Unit–4

MECHANICS

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Introduction

In our daily life we observe different motions of objects and the different causes of motion. The queries about the motion of objects were first given by Sir Isaac Newton more than 300 years ago. He explained the way in which forces pushes and pulls, influence the motion. Newton summed up his explanations in three summarizing laws. These laws explain what and how much is needed to make an object move.

After introducing Newton's law of motion, we will discuss about the gravitational force. The Earth's gravity is understood in universal law of Gravity. We will also learn how pressure, force and area are used in our daily life and their applications in science. Weight of a body on the earth is gravitational force exerted on it by the earth. Like all forces, weight is a vector quantity. The quantity of matter enclosed with in an object or a body is called mass. Kilogram is the unit of mass.

For thousands of years, doing work has been of vital concern for the human life. However, the forces the human body can exert are limited by physical strength and body design. Human beings have developed machines that increase the amount of force the human body can produce. We will learn about simple machines like lever, pulley inclined plane, screw and gears.

Objective

After reading the unit, you will be able to:

- recognize the basic ideas of physics
- describe Newton's first law of motion
- explain the significance of Newton's second law and use it to solve the problems of motion.
- describe the Newton's third law and describe the role of pairs of forces which are equal in magnitude and opposite in direction.
- describe inertia in detail and explain its role in our lives.
- identify that all objects in nature have the force of attraction between them, which is called the force of gravitation; especially the case of the attraction of the objects near the vicinity of Earth and Earth itself.
- relate force to work and explain how simple machines make easier by changing forces.

4.1 Force

When we think of a force, we usually imagine push or pull exerted on some object. For instance, you exert a force on a ball when you throw it or kick it. What happen to an object when it is acted by a force? Force is commonly defined as a push or a pull. We can apply the forces through contractions or extensions of our muscles. When you open a door, you pull it. By the contractions of your muscles we can exert a force. A **push** force moves something away from you and the **pull** force moves something closer. You can push hard or gently, left or right so the force has the magnitude as well as direction. Force is a vector quantity. The symbol F is used to represent the vector force. If you pull a spring or kick a ball, they change their positions due to the application of force. When you throw a ball in air it comes back due to the force of gravity of the earth.

Fig 4.1 a boy pushes a cart

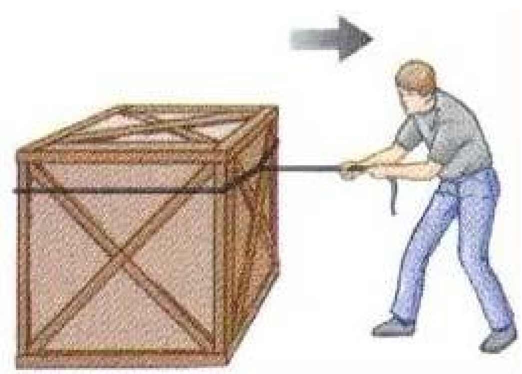

Fig 4.2 a man is pulling a heavy box.

Forces can be categorized into two types, one is the contact force and the other is the non-contact force. In fact when the objects are in contact directly with the forces are called contact forces. Examples from our daily life are normal push and pull force, surface tension of the liquids, air resistance carried by air planes and frictional forces (the cause of motion). The second types of forces are those which reason to attract and repel without get in touch with an object are called non-contact forces. Examples of the Non-contact forces are electric force, gravitational forces and magnetic force. These forces act due to the presence of their respective field's i.e. magnetic field created by the magnetic materials, similarly the gravitational force is the result of the gravitational field created by the Earth itself.

? **How many common push and pull forces do you apply in daily routine?**

An object that experience a push and pull has a force exerted on it. Notice that it is the object that is considered to be the **system**. The world around the object that exerts the force on object is called the **environment**. Each force has a specific, identifiable cause which is called **agent**. You should be able to name the agent of each force, for example when you push a book by your hand then the agent of pushing a book is your hand.

The first step in solving such problems is to create a pictorial model. To represent force acting on ball hanging by a rope, sketch the situation. Circle the system and identify where the system touches the environment. Next replace the object by a dot and each force is representing by arrows that points the direction of the force. Finally label each force acting on the system. Given below is the figure in which a ball is hanging by a rope. The gravitational force of Earth is acting downward and as result of this force a tension in the rope is present. The hanging ball with rope is the system. The gravitational force acting downward is the main agent. The system (ball) is represented by a dot in the pictorial model, where as the forces are represented by the arrows giving the directions of the forces.

