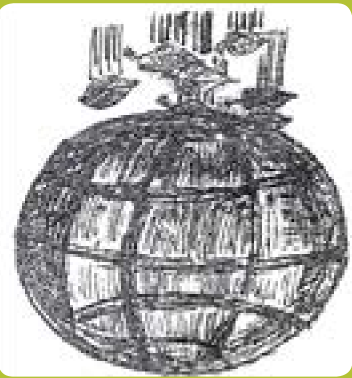
GRAVITY IN ACTION



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You might have wondered why objects when released from a certain height fall down on the ground. When you throw a ball up it does not continue going up, but soon comes to a halt at a certain height and then begins to fall. As it falls it gains speed. If we release two bodies of different masses from a certain height, say the roof of a house, will they reach the ground at the same time or at different times? This question is not at all easy to answer. If you drop a piece of paper and glass marble from a certain height, the marble will hit the ground much before the slip of paper reaches there. Even if we take objects of similar shape the answer is not easy. You might have noticed that larger rain-drops fall much faster than smaller ones – though all drops are spherical in shape. Even if we take two identical spheres, say one made of lead and the other of wood, can one say that they will fall together when released from a height simultaneously. The great Greek philosopher Aristotle (384 -322 B.C.) firmly believed that heavier objects fall faster than lighter objects of identical shape. No one questioned his judgement for many centuries and probably no one ever tried to verify whether what Aristotle said was correct.

The great Italian scientist Galileo Galilei (1564–1642) was amongst the first who wanted to experimentally test many of the ancient beliefs. He is rightly regarded as the father of modern scientific method. It is said that he dropped two identical spheres, made of different materials – one heavy and another light – from the top of the Leaning Towers at Pisa. He found that both the spheres reached the ground at the same time. This was a great discovery – objects fall to the earth at the same rate independent of their mass. You will note that this simple fact which we now take for granted is not at all obvious and took many centuries to get established.

We earlier considered examples of a glass marble and piece of paper and also raindrops of different sizes. These are observed to fall at different rates. How do we reconcile Galileo's observations with ours? In the case of certain objects like paper, feathers, parachutes or small spheres like rain- drops air plays a dominant role and changes the rules of falling bodies.

Kepler's Laws

The great Danish astronomer Tycho Brahe (1546-1601) is unparalled in the history of science. With naked eyes and instruments designed and built by him for measuring angles, he spent his entire life making precise measurements of the positions of celestial bodies. He accumulated accurate and vast data. As he did not have much talent in mathematics he could not himself make much use of the vast data. His Austrian assistant Johannes Kepler (1571-1630), an outstanding mathematician, analysed the available data. He provided confirmation for the Copernican model of the solar system, according to which the planet revolved around a stationary sun. Kepler formulated three laws for planetary orbits. These are:

1. Planets revolve round the sun in elliptical orbits.

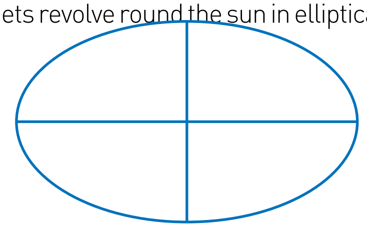

Fig. 1

2. An imaginary line drawn from the sun to the planet sweeps equal area in equal time (Fig. 2a, b).

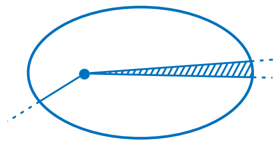

Fig. 2a

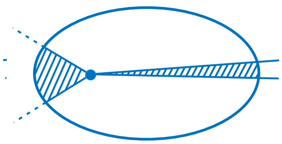

Fig. 2b

3. The squares of the times required by the planets for a complete orbital revolution about the sun is proportional to the cubes of their average distances from the sun (See Table 1).

These laws were discovered from observed data and no justification could be provided for them.

