On Board!
BOOKS

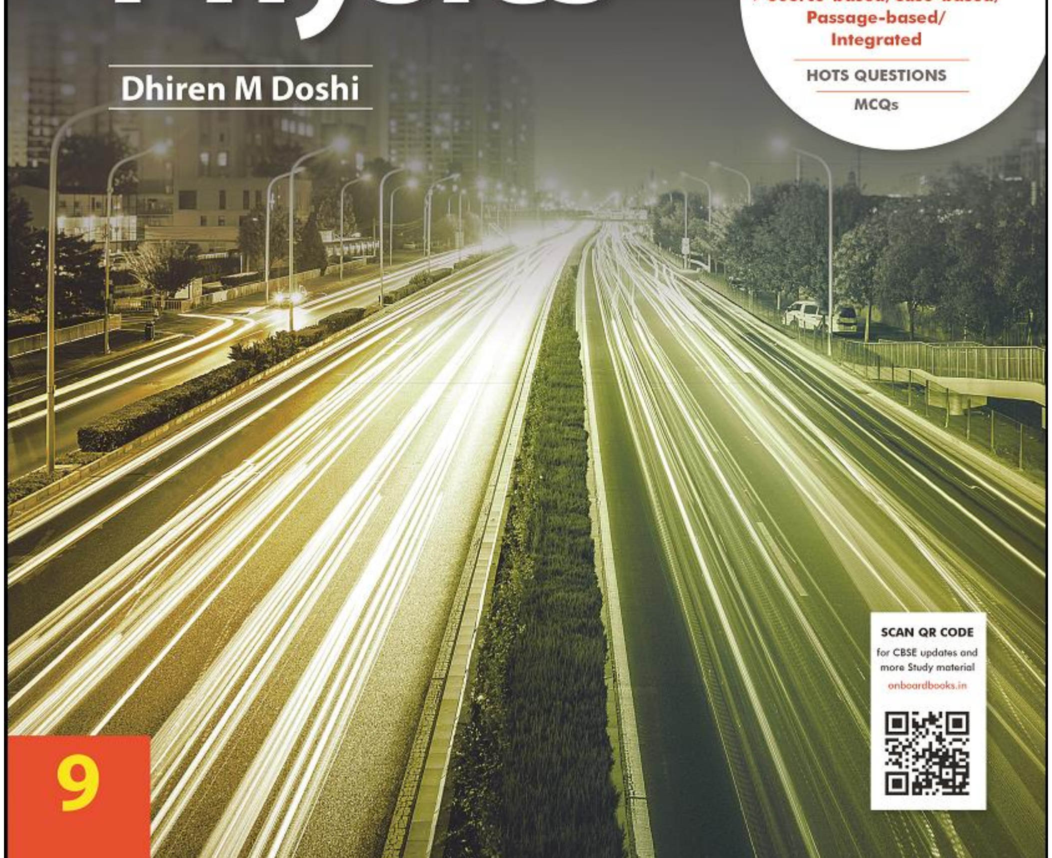
As per the guidelines of **NEP 2020**

Living Science
Physics

Dhiren M Doshi

Includes
COMPETENCY-BASED QUESTIONS (CBQs)
- ✓ Assertion-Reasoning
- ✓ Source-based/Case-based/Passage-based/Integrated

HOTS QUESTIONS
MCQs



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CBSE
Living Science
Physics

Class 9

Chapter-3 Gravitation

LEARNING OBJECTIVES

Universal Law of Gravitation

- **❖Universal gravitational constant**
- **❖Value of G**
- **❖ Inverse-Square Law**
- **❖ Importance of universal law of gravitation**

Newton's Third Law of Motion and Gravitation

Kepler's Laws Regarding the Motions of Planets

- **❖ Free Fall**
- **❖Acceleration due to gravity**
- **❖ Relation between g and G**
- **❖ Variation of acceleration due to gravity**

Equations of Motion for Freely Falling Bodies

Mass and Weight

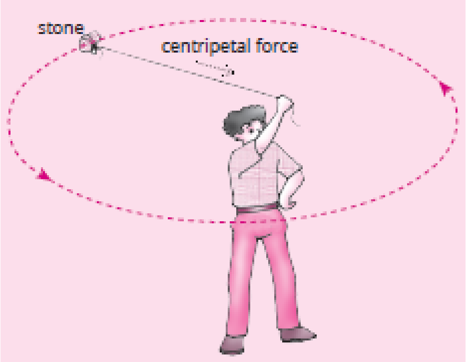
How is gravitation different from gravity?

