CHAPTER 4

THE FORCES

4.1 INTRODUCTION

Force is a word which we have all heard about. When you push or pull some object you exert a force on it. If you push a body you exert a force away from yourself; when you pull, you exert a force toward yourself. When you hold a heavy block in your hand you exert a large force; when you hold a light block, you exert a small force.

Can nonliving bodies exert a force ? Yes, they can. If we stand in a great storm, we feel that the wind is exerting a force on us. When we suspend a heavy block from a rope, the rope holds the block just as a man can hold it in air. When we comb our dry hair and bring the comb close to small pieces of paper, the pieces jump to the comb. The comb has attracted the paper pieces i.e. the comb has exerted force on the pieces. When a cork is dipped in water it comes to the surface; if we want to keep it inside water, we have to push it downward. We say that water exerts a force on the cork in the upward direction.

The SI unit for measuring the force is called a *newton.* Approximately, it is the force needed to hold a body of mass 102 g near the earth's surface. An accurate quantitative definition can be framed using Newton's laws of motion to be studied in the next chapter.

Force is an interaction between two objects. Force is exerted by an object A on another object B. For any force you may ask two questions, (i) who exerted this force and (ii) on which object was this force exerted? Thus, when a block is kept on a table, the table exerts a force on the block to hold it.

Force is a vector quantity and if more than one forces act on a particle we can find the resultant force using the laws of vector addition. Note that in all the examples quoted above, if a body A exerts a force on B, the body B also exerts a force on A. Thus, the table exerts a force on the block to hold it and the block exerts a force on the table to press it down. When a heavy block is suspended by a rope, the rope exerts a force on the block to hold it and the block exerts a force on the rope to make it tight and stretched. In fact these are a few examples of Newton's third law of motion which may be stated as follows.

Newton's Third Law of Motion

If a body A exerts a force $\vec{F}$ on another body B, then B exerts a force $-\vec{F}$ on A, the two forces acting along the line joining the bodies.

The two forces $\vec{F}$ and $-\vec{F}$ connected by Newton's third law are called *action-reaction pair*. Any one may be called 'action' and the other 'reaction'.

We shall discuss this law in greater detail in the next chapter.

The various types of forces in nature can be grouped in four categories :

(a) Gravitational, (b) Electromagnetic,
(c) Nuclear and (d) Weak.

4.2 GRAVITATIONAL FORCE

Any two bodies attract each other by virtue of their masses. The force of attraction between two point masses is $F = G\frac{m_1 m_2}{r^2}$, where m_1 and m_2 are the masses of the particles and r is the distance between them. G is a universal constant having the value $6{\cdot}67 \times 10^{-11}$ N-m ^{2}/kg ^{2}. To find the gravitational force on an extended body by another such body, we have to write the force on each particle of the 1st body by all the particles of the second body and then we have to sum up vectorially all the forces acting on the first body. For example, suppose each body contains just three particles, and let $\vec{F}_{ij}$ denote the force on the i th particle of the first body due to the j th particle of the second body. To find the resultant force on the first body (figure 4.1), we have to add the following 9 forces :

$$\vec{F}_{11}, \vec{F}_{12}, \vec{F}_{13}, \vec{F}_{21}, \vec{F}_{22}, \vec{F}_{23}, \vec{F}_{31}, \vec{F}_{32}, \vec{F}_{33}.$$

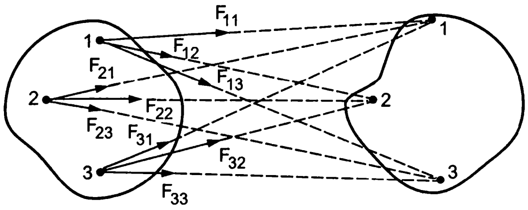

Figure 4.1

For large bodies having a large number of particles, we have to add quite a large number of forces. If the bodies are assumed continuous (a good approximation in our course), one has to go through the integration process for the infinite summation involved. However, the integration yields a particularly simple result for a special case which is of great practical importance and we quote it below. The proof of this result will be given in a later chapter.