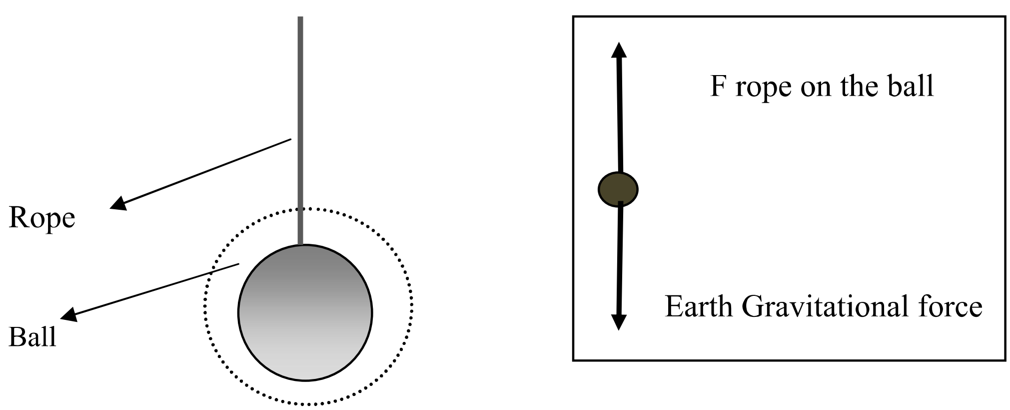

Fig 4.3 A pictorial model of ball hanging by a rope

You can push or pull hard or gently, left or right, so force has both magnitude and the direction. Force is a vector quantity. Here are some forces listed with their definitions and symbols.

Sr. No.	Force	Symbol	Definition	Direction
1.	Friction	F_f	The force of friction is the contact force that acts to go up against the sliding motion between the two surfaces.	Parallel to the surface at which the sliding occurs and opposite the direction of the sliding.
2.	Normal	F_N	The normal force is the contact force exerted by a surface on an object.	Perpendicular to and away from the surface
3.	Tension	F_T	The tension force is the pull exerted by a string, rope or cable when attached to a body and pulled out	Away from the object and parallel to the string, rope or cable at the point of attachment
4.	Weight	F_g	Weight is a non-contact force which produces the gravitational attraction between two objects, generally between the Earth and an object.	Straight down toward the center of the earth.

Table 4.1 Different forces, their symbols, definitions and directions

4.1.1 Newton's First Law of Motion:

? Is there any motion of an object when there is no force acting upon it?
Think of a ball rolling on a surface, how long will the ball continue to roll?

The motion of an object depends upon the force and also the quality of the surface. If you roll it on a thick carpet or sand, it will quickly come to rest. If you roll it on a marble floor, the ball rolls it for a long time. You could imagine that if all friction eliminated, the ball might roll forever. Galileo did all the above mentioned experiments and concluded that in ideal case, horizontal motion is eternal. He was the first to recognize the general principles of motion.

Newton generalized Galileo's results to motion in any direction. According to Newton:

An object that is at rest will remain at rest or an object that is moving will continue to move a straight line with constant speed, and if the net external force acting on that object is zero.

By external force we mean any force that results from the interaction between the object and its environment. In simpler terms, Newton's First Law states that when the net external force on an object is zero, its acceleration is zero. When

$$\Sigma F=0 \quad \text{then} \quad a=0$$

ΣF=0 means that the quantity of the applied force is equal the quantity of resistive force which is experienced by the object. Quantity is the same but the directions are opposite, in this way ΣF=0 is said to be zero.

Imagine a cricket ball and a tennis ball is placed side by side on the ground. First Law tells us that both remain at rest as long as no net external force is applied on them. Now imagine applying a force on each ball with a tennis ball, both balls resist to attempt to change their state of motion. But you know from the everyday experience that if the two balls are struck with same force, the tennis ball moves faster as compare to the cricket ball. Thus the cricket ball resists more to change their state of motion. The tendency of an object to resist change of motion is called inertia.