Any two particles (or objects) in the universe attract each other with a force called the **force of gravitation or gravitational force**. The phenomenon of attraction between different bodies in the universe is called **gravitation.** The force of gravitation exerted by the earth is called **gravity.**

Gravitational Force acting as a Centripetal force

Newton proposed that it was the gravitational force of the earth which was responsible for keeping the moon in its orbit around the earth. He argued that at each point in its orbit, the moon falls towards the earth, instead of going off along a straight line. So it must be attracted by the earth. But we do not really see the moon falling towards the earth.
Newton concluded that the motion of the moon around the earth is due to the centripetal force provided by the force of attraction of the earth.

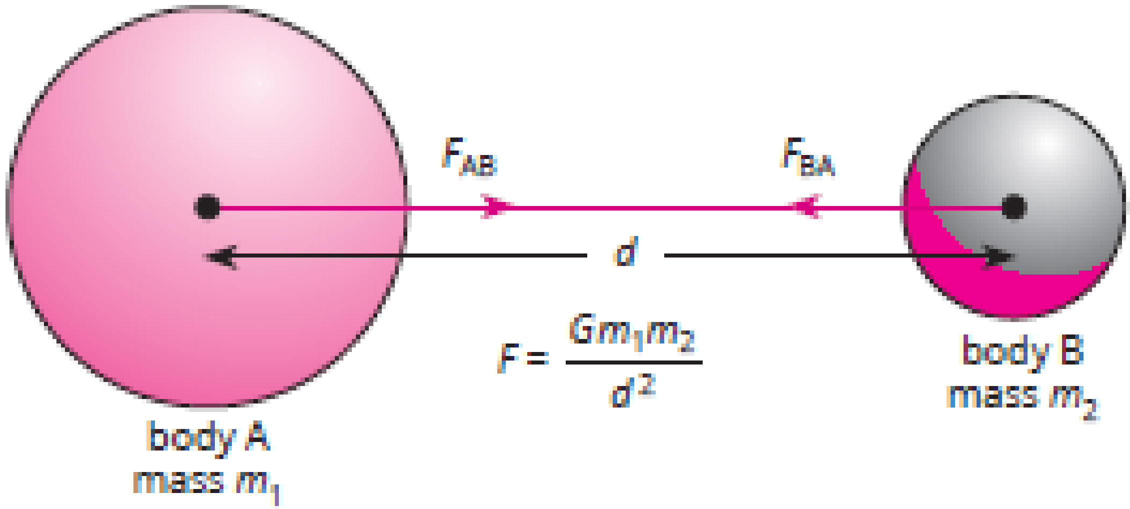
The force that causes acceleration and keeps the stone moving along circular path is acting towards the centre, i.e. towards the hands. This force is called **centripetal force.** Hence, centripetal force is the force which is needed to make an object travel in a circular path.



The hand holding the thread provides the centripetal force. When the thread is released, the stone does not experience the centripetal force and flies off along a straight line. This straight line is always tangential to the circular path (at that point).

Universal Law of Gravitation

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. The force acts along the line joining the centres of the two bodies.



Gravitational force $F = G\, m_1m_2/\, d^2$ where G is the constant of proportionality and is called the **universal gravitational constant.** The universal gravitational constant is equal to the force of attraction acting between two bodies each of unit mass (i.e. 1 kg) whose centres are placed unit distance (i.e. 1 m) apart. The SI unit of the universal gravitational constant (G) is N m^2/kg^2 or N m^2/kg^{-2}.