The gravitational force exerted by a spherically symmetric body of mass m_1 *on another such body of mass* m_2 *kept outside the first body is* $G\frac{m_1 m_2}{r^2}$, *where r is the distance between the centres of the two bodies. Thus, for the calculation of gravitational force between two spherically symmetric bodies, they can be treated as point masses placed at their centres.*

Gravitational Force on Small Bodies by the Earth

The force of attraction exerted by the earth on other objects is called *gravity*. Consider the earth to be a homogeneous sphere of radius R and mass M. The values of R and M are roughly 6400 km and 6×10^{24} kg respectively. Assuming that the earth is spherically symmetric, the force it exerts on a particle of mass m kept near its surface is by the previous result, $F = G\frac{Mm}{R^2}$. The direction of this force is towards the centre of the earth which is called the *vertically downward* direction.

The same formula is valid to a good approximation even if we have a body of some other shape instead of a particle, provided the body is very small in size as compared to the earth. The quantity $G\frac{M}{R^2}$ is a constant and has the dimensions of acceleration. It is called the *acceleration due to gravity*, and is denoted by the letter g (a quantity much different from G). Its value is approximately $9{\cdot}8\ \mathrm{m/s^2}$. For simplicity of calculations we shall often use $g = 10\ \mathrm{m/s^2}$. We shall find in the next chapter that all bodies falling towards earth (remaining all the time close to the earth's surface) have this particular value of acceleration and hence the name acceleration due to gravity. Thus, the force exerted by the earth on a small body of mass m, kept near the earth's surface is mg in the vertically downward direction.

The gravitational constant G is so small that the gravitational force becomes appreciable only if at least one of the two bodies has a large mass. To have an idea of the magnitude of gravitational forces in practical life, consider two small bodies of mass 10 kg each, separated by 0·5 m. The gravitational force is

$$F = \frac{6{\cdot}7 \times 10^{-11}\ \mathrm{N\text{–}m^2/kg^2} \times 10^2\ \mathrm{kg^2}}{0{\cdot}25\ \mathrm{m^2}}$$

$$= 2{\cdot}7 \times 10^{-8}\ \mathrm{N}$$

a force needed to hold about 3 microgram. In many of the situations we encounter, it is a good approximation to neglect all the gravitational forces other than that exerted by the earth.

4.3 ELECTROMAGNETIC (EM) FORCE

Over and above the gravitational force $G\frac{m_1 m_2}{r^2}$, the particles may exert upon each other electromagnetic forces. If two particles having charges q_1 and q_2 are at rest with respect to the observer, the force between them has a magnitude

$$F = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r^2}$$

where $\varepsilon = 8{\cdot}85419 \times 10^{-12}\ \mathrm{C^2/N\text{–}m^2}$ is a constant. The quantity $\frac{1}{4\pi\varepsilon_0}$ is $9{\cdot}0 \times 10^9\ \frac{\mathrm{N\text{–}m^2}}{\mathrm{C^2}}$.

This is called *Coulomb force* and it acts along the line joining the particles. If q_1 and q_2 are of same nature (both positive or both negative), the force is repulsive otherwise it is attractive. It is this force which is responsible for the attraction of small paper pieces when brought near a recently used comb. The electromagnetic force between moving charged paritcles is comparatively more complicated and contains terms other than the Coulomb force.

Ordinary matter is composed of electrons, protons and neutrons. Each electron has $1{\cdot}6 \times 10^{-19}$ coulomb of negative charge and each proton has an equal amount of positive charge. In atoms, the electrons are bound by the electromagnetic force acting on them due to the protons. The atoms combine to form molecules due to the electromagnetic forces. A lot of atomic and molecular phenomena result from electromagnetic forces between the subatomic particles (electrons, protons, charged mesons, etc.).

Apart from the atomic and molecular phenomena, the electromagnetic forces show up in many forms in daily experience. Some examples having practical importance given below.

(a) Forces between Two Surfaces in Contact

When we put two bodies in contact with each other, the atoms at the two surfaces come close to each other. The charged constituents of the atoms of the two bodies exert great forces on each other and a measurable force results out of it. We say that the two bodies in contact exert forces on each other. When you place a book on a table, the table exerts an upward force on the book to hold it. This force comes from the electromagnetic forces acting between the atoms and molecules of the surface of the book and of the table.

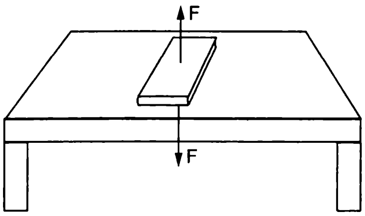

Figure 4.2

Generally, the forces between the two objects in contact are along the common normal (perpendicular) to the surfaces of contact and is that of a push or repulsion. Thus, the table pushes the book away from it (i.e., upward) and the book pushes the table downward (again away from it).