Table 1

Planet	T (Period in years)	R (Distance from the sun is terms of earth sun distance)	T^2	R^3
Mercury	0.241	0.387	0.058	0.058
Venus	0.615	0.723	0.378	0.378
Earth	1	1	1	1
Mars	1.881	1.523	3.276	3.533
Jupiter	11.862	5.203	140.7	140.85
Saturn	29.46	9.564	867.9	874.8

Law of Gravitation

The year Galileo died, Isaac Newton (1642-1727) was born in England. He is ranked amongst the world's top scientists for all times. He contributed in a major way in many fields of science. You may have heard of the three basic laws of motion which go by his name. He demonstrated that white light is composed of seven colours. He was one of the persons to develop the whole field of calculus in mathematics. He also gave the law of universal gravitation. We will discuss this last topic in some detail here.

There is a story often told about Newton. It is said that once while he was sitting in a garden, he saw an apple fall from an apple tree. This set him thinking as to why things fall to the earth and not fly away. He conjectured that just as the earth pulls the apple towards itself, all matter must attract other matter. But what should be the law of attraction? How does the attraction depend upon the masses of the bodies and how does it depend upon the distance between them? It was the genius of Newton that form a simple observation of a falling apple and the laws of Kepler, that were known to him, he obtained, what we now call as Newton's law of universal gravitation. According to this law two mass M_1 and M_2 attract each other with a force proportional to the product of their masses and inversely proportional to the square of the distance R, separating them. That is, the force

$$F \alpha \frac{M_1 M_2}{R^2} \quad \text{or} \quad F = G\frac{M_1 M_2}{R^2} \qquad \text{........... (1)}$$

where G is the constant of proportionality and is called the gravitational constant. If F is measured in newtons, M in kilograms and R in metres, then

$G = 6.67 \times 10^{-11} \leftarrow m^3 / kgs^2$

Before we look into the consequences of this law, let us see what impact it had on the thinking of the times.

As we mentioned above, experimental science, in the modern sense, started with Galileo, only a few decades before Newton. A few laws of Nature had been discovered from observations made in the laboratory or outside. There were no reasons to assume that the laws so discovered would also hold in very different situations. Hence, when Newton showed that Kepler's third law followed from his law of gravitation, it has great impact on the thinking of the times. It established that the laws discovered by man from his observations on the earth also applied to the heavens. It is this which made the entire universe amenable to study by man.

Falling Bodies

Let us now come back to the problem with which we started, that of falling bodies on the earth. Let the radius of the earth be R and its total mass M. If we have a body of mass m close to the earth's surface, the force exerted on it by the earth will be

$$F = \frac{GMm}{R^2} = gm \qquad \text{........... (2a)}$$

Where $g = \frac{GM}{R^2}$ or $M = \frac{gR^2}{G}$ .... (2a)

This force is directed towards the centre of the earth. Here g is a constant. Thus the force of attraction on a body of mass m, near the surface of the earth is directly proportional to its mass m. We now involve Newton's second law of motion: The force acting on a body is equal to the product of its mass and its acceleration, and is directed along the acceleration written mathematically it is

$$F = ma \qquad \text{........... (3)}$$

where a is the acceleration. If we are dealing with the earth's force of gravitation then from equations (2) and (3) we have

$F = gm = ma$ .... (4)

i.e. $a = g$

The quantity g is called acceleration due to gravity. Eq. (4) implies that the acceleration experienced by anybody falling under gravity is independent of the body's mass. Hence all falling bodies fall with the same constant acceleration, g.

It is important to note that we have nowhere talked of the atmosphere and the influence of air on falling bodies. Eq. (4) holds only when the resistance offered by air to a falling body can be neglected.

The value of g can be determined by studying falling bodies. It is nearly

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

The value of g varies slightly from place to place on the surface of the earth, since it is not a perfect sphere.

We note from Eq. (2b), that if we can find the radius of the earth, knowing g and G, we can easily find the total mass of the earth. The radius of the earth had already been determined by the Greeks by measuring the lengths of shadows cast by objects, at two different cities whose distance was known. The presently accepted value of earth's radius is 6371.02 km. Taking roughly

$R = 6.4 \times 10^5$, we find

$$M = \frac{gR^2}{G} = \frac{9.8 \times (6.4)^2 \times 10}{6.67 \times 10^{-11}} \text{ km}$$

$= 6 \times 10^{24}$ km.