Value of G

$$G = Fd^{2} / m1 \times m2$$

The SI unit of the universal gravitational constant (*G*) is $N\ m^2/kg^2$ or $N\ m^2/kg^{-2}$

- Universal Gravitational Constant *G* is a **scalar quantity**.
- The value of *G*, $6.673 \times 10^{-11}\ N\ m^2/kg^2$ is same throughout the universe. This is the reason, it is called the universal gravitational constant
- The value of *G* does not depend upon the nature, size or masses of the bodies.
- The value of *G* does not depend upon the nature of medium between the two bodies.

Inverse-Square Law

Universal law of gravitation is also known as the **Inverse-Square Law** because the force of attraction (*F*) between two bodies is inversely proportional to the square of the distance (*d*) between them.

Universal law of gravitation is also known as **universal law** because it is applicable to all bodies, whether they are big or small, or whether they are terrestrial or celestial.

Importance of universal law of gravitation

1. It is the gravitational force between the sun and all the eight planets which makes them move around the sun.

2. It is the gravitational force between the earth and the moon which makes the moon move around the earth.

3. It is the gravitational force exerted by the sun and the moon on sea water leading to the formation of tides in the sea.

4. It is the gravitational pull of the earth which is responsible for holding the atmosphere near the surface of the earth.

5. It is the gravitational pull of the earth which is responsible for the fall of the rain and snow towards the surface of the earth.

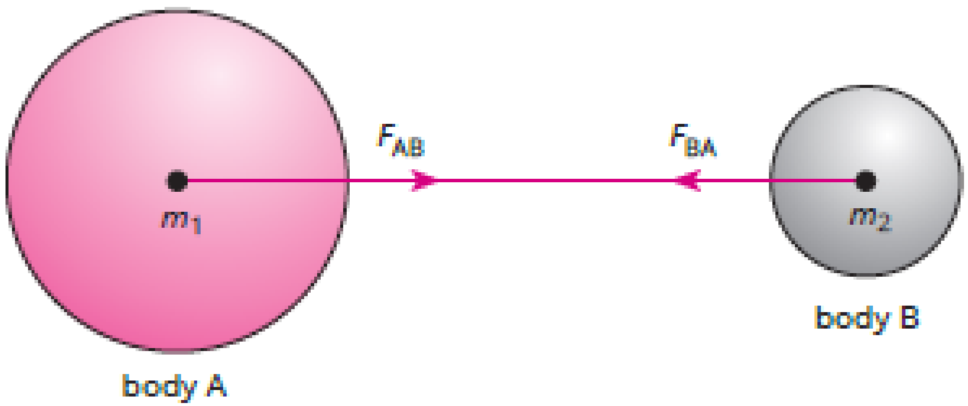
6. The prediction about solar and lunar eclipses, made on the basis of universal law of gravitation, always come out to be accurate.

Gravitational force is the weakest and yet it is the strongest force in nature

The force between two objects (or bodies) which are very small is extremely negligible, whereas that between two objects which are very big and have very large masses is extremely large.

Newton's Third Law of Motion and Gravitation

The gravitational force exerted by body A on body B is equal and opposite to that exerted by body B on body A.



$$F = G\,Mm/\,d^2$$

We know, mass of the earth (M) = 6×10^{24} kg , Mass of a rock (m) = 1 kg

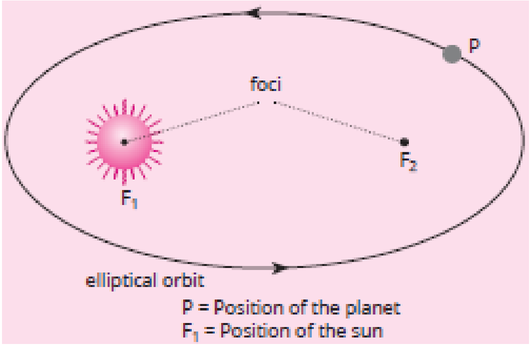
Distance between the rock and centre of the earth, i.e. radius of the earth (d) = 6.4×10^{6} m and $G = 6.67 \times 10^{-11}$ N m^2/kg^2