However, the forces between the two bodies in contact may have a component parallel to the surface of contact. This component is known as *friction*. We assume existence of frictionless surfaces which can exert forces only along the direction perpendicular to them. The bodies with smooth surfaces can exert only small amount of forces parallel to the surface and hence are close to frictionless surface. Thus, it is difficult to stay on a smooth metallic lamp-post, because it cannot exert enough vertical force and so it will not hold you there. The same is not true if you try to stay on the trunk of a tree which is quite rough. We shall often use the word smooth to mean frictionless.

The contact forces obey Newton's third law. Thus the book in figure (4.2) exerts a downward force F on the table to press it down and the table exerts an equal upward force F on the book to hold it there. When you stay on the trunk of a tree, it exerts a frictional upward force (frictional force because it is parallel to the surface of the tree) on you to hold you there, and you exert an equal frictional downward force on the tree.

(b) Tension in a String or a Rope

In a tug of war, two persons hold the two ends of a rope and try to pull the rope on their respective sides. The rope becomes tight and its length is slightly increased. In many situations this increase is very small and goes undetected. Such a stretched rope is said to be in a state of tension.

Similarly, if a heavy block hangs from a ceiling by a string, the string is in a state of tension. The electrons and protons of the string near the lower end exert forces on the electrons and protons of the block and the resultant of these forces is the force exerted by the string on the block. It is the resultant of these electromagnetic forces which supports the block and prevents it from falling. A string or rope under tension exerts electromagnetic forces on the bodies attached at the two ends to *pull* them.

(c) Force due to a Spring

When a metallic wire is coiled it becomes a spring. The straight line distance between the ends of a spring is called its length. If a spring is placed on a horizontal surface with no horizontal force on it, its length is called the *natural length*. Every spring has its own natural length. The spring can be stretched to increase its length and it can be compressed to decrease its length. When a spring is stretched, it pulls the bodies attached to its ends and when compressed, it pushes the bodies attached to its ends. If the extension or the compression is not too large, the force exerted by the spring is proportional to the change in its length. Thus, if the spring has a length x and its natural length is x_0 the magnitude of the force exerted by it will be

$$F = k\,|x - x_0| = k\,|\Delta x|.$$

If the spring is extended, the force will be directed towards its centre and if compressed, it will be directed away from the centre. The proportionality constant k, which is the force per unit extension or compression, is called the *spring constant* of the spring. This force again comes into picture due to the electromagnetic forces between the atoms of the material.

The macroscopic bodies which we have to generally deal with are electrically neutral. Hence two bodies not in contact do not exert appreciable electromagnetic forces. The forces between the charged particles of the first body and those of the second body have both attractive and repulsive nature and hence they largely cancel each other. This is not the case with gravitational forces. The gravitational forces between the particles of one body and those of the other body are all attractive and hence they add to give an appreciable gravitational force in many cases. Thus, the gravitational force between the earth and a 1 kg block kept 100 m above the earth's surface is about 9·8 N whereas the electromagnetic force between the earth and this block is almost zero even though both these bodies contain a very large number of charged particles, the electrons and the protons.

Example 4.1

Suppose the exact charge neutrality does not hold in a world and the electron has a charge 1% less in magnitude than the proton. Calculate the Coulomb force acting between two blocks of iron each of mass 1 kg *separated by a distance of* 1 m. *Number of protons in an iron atom* = 26 *and* 58 kg *of iron contains* 6×10^{26} *atoms.*

Solution : Each atom of iron will have a net positive charge $26 \times 0{\cdot}01 \times 1{\cdot}6 \times 10^{-19}$ C on it in the assumed world. The total positive charge on a 1 kg block would be

$$\frac{6 \times 10^{26}}{58} \times 26 \times 1{\cdot}6 \times 10^{-21}\ \text{C}$$

$$= 4{\cdot}3 \times 10^{5}\ \text{C}.$$

The Coulomb force between the two blocks is

$$= \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r^2} = \frac{9{\cdot}0 \times 10^{9}\ \text{N–m}^2/\text{C}^2 \times (4{\cdot}3 \times 10^{5}\ \text{C})^2}{(1\ \text{m})^2}$$

$$= 9 \times 10^{9} \times 18{\cdot}49 \times 10^{10}\ \text{N}$$

$$= 1{\cdot}7 \times 10^{21}\ \text{N}.$$

A tremendous force indeed !