Did you even think what could be the mass of our earth and how it could be estimated? Is it not a wonder that by studying falling bodies, we can estimate its mass. It is instructive to determine the average density of the earth. Since we know its mass and its radius, it is easy to calculate the density.

$$\text{Density } P = \frac{\text{Mass}}{\text{Volume}}$$

$$= \frac{\text{Mass}}{4/3 R^3} = \frac{3gR^2}{4GR^3} = \frac{3g}{4GR}$$

$= 5.5 \times 10^3 \text{ kg/m}^3$

You know that the earth rotates about its axis once in 24 hours. This is what causes day and night. We live on the surface of the earth. What is the speed with which this surface is moving? This would be the speed with which we go round, without even being aware of it (Fig. 3). Let us calculate this speed. It will be

$$\text{Speed} = \frac{\text{Circumference}}{\text{Time of one rotation}} = \frac{2\pi R}{24 \text{ hours}}$$

$= 0.47$ km/s

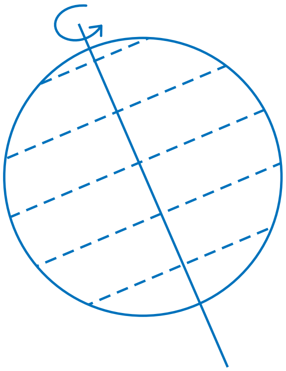

Fig. 3

i.e., nearly half a kilometre per second or 1800 km/hr. This is almost the speed of present day jet planes.

If we are travelling at such a high speed sitting on a rotating sphere, why are we not thrown off into space? The answer is that the attraction due to gravity is much stronger than this and keeps almost tied to the ground. Can we set ourselves free from this grip of the earth? Yes, we can. If the kinetic energy of a body is equal to its potential energy on the surface, then it can escape from the gravitational attraction. We can write the condition for a body of mass and speed as

$$\frac{1}{2}mv^2 = \frac{GMm}{R}$$

$$\text{or } v^2 = \frac{2GM}{R} = 2gR$$

.... (5)

This gives v = $\sqrt{2gR}$ = 11.2 km/s.

If a body should have a speed equal to or greater than about 11.2km/s, it will be able to get away from the earth's attraction. If the speed is lower, it will go up, stop and come down again.

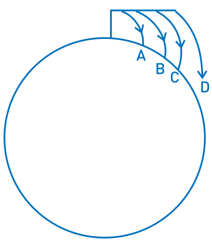

Fig. 4

The Moon

Unlike some large planets like Jupiter and Saturn which have a large number of moons (12 and 9 respectively), our earth has only one, but what a beautiful one! It goes round the earth in 27.3 days. The period of rotation about its own axis is also the same. This is why from the earth we see only one face of the moon. The other side is hidden from us. (We now have photographs of the other side too, taken by satellites which went round the moon). The moon goes round the earth because of its gravitational attraction.

Consider a tail tower over the surface of the earth. If a ball is thrown horizontally from the top of the tower, it will gradually come down and fall down on the surface of the earth, say at A (Fig. 4).

If we throw another ball with greater horizontal speed, it will fall at some point B, farther from the base than point A. if we were to throw a ball with such a speed that the surface of the earth bends by as much as the ball falls towards the earth, then it will continue to move in a circular path without ever falling on the surface. The moon too is falling towards the earth like any other object, but since it also has a tangential speed, it fails to hit the ground, and keeps moving in a circular orbit.

Since we know the period of revolution of the moon around the earth, we can calculate its distance from us. Let M be the mass of the earth and R the distance of the moon from the earth, then

$$\frac{GMe}{R^2} = \frac{v^2}{R} = \frac{[2\pi R]^2}{T^2} = \frac{1}{R} = \frac{4\pi^2 R}{T^2} \quad \text{............... (6)}$$

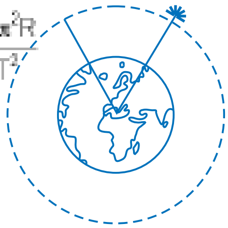

Fig. 5

Here T is the period of revolution of the moon around the earth. This equation leads to

$$R = \sqrt[3]{\frac{GMeT^2}{4\pi^2}} \quad \text{or} \quad T = \sqrt{\frac{4\pi^2 R^3}{GMe}} \quad \text{............. (7)}$$

(Note that Eq. (7) is the mathematical form of Kepler's third law). Substituting the values of G Me and T in Eq. (7) we get

R = 383000 km

which is nearly 60 times the radius of the earth. (The more correct value is 384400 km).