Putting these values of G, M, m and d in the above formula, we get

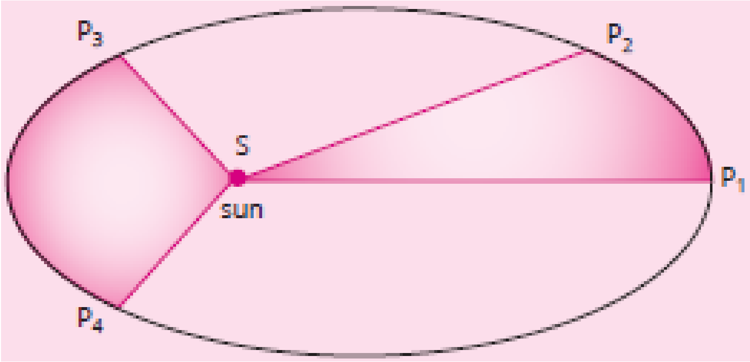
$$F = 9.8\text{N}$$

Thus, the gravitational force acting between the rock of mass 1 kg and the earth is 9.8 N.

Kepler's Laws Regarding the Motions of Planets



Kepler's first law: According to Kepler's first law of planetary motion, every planet revolves around the sun in an elliptical orbit with the sun situated at one of the foci of the ellipse.



Kepler's Second Law: According to Kepler's second law of planetary motion, each planet moves in such a way that an imaginary line drawn from the sun to the planet sweeps out equal areas in equal intervals of time.

Kepler's Third Law: According to Kepler's third law of planetary motion, the cube of a planet's average distance from the sun is directly proportional to the square of the time period of revolution of the planet around the sun.

If T is the time needed by a planet to complete its one revolution around the sun and r is the mean distance of the planet from the sun, then according to Kepler's third law of planetary motion

$$r^3 \propto T^2 \quad \text{or} \quad r^3/T^2 = \text{constant}$$

An ellipse, in geometry, is a closed two-dimensional curve

Free Fall

Whenever objects fall towards the earth only under the gravitational force of the earth (with no other forces acting on it), we say the objects are in the state of free fall. Galileo showed that all bodies, whether light or heavy, fall at the same speed towards the earth.

Robert Boyle's Experiment

Galileo's arguments were experimentally tested by the British scientist Robert Boyle. He kept a coin and a feather in a big glass jar. The air inside the jar was removed by using a vacuum pump. After evacuation of air from the glass jar, it was inverted. Both feather and the coin fell to the bottom of the jar at the same time, thereby proving Galileo right. Thus, acceleration produced in free falling bodies is the same and does not depend on masses of the falling bodies.

Acceleration due to gravity

The uniform acceleration produced in a body when it falls freely under the effect of gravity (gravitational force of earth) alone is known as acceleration due to gravity. It is denoted by the letter, *g*. The SI unit of *g* is the same as that of acceleration, i.e. m/s^2.

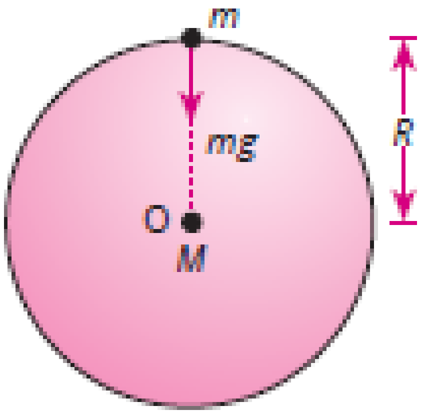
Relation between g and G

According to Newton's Universal Law of Gravitation,

$$F = G\,Mm/R^2$$

But $F = ma = mg$ So, $mg = G\,Mm/R^2$

$$g = G\,M/R^2$$

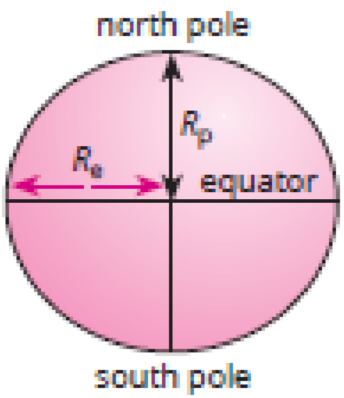


The value of acceleration due to gravity g is independent of mass, shape and size of the body but depends upon mass and radius of the earth. $g = 9.8\ m/s^2$