4.4 NUCLEAR FORCES

Each atom contains a certain number of protons and neutrons in its nucleus. The nucleus occupies a volume of about $10^{-44}\ \text{m}^3$ whereas the atom itself has a volume of about $10^{-23}\ \text{m}^3$. Thus, the nucleus occupies only $1/10^{21}$ of the volume of the atom. Yet it contains about 99·98% of the mass of the atom. The atomic nucleus of a non-radioactive element is a stable particle. For example, if both the electrons are removed from a helium atom, we get the bare nucleus of helium which is called an *alpha particle.* The alpha particle is a stable object and once created it can remain intact until it is not made to interact with other objects.

An alpha particle contains two protons and two neutrons. The protons will repel each other due to the Coulomb force and will try to break the nucleus. Neutrons will be silent spectators in this electromagnetic drama (Remember, neutron is an uncharged particle). Then, why does the Coulomb force fail to break the nucleus? Can it be the gravitational attractive force which keeps the nucleus bound? All the protons and the neutrons will take part in this attraction, but if calculated, the gravitational attraction will turn out to be totally negligible as compared to the Coulomb repulsion.

In fact, a third kind of force, altogether different and over and above the gravitational and electromagnetic force, is operating here. These forces are called *Nuclear forces* and are exerted only if the interacting particles are protons or neutrons or both. (There are some more cases where this force operates but we shall not deal with them.) These forces are largely attractive, but are short ranged. The forces are much weaker than the Coulomb force if the separation between the particles is more than say 10^{-14} m. But for smaller separation ($\approx 10^{-15}$ m) the nuclear force is much stronger than the Coulomb force and being attractive it holds the nucleus stable.

Being short ranged, these forces come into picture only if the changes within the nucleus are discussed. As bare nuclei are less frequently encountered in daily life, one is generally unaware of these forces. Radioactivity, nuclear energy (fission, fusion) etc. result from nuclear forces.

4.5 WEAK FORCES

Yet another kind of forces is encountered when reactions involving protons, electrons and neutrons take place. A neutron can change itself into a proton and simultaneously emit an electron and a particle called *antinutrino*. This is called β^- decay. Never think that a neutron is made up of a proton, an electron and an antineutrino. A proton can also change into neutron and simultaneously emit a positron (and a neutrino). This is called β^+ decay. The forces responsible for these changes are different from gravitational, electromagnetic or nuclear forces. Such forces are called weak forces. The range of weak forces is very small, in fact much smaller than the size of a proton or a neutron. Thus, its effect is experienced inside such particles only.

4.6 SCOPE OF CLASSICAL PHYSICS

The behaviour of all the bodies of linear sizes greater than 10^{-6} m are adequately described on the basis of relatively a small number of very simple laws of nature. These laws are the Newton's laws of motion, Newton's law of gravitation, Maxwell's electromagnetism, Laws of thermodynamics and the Lorentz force. The principles of physics based on them is called the *classical physics*. The formulation of classical physics is quite accurate for heavenly bodies like the sun, the earth, the moon etc. and is equally good for the behaviour of grains of sand and the raindrops. However, for the subatomic particles much smaller than 10^{-6} m (such as atoms, nuclei etc.) these rules do not work well. The behaviour of such particles is governed by *quantum physics*. In fact, at such short dimensions the very concept of "particle" breaks down. The perception of the nature is altogether different at this scale. The validity of classical physics also depends on the velocities involved. The classical mechanics as formulated by Newton has to be considerably changed when velocities comparable to 3×10^8 m/s are involved. This is the speed of light in vacuum and is the upper limit of speed which material particle can ever reach. No matter how great and how long you apply a force, you can never get a particle going with a speed greater than 3×10^8 m/s. The mechanics of particles moving with these large velocities is known as *relativistic mechanics* and was formulated by Einstein in 1905.