Eq. (7) will also hold for artificial satellites. For example we can calculate the height above the earth's surface where a geostationary satellite is established. Since these satellites appear stationary with reference to a particular place directly below on the surface of the earth, they must also revolve round the earth with a period of 24 hours. Hence using Eq. (7) we find, R = 42200 km. Subtracting from this a distance equal to the radius of the earth (=6400 km), we get 35800 km as the height of a geostationary satellite from the earth's surface (Fig. 5).

Let us now calculate the value of g on the surface of the moon. Using the parameters of the moon given in Table 3 and using Eq. (2b), we find

g_{moon} = 1.66 m/s^2

which is nearly 1/6th of the value of g on the earth.

Table 2

Earth

mass = 5.976 × 10^{24} kg

mean radius = 6371.02 km

(rounded off to 6400 km)

Moon

mass = 7.35 × 10^{22} kg

mean radius = 1720.2 km

Distance of the earth from the sun = 149.6 × 10^6 km

Distance of the moon from the earth = 0.3844 × 10^6 km

This means that moon's hold on objects on its surface is much weaker than that of the earth. For the same effort, a man may be able to jump six times the height he jumps on the earth.

The escape velocity (Eq. 5) on the surface of the moon is

v_{moon} = 2.42 km/s

which is almost 1/5th of what it is on the earth.

Centre of Mass

In deriving Eq. (7) for the moon going round the earth, we had to define the distance between these two large objects. From which point on earth to measure this distance and up to which point on the moon? Law of gravitation implies that there should always be one point in everybody at which we can take its total mass to be concentrated, so far as its interaction with other objects is concerned. This point is called the Centre of mass. For a uniform sphere, the centre of mass is at its centre.

Let us considering a simple but interesting example. Take a stiff card and draw on it (or trace) the figure of the bird shown in Fig 6a. On both A and B place a 50 paise coin and attach it there with the help of cellotape. Turn the bird up-side down so that the 50p coins are now on the lower side. You can now balance the bird from its beak on your finger tip (Fig. 6b). This is because the centre of mass of the object is near its beak.

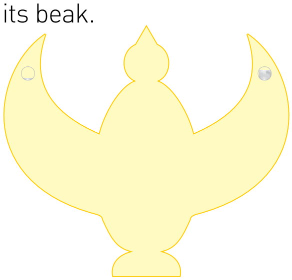

Fig. 6a

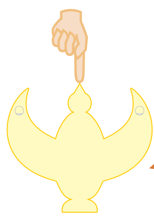

Fig. 6b

Consider a small table lying on a flat surface whose inclination to the horizontal can be varied. The force of gravity of the earth acts on the centre of mass of the table along a line perpendicular to the earth's surface (and pointing towards the centre of the earth). If this line intersects the surface on which the table is resting (Fig. 7) at some point inside the area defined by the four legs. The table will be stable. However, if the point of intersection lies outside this area the table will topple over.

You can try a simple experiment yourself. Stand close to a wall with one foot and one arm in contact with it. Try to bring the other foot in contact with the one in contact with the wall, without seeking any support. You will find that this cannot be done. This is because our centre of mass is close to the navel and if both feet are in contact with the wall, the vertical line drawn through our centre of mass will be outside the support base and the body will become unstable. When we stand in the normal posture, the vertical line through our centre of mass lies between our feet, and our body is stable (Fig. 8).

If you have climbed a hill or a steep slope, you must have observed that one has to bend forward. This is again to ensure that the vertical line through the centre of mass passes through the support base.