Variation of acceleration due to gravity (g)

$$g = (G \times M)/R^2$$

So, the value of acceleration due to gravity changes with height (or altitude), depth and shape of the earth.



Effect of the shape of the earth

We know that $g \propto 1/R^2$

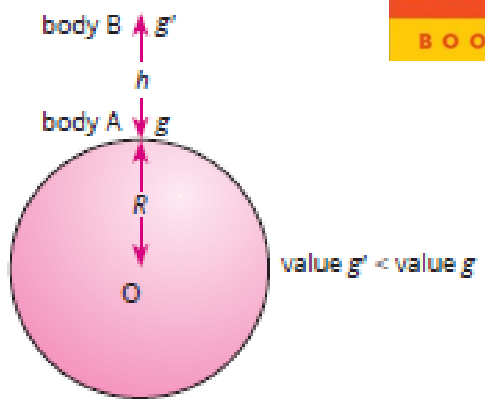
As the radius of the earth is maximum at the equator, so the value of g is minimum at the equator, and since the radius of the earth is minimum at the poles, the value of g is maximum at the poles. It means the value of acceleration due to gravity, g increases as we go from equator to the poles.

Effect of altitude

We know that

$$g \propto 1/R^2$$

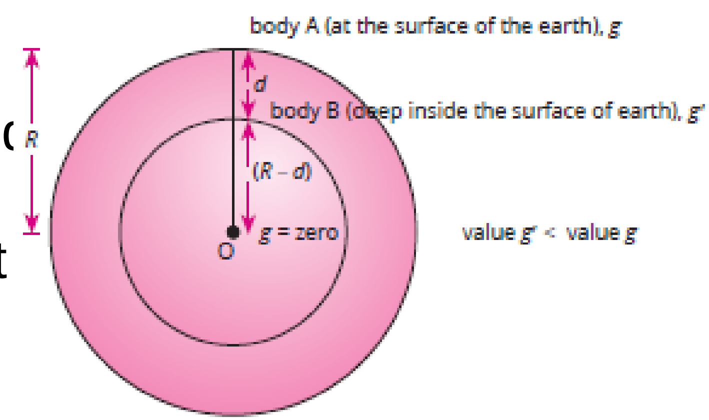
So, the value of *g* is inversely proportional to the square of distance from the centre of the earth.



Now, as we go above the surface of the earth, the distance from the centre of the earth increases and hence, the value of *g* decreases, i.e. the value of *g* decreases with height (altitude). It is due to this reason that the value of acceleration due to gravity is lesser at mountains than on plains.

Effect of height

As we go below the surface of the earth, the acceleration due to gravity goes on decreasing and becomes zero at the centre of the earth. So, the value of acceleration due to gravity is maximum at the earth's surface, decreases with depth and becomes zero at the centre of the earth.