4.1.1.2 Balance and Unbalance Forces

We have learnt in the above section about Newton's First Law of motion. It actually predicts the behavior of objects that if the forces are balanced in the state of rest such that a man is standing on the floor. The weight is a force which is acting downward and the floor also exerting the force in the upward direction. If both the forces are balanced then the man is said to be stabled or in the equilibrium position. The force of gravity applies the force which is actually the weight of the man.

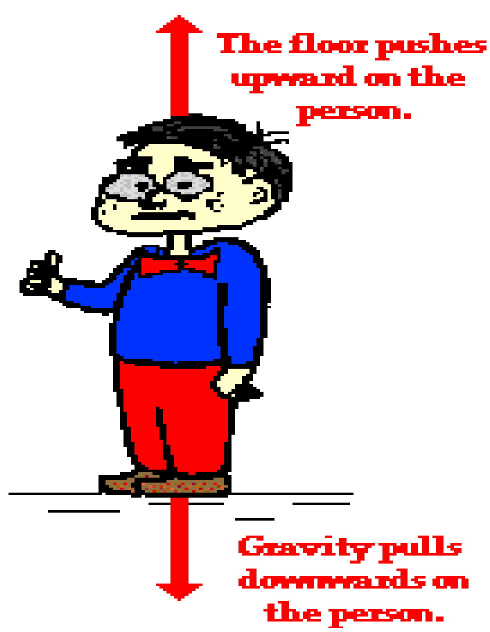

Fig 4.4 Forces shown on a person standing on the floor in a balance position

Similarly the First Law describes that the objects in constant motion will continue to move with constant velocity. The objects are in the state of balance. Newton discovered that objects will continue to do what they are doing until a net, or unbalanced force, acts on the object. A car is moving with a constant velocity on the road then the situation is said to be balanced because the car is applying a force by overcoming the friction of the road. The applying force is the power generated by the car whereas the friction of road is the reactive forces. Both forces have the same magnitude but are opposite in direction. If the car accelerates, then the condition of the balance will no more in balance but it is now in the unbalance condition. The car has applied more force and the friction it will have on less, so the applying force is more as compare to the friction of the road.

Fig 4.5 Car is accelerating, example of the un-balance force.

4.1.1.3 Inertia

The law of inertia is actually called the Newton's First Law of motion.

Inertia is the resistance of any physical object to a change in its state of motion or rest, or the tendency of an object to resist any change in its motion

If an object is at rest it will remain at rest until and unless a force is acted upon it. Whereas, if an object is moving with constant speed then it will try to move with the same speed constantly, until some force acts upon it and stops its motion.

Newton's first law of motion describes that a force is not desirable to keep an object moving because if an object is pushed by some force then it should continue to move unless some force or agent causes it to stop. As we all know that when we slide a book across a table after some time its motion stop and it comes to a rest position. The book in motion on the table comes to a rest position not because of the non-existence of a force, but due to the existence of a force. That force is the force of friction between the book and the surface of the table. It should be realized that in the absence of force of friction, the book continues to move with the same initial speed .So we can conclude that the presence of force is necessary to stop the motion of a book.

Mass is a measurement of inertia, and the SI unit of mass is Kilogram (Kg). The greater the quantity of mass in the body, the greater would be the inertia of that body. Mass is a scalar quantity. This is the nature of all objects that they refuse to accept the changes in their state of motion or the rest. All objects have this tendency, so they possess inertia. Objects having more mass have the large tendency to resist the state of rest or motion. The tendency of an object to resist changes in its state of motion varies with mass. Mass is that quantity that is solely reliant upon the inertia of an object. The more inertia an object has the more mass it possesses.

Suppose that there are two identical blocks, one is of brick and the other is of metal on the table. Apply the same force to push the two bricks or change their state of rest. The block that is made of brick, will resist less as compare to the metal brick. The reason is that the metal brick has large mass, so more inertia.
Similarly if two buckets are hanged by a stand, one is filled with sand and the other is empty, push the two buckets. The bucket which is filled with sand needs more force. Whereas the empty bucket needs only a little push.

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1. Describe some common examples about inertia.

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2. If four books are placed on each other. The last book is pulled out, what will happen?

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Activity 1

Find Out About Inertia

<u>Material Required:</u>
One glass, one coin, a piece of paper measuring 3″ x 3″.

<u>Procedures and Observations:</u>

1. Place the 3″ x 3″ measuring piece of paper on the empty glass. Then placed the coin in the center of the paper. Do you think that the weight of paper will be more than coin weight?