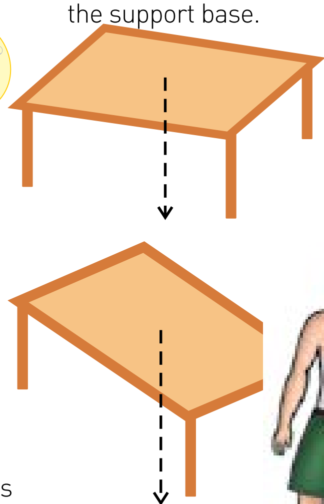

Fig. 7

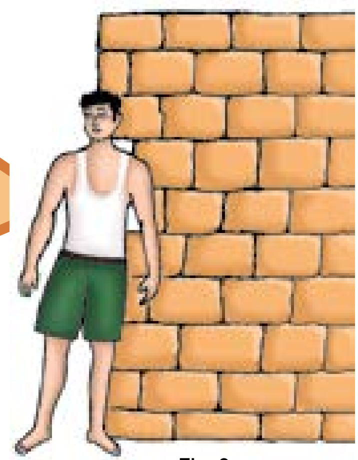

Fig. 8

Our Atmosphere

As you know, our atmosphere consists of mainly three gases – nitrogen, oxygen and carbon-di-oxide (also water vapour). Table 3 gives more details of the constituents. Life on earth has evolved only because of the relatively large abundance of oxygen. If we examine the composition of the Universe, we find that hydrogen and helium dominate over all other elements. Then how is it that our atmosphere has so little hydrogen and helium?

Table 3

Gas	Percentage	Molecular Weight	Average (rms) speed at room temperature
N_2	78	28	0.52 km/s
O_2	21	32	0.48
C_2O	0.03	40	0.432
Nobel gases	0.9	-	-
H_2	Trace	2	1.93

Let us assume that our entire atmosphere is at a uniform temperature of say 27^0C (300 kelvin). The average energy of nitrogen molecules will be the same as that of molecules of other gases, e.g., O_2 or H_2,...This is technically referred to as the law of equipartition of energy. However, this does not mean that the average speed of N_2 molecules will be the same as that of H_2 molecules. We know that the kinetic energy E of a body is related to its speed by the relation

$$E = \frac{1}{2} mv^2 \qquad .... (8)$$

where m is the mass of the object. For different gases at room temperature the average speeds of molecules are given in Table 3.

We note that the average speed of hydrogen molecules is nearly 2 km/s. In a gas one will find molecules with all possible speeds ranging from almost zero to extremely large values, may be hundreds of km/s. If the average speed is around 2 km/s the fraction of molecules having speeds exceeding the escape velocity (11.2 km/s) will be substantial. Hence there will be fair change of their escaping from the earth's hold. On the other hand if we consider oxygen molecules, their average speed is around 9.5 km/s. Thus the fraction of molecules with speeds exceeding the escape velocity will be small. This partly accounts for the present composition of our atmosphere.

We saw that on the surface of the moon, the escape velocity is only about 2.5 km/s. Because of this all gases have escaped from its surface, and there is no air on the moon. Hence no life can exist there. Even two astronauts will have to communicate with each other through radio waves – there is nothing like sound there.

Gravity in Action

Many phenomena which we observe on our earth are a direct consequence of gravity, though in some cases the connection may not be obvious. Air pressure, water pressure inside oceans, tides, water falls are a few examples. Let us examine them in some detail.

Air Pressure: Inside a quiet room we hardly feel the air around us. But the pressure it exerts on our body is equivalent to a water column of 10 m height. How is it that we are not crushed

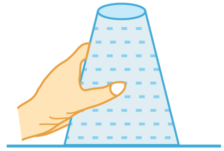

Fig. 9

under so much pressure? This is because, there is the same air inside our bodies and the two forces from inside and outside just balance. An easy way to demonstrate this pressure is the following: Take a tumbler and fill it with water upto the brim. Slip a card over the mouth of the tumbler so that it is fully covered. Hold the tumbler in your hand and place the palm of the left hand over the card. Quickly turn the whole thing upside down. Remove your left hand from under the card.

The card should stick to the tumbler and not fall off. This is because the force exerted on the card by the air from below is much greater than that exerted from above by water inside the tumbler.

Tides: The gravitational attraction of the moon cause tides in the oceans. High tides occur both in the part of the ocean directly towards the moon as well as in the ocean directly opposite. If the sun happens to be close to the direction of the moon, then the tides are very high.