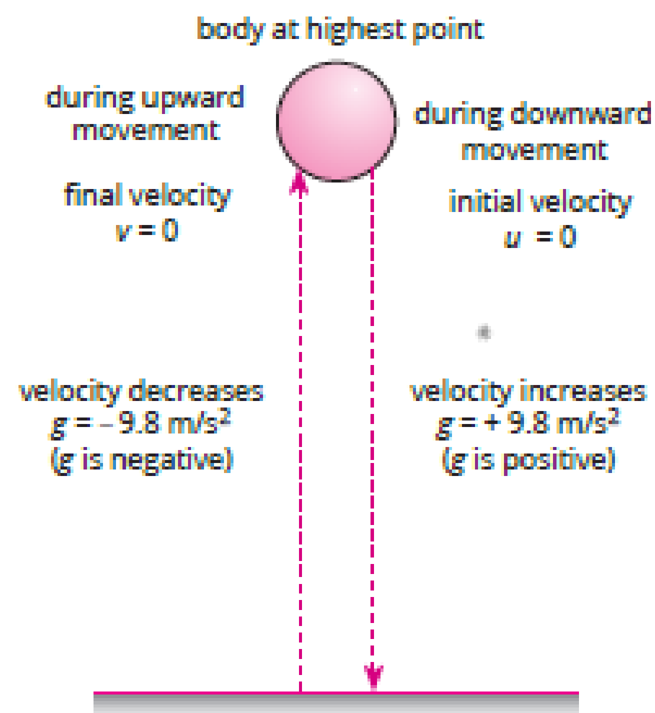


Note: Refer to Table 3.1 for Differences between G and g, and Table 3.2 for Differences between gravitation and gravity.

Equations of Motion for Freely Falling Bodies

General equations of motion	*Equations of motion for freely falling bodies*
1. $v = u + at$	changes to $v = u + gt$
2. $S = ut + 1/2\ at^2$	changes to $h = ut + 1/\ 2\ gt^2$
3. $v^2 = u^2 + 2aS$	changes to $v^2 = u^2 + 2gh$

The following points must be kept in mind while solving numerical problems on freely falling bodies:



1. When a body is thrown vertically upwards its final velocity, *v* becomes zero.

2. When a body is dropped from a certain height, its initial velocity, *u* is taken as zero.

3. Acceleration due to gravity, *g* is taken as negative when a body is thrown vertically upwards, i.e. *g* is taken as – 9.8 m/s^2.

4. Acceleration due to gravity, *g* is taken as positive when a body is dropped from a certain height, i.e. *g* is taken as + 9.8 m/s^2.

5. Time taken by a body to reach the highest point is equal to the time it takes to fall from the same height.

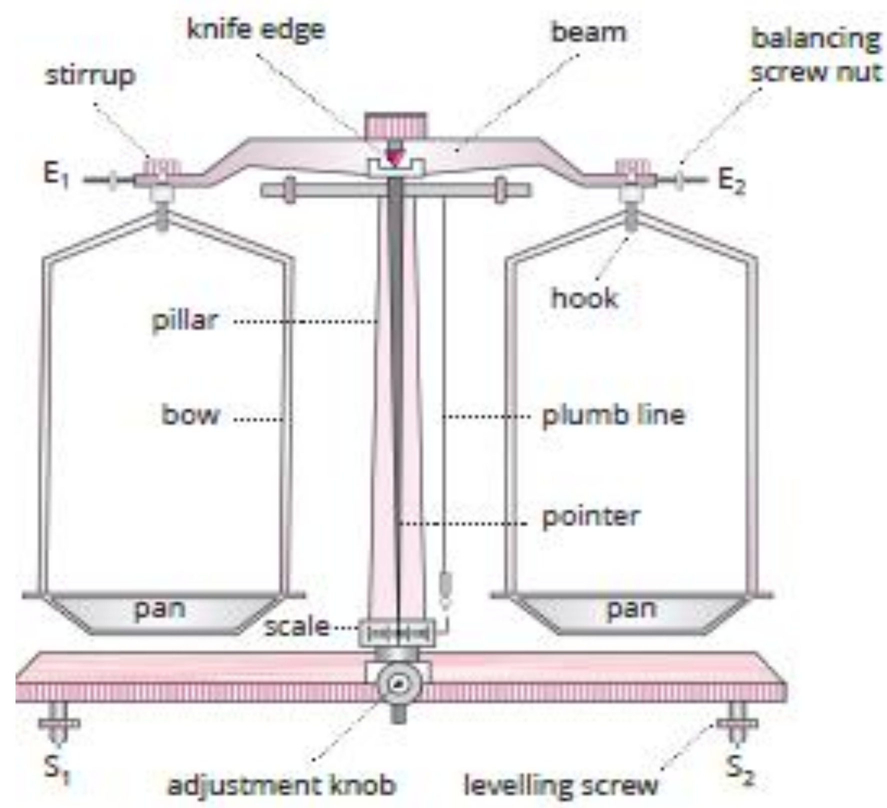
Mass

Mass is the quantity of matter contained in a body. **The mass of an object is a measure of its inertia.** The more is the mass of a body, the harder it is to change its state of rest or of motion.