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2. Apply little push on the paper by the finger in the right hand direction. The paper flew away while the coin drops in the glass, why?

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3. Repeat step 2 by applying the push in left hand direction. Describe what happens?

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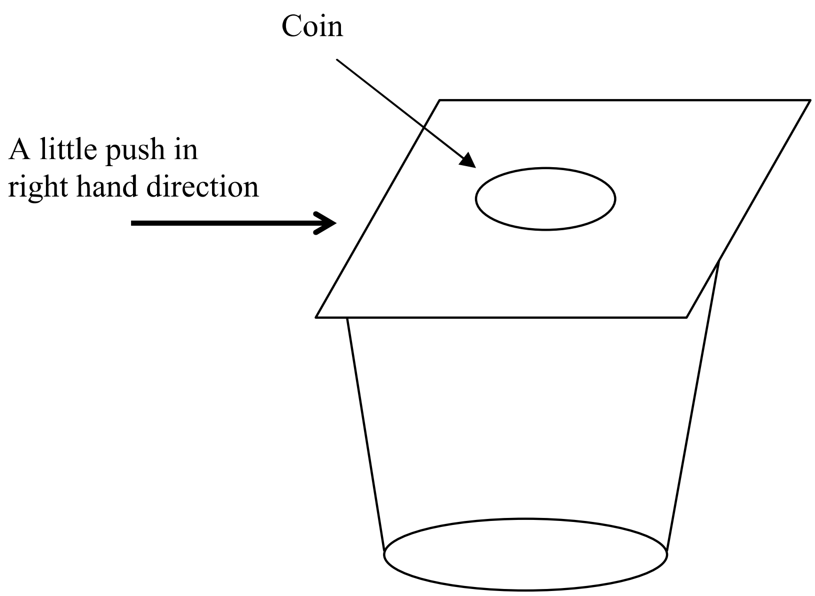

Fig 4.6 Car is accelerating, example of the un-balance force.

4.1.2 Newton's Second Law of Motion

Newton's first law describes that what happens to an object when the net force acting on it is zero, the object either remain at rest or move with constant velocity. Newton's Second Law describe what happen to an object that has a non-zero net force acting on it. Newton's Second Law explains the inter connectivity between the net force applied on an object and its acceleration. The second law discovers the root cause of a change in velocity and the resulting displacement.

By the application of force the objects moves, the rate of change of displacement is called velocity and rate of change of velocity is called acceleration.

$v = ds / dt$

Where v= velocity

ds = change of displacement (how much distance it cover) ,

dt = change in time

$a = dv/ dt$

a = acceleration,

dv = change of velocity

dt is change in time

Imagine pushing a block of ice across a frictionless horizontal surface. When you exert some force on the block, it moves in the direction of force, if you apply double force then it moves faster or we can say that by applying more force the acceleration of the body increases. So we can conclude that

Acceleration of the body is directly proportional to the applied force.

We have common experience while pushing objects, the mass of a body also affects the acceleration. Imagine that two blocks of metals are placed, one is of 10 kg and the other is of 5 kg. The force required to move the 10 kg metal block will be more as compare to 5 kg of metal block. So we can conclude form the above results that the

Acceleration of the objects in inversely proportional to the mass of the object.

These observations are summarized in the second law of motion:

The acceleration of an object is directly proportional to applied net force and inversely proportional to its mass".

In the equation form we can say that

$a \propto \Sigma F$ (acceleration is directly proportional to applied net force)

$a \propto 1/m$ (acceleration is inversely proportional to mass of object)

$$\Sigma F = ma$$

4.1.2.1 Mass and Weight

As we all know that in our daily life the mass of an object and the weight of an object are said to be the same quantity. But in reality they are not same but these are two different concepts and quantities. In general science, mass of a body refers to the quantity of "matter" an object has. Weight of a body refers to the force subjected by the Earth gravitational force on the body. So a mass of 10 kilograms will weigh 98 Newton.

