3. GRAVITATIONAL FORCE

The Gravitational Force All objects fall because of the gravitational force of attraction exerted on them by the earth. The acceleration due to gravity g is independent of the mass of the object. The force acting is given by F= mg and is the weight of the object. The direction of this acceleration and consequently F is towards the centre of the earth. This direction therefore varies from point to point on the earth, although we may assume it to be constant over a small region. The value of g which is about $9.8 m/s^2$ also shows minor geographical variations. The weight of the body varies accordingly, but its mass remains the same.

It is the gravitational pull of the earth that keeps the moon and the man-made satellites in their orbits. However, gravitation is not just a phenomenon associated with the earth alone. According to Newton's universal law of gravitation there exists a gravitational force of attraction between any two objects. It is a gravitational force of attraction between any two objects. It is this aspect that makes gravitation, a fundamental force in nature.

Newton's law of universal gravitation states: The force between any two particles or masses m_1, and m_2 separated by a distance r, is an attraction acting along the line joining the particles and has the magnitude

$$F=Gm_1m_2/r^2$$

Where G is the universal constant having the same value for all pairs of particles. The value of G is now accepted (in SI units) as

$$6.67 \text{ X } 10^{-11} N.m^2/kg^2$$

The words 'gravity' and 'gravitation' are sometimes used as if they meant the same thing. Strictly speaking, gravitation refers to the acceleration of any two objects in the universe towards each other, while gravity represents the gravitational acceleration towards the centre of the earth. The word "gravity" has also been applied to the gravitational acceleration towards the centre of other celestial bodies. Thus we can speak of the force of gravity on the planet Mars.

Factors affecting g are: (i) Distance from the centre of the earth; the nearer an object is to this point, the greater is the earth's attraction for it and the greater the value of g. (ii) The uneven distribution of the mass on the earth, particularly in the crust.

Weightlessness. Weightlessness is a condition induced by the effective lack of resistance to gravitational force on an object or organism, sometimes known as free fall.

As a body moves from the earth's surface to a location an infinite distance from the earth, the gravitational force approaches zero and the body approaches weightlessness. In the true sense, a body can be weightless only when it is at an infinite distance from all other objects.

Weightlessness is also defined as a condition in which no acceleration, whether of gravity or any other force, can be detected by an object or organism within the system in question. When a gravitational force on a body is opposed by an equal and opposite inertial force, a weightless state is produced. This is based on the fact that the mass that determines the gravitational force of a body is the same as the mass related to the acceleration produced by an inertial force of any kind. These inertial forces have no external physical origin, but are the consequences of an accelerated state of motion. Because of inertia, a moving object always tends to follow a straight line. When a person swings a bucket by the handle in a large circle, he or she feels a pull on his or her hand, because inertial force (also called centrifugal force in this case) tends to keep the bucket moving in a straight line, while the bucket holder exerts a counter force constraining the bucket to move along the circle. A similar situation exists in a spaceship orbiting the earth, 320 km above the earth's surface, where the gravitational field is only slightly weaker than at sea level. The ship, in free fall with negligible atmospheric drag is pulled toward the earth by the earth's gravitational attraction force, while the inertial or centrifugal force of the moving ship is directed radially outward from the earth; consequently, the force of gravity on the orbiting ship is opposed and nullified by the centrifugal force, and apparent weightlessness results.

Artificial Satellites

If we throw a stone with some speed in a horizontal direction, it follows a curved path as it falls to the ground. If the stone is thrown with a higher speed it follows a path of bigger radius as it falls. We thus conclude that the higher the speed of the stone, the greater the radius of the curved path. If somehow we could throw the stone with such tremendous speed that the radius of its path became a little greater than the radius of the earth, the stone would never fall on the earth and would keep revolving around it. This is the principle of an artificial satellite.

In the case of a satellite, the centripetal force is provided by the gravitational pull of the earth. We can calculate the speed of a satellite at a distance r from the centre of the force. Thus if m is the mass of the satellite and g the acceleration due to gravity, we have

$$V=Org \quad \text{and} \quad v=OGM/r$$

From both the relation, we see that the speed of the satellite does not depend on it mass. It means that at a particular distance from the earth, all objects would have the same speed of revolution.