Characteristics of mass

1. Mass is a scalar quantity.

2. A body contains the same quantity of matter whether it is on the earth, the moon or anywhere in the universe.



A physical balance

The mass of an object is the same everywhere. It does not change from place to place. It is constant.

3. The mass of a body can never be zero.

4. The SI unit of mass is kilogram (kg) and the CGS unit of mass is gram (*g*).

Weight

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

$$W = m \times g$$

Weight of the body = Mass of the body $\times$ Acceleration due to gravity

SI unit of weight is newton (N).

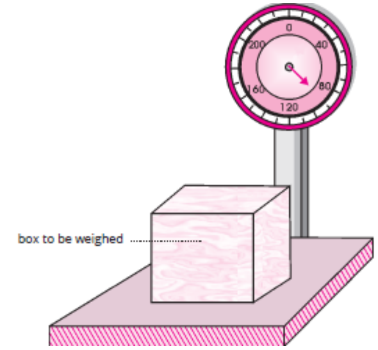
Characteristics of weight

1. It is a vector quantity having direction towards the centre of the earth, i.e. acting in vertically downward direction.

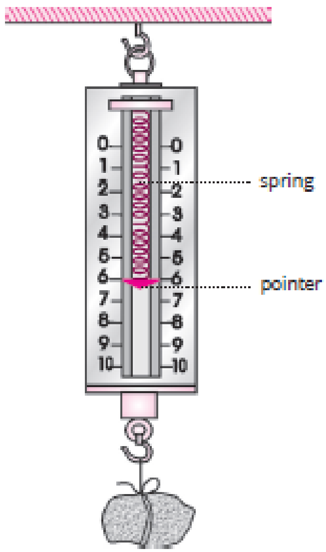
2. Weight is measured with a spring balance or by a weighing machine.

3. Since the weight of a body is given by $W = m \times g$, and the value of g (acceleration due to gravity) changes from place to place, the weight of a body changes from place to place.

a. The value of *g* is minimum at the equator and maximum at the poles. That is why, a body weighs more at the poles than at the equator.
b. The value of *g* decreases with height (altitude). It is due to this reason that a body weighs less on mountains than at plains.
c. The value of *g* is zero at the centre of the earth. So, the weight of body at the centre of the earth will be zero.



A weighing machine



A spring balance

4. Since the value of *g* is constant at a given place, the weight of an object at a given place is directly proportional to its mass *m*, i.e. $W \propto m$. It is due to this reason that **at a given place, we can use the weight of an object as a measure of its mass.**

5. The weight of a body on the moon is 1/6th of its weight on the earth.

Note: Refer to Table 3.3 for Differences between mass and weight.

SUMMARY

1. Gravitation: Any two particles (or objects) in the universe attract each other by a force called gravitational force. The phenomenon of attraction between different bodies in the universe is called gravitation.

2. Centripetal force: The force which is needed to make an object travel in a circular path is called centripetal force.

3. Newton's law of gravitation: 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. The force acts along the line joining the centres of the two bodies.

4. Acceleration due to gravity: The uniform acceleration produced in a body when it falls freely under the effect of gravity alone is known as acceleration due to gravity.

5. Mass: The quantity of matter contained in a body is called its mass.

6. Weight: The weight of a body is the force with which it is attracted towards the centre of the earth.

7. Free fall: Whenever objects fall towards the earth only under the gravitational force of the earth, we say the objects are in a state of free fall.