Thus, classical physics is a good description of the nature if we are concerned with the particles of linear size > 10^{-6} m moving with velocities < 10^8 m/s. In a major part of this book, we shall work within these restrictions and hence learn the techniques of classical physics. The size restriction automatically excludes any appreciable effects of nuclear or weak forces and we need to consider only the gravitational and electromagnetic forces. We might consider the subatomic particles here and there but shall assume the existence of gravitational and electromagnetic forces only and that classical physics is valid for these particles. The results arrived at by our analysis may only be approximately true because we shall be applying the laws which are not correct in that domain. But even that may play an important role in the understanding of nature. We shall also assume that the Newton's third law is valid for the forces which we shall be dealing with. In the final chapters we shall briefly discuss quantum physics and some of its important consequences.

Worked Out Examples

1. *Figure (4-W1) shows two hydrogen atoms. Show on a separate diagram all the electric forces acting on different particles of the system.*

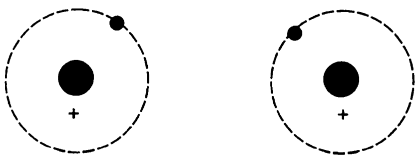

Figure 4-W1

Solution : Each particle exerts electric forces on the remaining three particles. Thus there exist 4 × 3 = 12 forces in all. Figure (4-W2) shows them.

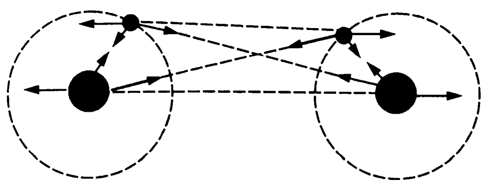

Figure 4-W2

2. *Figure (4-W3) shows two rods each of length l placed side by side, with their facing ends separated by a distance a. Charges + q, − q reside on the rods as shown. Calculate the electric force on the rod A due to the rod B. Discuss the cases when l>>a, a>>l.*

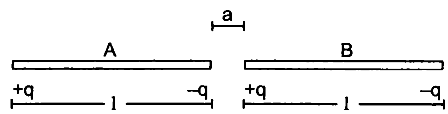

Figure 4-W3

Solution : The force on the rod A due to the charge $+q$ of the rod B

$$= -\frac{q^2}{4\pi\varepsilon_0(l+a)^2} + \frac{q^2}{4\pi\varepsilon_0 a^2}$$

towards right. The force on this rod due to the charge $-q$

$$= \frac{q^2}{4\pi\varepsilon_0(2l+a)^2} - \frac{q^2}{4\pi\varepsilon_0(l+a)^2}$$

towards right.

The resultant force on the rod is

$$F = \frac{q^2}{4\pi\varepsilon_0}\left[\frac{1}{a^2} - \frac{2}{(l+a)^2} + \frac{1}{(2l+a)^2}\right] \text{ towards right.}$$

If $l >> a$, the last two terms in the square bracket are negligible as compared to the first term. Then,

$$F \approx \frac{q^2}{4\pi\varepsilon_0 a^2}.$$

If $a >> l$

$$F \approx \frac{q^2}{4\pi\varepsilon_0}\left[\frac{1}{a^2} - \frac{2}{a^2} + \frac{1}{a^2}\right] \approx 0.$$

Two neutral objects placed far away exert only negligible force on each other but when they are placed closer they may exert appreciable force.

3. *Calculate the ratio of electric to gravitational force between two electrons.*

Solution : The electric force $= \dfrac{e^2}{4\pi\varepsilon_0 r^2}$

and the gravitational force $= \dfrac{G(m_e)^2}{r^2}$.

The ratio is $\dfrac{e^2}{4\pi\varepsilon_0 G(m_e)^2}$

$$= \frac{9\times 10^9 \dfrac{\text{N-m}^2}{\text{C}^2} \times (1{\cdot}6\times 10^{-19}\ \text{C})^2}{6{\cdot}67\times 10^{-11}\dfrac{\text{N-m}^2}{\text{kg}^2}\times (9{\cdot}1\times 10^{-31}\ \text{kg})^2} = 4{\cdot}17\times 10^{42}.$$

□

QUESTIONS FOR SHORT ANSWER

1. A body of mass m is placed on a table. The earth is pulling the body with a force mg. Taking this force to be the action what is the reaction ?
2. A boy is sitting on a chair placed on the floor of a room. Write as many action-reaction pairs of forces as you can.
3. A lawyer alleges in court that the police has forced his client to issue a statement of confession. What kind of force is this ?
4. When you hold a pen and write on your notebook, what kind of force is exerted by you on the pen ? By the pen on the notebook ? By you on the notebook ?
5. Is it true that the reaction of a gravitational force is always gravitational, of an electromagnetic force is always electromagnetic and so on ?
6. Suppose the magnitude of Nuclear force between two protons varies with the distance between them as shown in figure (4-Q1). Estimate the ratio "Nuclear force/Coulomb force" for (a) x = 8 fm (b) x = 4 fm, (c) x = 2 fm and (d) x = 1 fm (1 fm = 10^{-15} m).