To see the dependence of *v* on r, we cannot use v = $\sqrt{rg}$ because g also depend on r. However, v = $\sqrt{GM/r}$ shows that v is inversely proportional to the square root of r. Thus if a satellite moves from a higher orbit to a lower orbit, its speed increase.

For an approximate value of v, we can use the radius of the earth, 6.4×10^6 m, and the acceleration due to the gravity, 9.8 m/s^2, which yield

$$v = \sqrt{6.4 \times 10^6 \times 9.8} = 7.9 \times 10^3 \text{ m/s}$$

This is approximately equal to 28,500 km/h. If the speed is lower than this, the projected satellite would simply fall to the earth, while at a higher speed it would have an elliptical rather than a circular orbit, if, however the speed is more than 11.2 km/s or 25,000 miles/hour, the satellite would escape from the earth entirely and would never come back. This is called escape velocity.

This existence of gaseous atmosphere on the earth is due to the high value of its escape velocity. Since the gaseous molecules have velocities much less than 11.2 km/s, they cannot escape from the earth's field and hence form the atmosphere around. On the moon value of the escape velocity is 1.9 km/s (nearly one-sixth of that on earth). If any gases are formed on the moon, the molecules would have velocities greater than 1.9 km/s and would therefore escape, leaving the moon bare.

To give the desired speed to a satellite and overcome the force of gravity, the launching of a satellite requires a tremendous force. This is achieved with the help of rockets. Since the force of gravity is minimum at the equator, it is easier to launch satellite from equatorial regions. Since the earth rotates from west to east, satellites are launched in the eastward direction to give them additional push. It is still easier to launch satellites from space shuttles orbiting the earth. The USA launched a geostationary satellite from its space shuttle 'Discovery' in 1985.

Geostationary or Synchronous Satellites

A geostationary satellite is one which appears stationary with respect to the earth. The period or rotation of the earth about its axis is 24 hours. Thus if a satellite orbiting the earth over the equator has a 24-hour period of revolution, it appears stationary. The 24-hour period is possible when a satellite is at a height of nearly 35,000 km above the earth. Geostationary, satellites are used for communication and weather forecasting.

CENTRE OF GRAVITY AND STABILITY OF BODIES

Centre of Gravity If the body is in a constant gravitational field, the centre of gravity is the point at which the weight may be considered to act. When a body is suspended from its centre of gravity, it will remain in equilibrium. The centre of gravity of a body may lie even outside it, e.g. in a ring.

In the case of solid bodies with regular geometric shapes, the centre of gravity is always at the geometric centre of the body–that is, if the density is the same throughout. The centre of gravity of a cube or of a sphere is at the exact centre of these solids. For a cone, it is on the axis and at a point a fourth of the way from the base of the cone to its vertex, or tip.

If a body is in the form of a sheet, the centre of gravity corresponds to the centre of the area. If the sheet is rectangular in shape, the centre of gravity is located at the point where the two diagonals intersect. In the case of a triangle, it is one third of the distance from the middle point of any of the three sides to the opposite point. For a circular sheet it is at the centre of the circle.

The location of a body's centre of gravity will determine how stable it is–that is, to what extent it resists any effort to disturb its equilibrium, or balance. Generally speaking, there are three states of equilibrium. They are known as stable, unstable and neutral.

A body is said to be in stable equilibrium if we raise its centre of gravity when we tip it or lift one end. If we release the body, it will fall back to its former position. A square block of wood resting on the floor is a good example of a body that is in stable equilibrium. If we lift up one end of the block slightly, the weight of the body, concentrated at the centre of gravity, will make it return to its original position. However, if we were to tip the block so that a vertical line from the centre of gravity would fall outside the base of the block, it would tip over. It would be in a state of stable equilibrium in its new position. To keep a body as stable as possible, it is advisable to provide a wide base and a low centre of gravity. This is done in designing automobiles boats, furniture, and the like.

If we lower the centre of gravity of a body when we tip it, the body is in unstable equilibrium. Suppose we set a pointed stick in a vertical position on a horizontal table. Any slight tipping of the stick will lower the centre of gravity and will make it fall over suddenly.

If the centre of gravity of a body is neither raised nor lowered when the body is displaced we say that the body is in a state of neutral equilibrium. A ball on a table is in a state of neutral equilibrium, because any force that moves the ball sideways neither lowers nor raises the centre of gravity. It will continue to remain in equilibrium, no matter how we move it along the table.