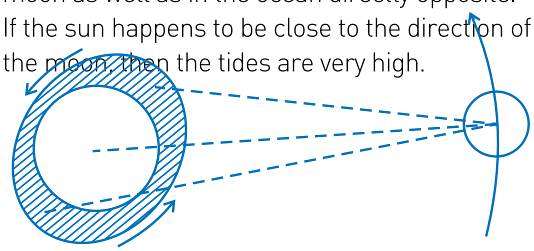

Fig. 10

Water Falls: You may have seen some water falls. They are usually a very grand sight. Some are seasonal and some perennial. When there is a sudden change in the level of the ground along which a river flows, water falls develop. Water falls from a higher level to the lower level because of gravity. In Europe many small water falls were utilised to drive flour mills. Large water falls can be used to generate electricity.

Dams: These days we used lot of energy in the form of electricity. Major electric power in our country is produced in power stations burning coal. Coal stocks are limited and hence lot of attention is being given to nuclear energy and renewable energy sources like solar energy and hydro-electricity. To generate hydro-electricity, a high dam is built across a river when it is flowing among mountains or raised ground. You must have heard of Bhakra and Nangal dams in Punjab and Nagarjuna Sagar dam in Karnataka. Water is allowed to fall from near the top of the dam, to lower levels. This falling water acquires lot of kinetic energy due to gravity, which can be used to run electric generators.

Pendulum: Man has learnt to make use of gravity in various ways. Galileo, while sitting in a Cathedral observed that the period of oscillation of a chandelier hanging from the roof, did not depend upon the amplitude of oscillation. This was a very important discovery, and led to the concept of present day pendulum. It is very easy to set up and study a pendulum. It is just small mass attached to a string, which is died at the other hand to a rigid support. The mass must be free to oscillate. The time-period of a pendulum is defined as the time required to complete one oscillation say from O to A to B and back to O (Fig. 11).

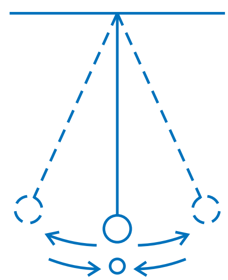

Fig. 11

The time period is dependent on the length of the pendulum and not on the amplitude of oscillation. At one time, pendulum clocks were very common in homes. They have now been replaced by battery driven electric clocks. We have considered here a few examples where gravity is seen to operate. As a matter of fact, life in the universe exists because of this or more generally the sun and the stars and the planets are there because of this universal property of all matter.

NUCLEAR TECHNOLOGY AND PUBLIC HEALTH

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The words "nuclear technology" registers in many people's mind an atomic and a nuclear bomb hence nothing more than destruction. This impression is not always correct since nuclear technology is also used for peaceful purposes. Isotopes of some elements emit radiation as their nuclear decay and they are called radioactive isotopes, radioisotopes or radionuclides. Some of these radionuclides occur naturally while others are artificial and the study of these radionuclides is called nuclear science. Nuclear technology is therefore the various nuclear techniques developed from nuclear science which make use of mainly radioisotopes or radiation procedures in response to the challenges imposed by the nuclear age. Their range of application is extremely broad which may be both constructive and destructive.

The application of these nuclear techniques will therefore have some advantages and disadvantages on public health; since these radionuclides will be used in the environment. The inhabitants of the environment such as man, animals and plants may benefit from the detrimental effects of the nuclear accidents and radiations.

Advantages of Nuclear Technology

The socio-economic development of many great nations have been achieved through the help of nuclear technology. Some of the areas in which nuclear technology have been applied are power generation, medicine, industry, agriculture, research and environmental management.

The generation of electricity from nuclear power plants have now been practiced in many countries of the world. This source of energy has been recognised as an economic and a clean source of energy as compared to the other sources of energy. According to Atseyinlu (1992), the nuclear energy is a viable energy source, and is beneficial in many respects, but it involves great risks and environmental problems.

The determination of metabolic pathways, visualisation of organs, localisation of tumors, detection of abnormalities in diagnosis, use of radiation sources for therapy, sterilisation of medical instruments are some of the major goals of nuclear medicine. Nuclear medical equipment, including scintillation gamma