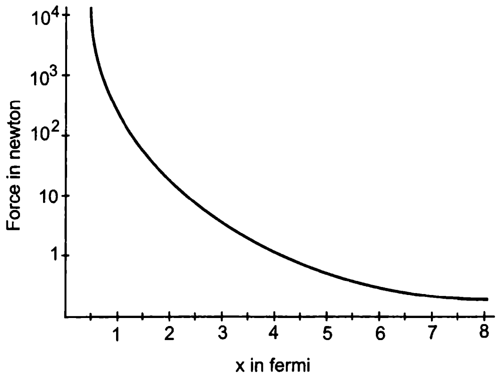

Figure 4-Q1

7. List all the forces acting on the block B in figure (4-Q2).
8. List all the forces acting on (a) the pulley A, (b) the boy and (c) the block C in figure (4-Q3).

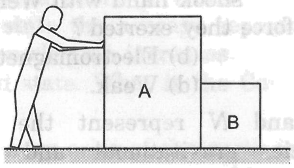

Figure 4-Q2

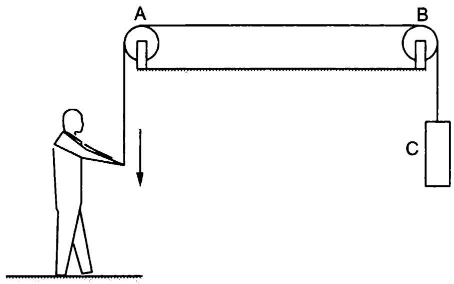

Figure 4-Q3

9. Figure (4-Q4) shows a boy pulling a wagon on a road. List as many forces as you can which are relevant with this figure. Find the pairs of forces connected by Newton's third law of motion.

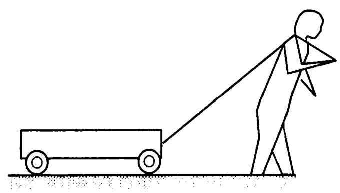

Figure 4-Q4

10. Figure (4-Q5) shows a cart. Complete the table shown below.

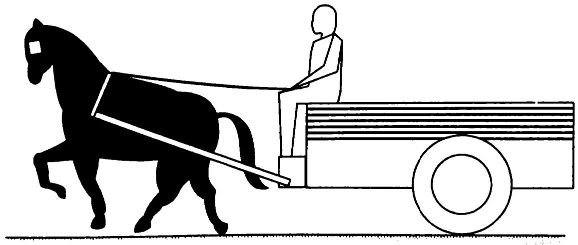

Figure 4-Q5

Force on	Force by	Nature of the force	Direction
Cart	1 2 3 :		
Horse	1 2 3 :		
Driver	1 2 3 :		

OBJECTIVE I

1. When Neils Bohr shook hand with Werner Heisenberg, what kind of force they exerted ?
(a) Gravitational (b) Electromagnetic
(c) Nuclear (d) Weak.

2. Let E, G and N represent the magnitudes of electromagnetic, gravitational and nuclear forces between two electrons at a given separation. Then
(a) $N>E>G$ (b) $E>N>G$ (c) $G>N>E$ (d) $E>G>N$.

3. The sum of all electromagnetic forces between different particles of a system of charged particles is zero
(a) only if all the particles are positively charged
(b) only if all the particles are negatively charged
(c) only if half the particles are positively charged and half are negatively charged
(d) irrespective of the signs of the charges.

4. A 60 kg man pushes a 40 kg man by a force of 60 N. The 40 kg man has pushed the other man with a force of
(a) 40 N (b) 0 (c) 60 N (d) 20 N.

