, the effective weight of the body becomes zero.

Case III: When the body is inside a lift falling freely under Earth's gravitational force

Acceleration of the lift, $a = g$

Effective acceleration due to gravity = $g' = g - a = g - g = 0$

Hence, effective weight of the body = 0

Solved Examples

Easy

Example:

What is the weight of a body of mass *m* near Earth's surface during its free fall?

Solution:

Weight is a physical quantity that can be experienced only when the body opposes the force of gravity. During free fall, the body does not oppose Earth's gravitational force; hence, its weight is zero.

Did You Know?

The motion of a satellite around Earth is an example of free fall. The satellite, at every point, is falling freely toward Earth.

A black hole is formed when a star completely collapses on its gravitational force. A black hole has an intense gravitational field around itself. Nothing can escape from this gravitational field, not even light!