OBJECTIVE II

1. A neutron exerts a force on a proton which is
(a) gravitational (b) electromagnetic
(c) nuclear (d) weak.

2. A proton exerts a force on a proton which is
(a) gravitational (b) electromagnetic
(c) nuclear (d) weak.

3. Mark the correct statements :
(a) The nuclear force between two protons is always greater than the electromagnetic force between them.
(b) The electromagnetic force between two protons is always greater than the gravitational force between them.
(c) The gravitational force between two protons may be greater than the nuclear force between them.
(d) Electromagnetic force between two protons may be greater than the nuclear force acting between them.

4. If all matter were made of electrically neutral particles such as neutrons,
(a) there would be no force of friction
(b) there would be no tension in the string
(c) it would not be possible to sit on a chair
(d) the earth could not move around the sun.

5. Which of the following systems may be adequately described by classical physics ?
(a) motion of a cricket ball
(b) motion of a dust particle
(c) a hydrogen atom
(d) a neutron changing to a proton.

6. The two ends of a spring are displaced along the length of the spring. All displacements have equal mangnitudes. In which case or cases the tension or compression in the spring will have a maximum magnitude ?
(a) the right end is displaced towards right and the left end towards left
(b) both ends are displaced towards right
(c) both ends are displaced towards left
(d) the right end is displaced towards left and the left end towards right.

7. Action and reaction
(a) act on two different objects
(b) have equal magnitude
(c) have opposite directions
(d) have resultant zero.

EXERCISES

1. The gravitational force acting on a particle of 1 g due to a similar particle is equal to $6{\cdot}67 \times 10^{-17}$ N. Calculate the separation between the particles.
2. Calculate the force with which you attract the earth.
3. At what distance should two charges, each equal to 1 C, be placed so that the force between them equals your weight ?
4. Two spherical bodies, each of mass 50 kg, are placed at a separation of 20 cm. Equal charges are placed on the bodies and it is found that the force of Coulomb repulsion equals the gravitational attraction in magnitude. Find the magnitude of the charge placed on either body.
5. A monkey is sitting on a tree limb. The limb exerts a normal force of 48 N and a frictional force of 20 N. Find the magnitude of the total force exerted by the limb on the monkey.
6. A body builder exerts a force of 150 N against a bullworker and compresses it by 20 cm. Calculate the spring constant of the spring in the bullworker.
7. A satellite is projected vertically upwards from an earth station. At what height above the earth's surface will the force on the satellite due to the earth be reduced to half its value at the earth station ? (Radius of the earth is 6400 km.)
8. Two charged particles placed at a separation of 20 cm exert 20 N of Coulomb force on each other. What will be the force if the separation is increased to 25 cm ?
9. The force with which the earth attracts an object is called the weight of the object. Calculate the weight of the moon from the following data : The universal constant of gravitation $G = 6{\cdot}67 \times 10^{-11}$ N–m ^{2}/kg ^{2}, mass of the moon $= 7{\cdot}36 \times 10^{22}$ kg, mass of the earth $= 6 \times 10^{24}$ kg and the distance between the earth and the moon $= 3{\cdot}8 \times 10^{5}$ km.
10. Find the ratio of the magnitude of the electric force to the gravitational force acting between two protons.
11. The average separation between the proton and the electron in a hydrogen atom in ground state is $5{\cdot}3 \times 10^{-11}$ m. (a) Calculate the Coulomb force between them at this separation. (b) When the atom goes into its first excited state the average separation between the proton and the electron increases to four times its value in the ground state. What is the Coulomb force in this state ?
12. The geostationary orbit of the earth is at a distance of about 36000 km from the earth's surface. Find the weight of a 120-kg equipment placed in a geostationary satellite. The radius of the earth is 6400 km.

□

ANSWERS

OBJECTIVE I

1. (b) 2. (d) 3. (d) 4. (c)

OBJECTIVE II

1. (a), (c) 2. (a), (b), (c) 3. (b), (c), (d)
4. (a), (b), (c) 5. (a), (b) 6. (a), (d)
7. (a), (b), (c), (d)

EXERCISES

1. 1 m
4. $4{\cdot}3 \times 10^{-9}$ C
5. 52 N
6. 750 N/m
7. 2650 km
8. 13 N
9. 2×10^{20} N
10. $1{\cdot}24 \times 10^{36}$
11. (a) $8{\cdot}2 \times 10^{-8}$ N,(b) $5{\cdot}1 \times 10^{-9}$ N
12. 27 N

□