We have learned in the above section that the mass is the measure of inertia, the resistance offered by the object to change of its state of rest or motion. Mass is a measure of the amount of substance in a body. The SI unit of mass is Kilogram (kg). Mass cannot be changed by the location, shape and speed of the body. Every object possesses mass, an electron has 10^{-03} kg mass, where a single pea has 10^{-3} kg and earth mass is 10^{24} kg. Mass is a scalar quantity. If a mass of 3 kg produces 4 m /s^2 acceleration then the same force will applied on a 6kg mass will produce 2 m /s^2 acceleration. The greater the mass the less acceleration it has and lower the mass greater will be the acceleration.

Fig 4.6 Electronic Balance

Mass is measured by using a balance, in which a known amount of matter is compared with an unknown amount of matter with the help of spring balance, or electronic balance.

Newton observed the fall of an apple from a tree. He began to think about the following lines: when the apple from the tree moved downward, it motion accelerated. The speed was zero as it was hanging on the tree and has the velocity when it moved toward the ground. Thus, by Newton's Second Law, he concluded that there was some force present which actually acted upon the apple in order to accelerate the apple. He called this force as the force of gravity, and the related acceleration to the acceleration due to gravity.

We all are aware that objects are attracted towards the Earth. The force exerted by the earth on an object is the gravitational force **Fg**. This force is directed approximately towards the centre of the Earth and its magnitude varies the distance from the center of earth. The magnitude of the gravitational force is called the weight of the object. While the weight of a mass is a function of the power of gravity, the mass of an object remains constant.

$$W = mg$$

W = weight of the object

M = mass of the object

g = acceleration due to the gravity.

The SI unit of weight is Newton (N), it is actually the force exerted by the Earth on an object. Bodies have less weight at high altitudes as compare to the sea level. This is the same case that astronauts feel weightlessness at the moon. Hence the weight is not the inherent property of an object. If an object has a mass of 70 kg then at the sea level, its weight will be

$$W = 70 \times 9.8 = 686 \text{ N}$$

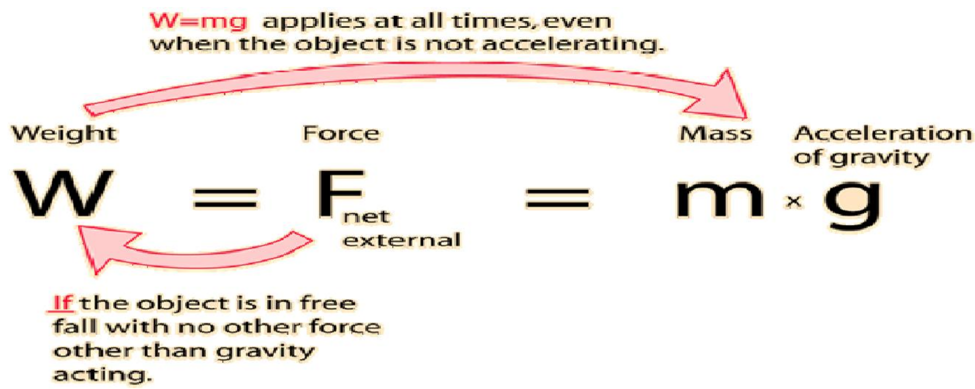

Fig 4.7 Weight is the net external force on an object due to gravity

Weight	Mass
pull of gravity on the body	amount of matter in the body
has both magnitude and direction	has only magnitude but no direction
measured in Newton	measured in kilograms
mass is measured by using a balance	weight is measured on a scale
comparing a known amount of matter to an unknown amount of matter	

Table 4.1 Comparison of mass and weight

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1. What is the relation between mass and weight?

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2. Describe the role of "g" the acceleration due to gravity in the equation w= mg .

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Activity 2

Does the air have weight?

Material Required:
Two balloons, 1/2 meter fine thread, a wooden stick, a needle.

Procedures and Observations:

1. Fill the two balloons with air until they are equal in size. Cut the thread in equal three pieces. Then attach the piece of fine thread to the each balloon. Now attach the two pieces of thread with the two balloons in such a way that the length of the thread will be the same. Then place the threaded balloons to the corner of the stick. Keep the balloons on the same distance from the end of the stick. Tie the third string to the middle of the stick and hang it from the edge of a table. Find the balance point where the stick is parallel to the floor. What is the situation of equilibrium?

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2. Puncture the one balloon, what will happen?

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3. Describe that the unbalance situation of the stick and give reason that the air possesses weight.

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4.1.3 Newton's Third Law of Motion

Let's consider the task of driving a nail into a block of wood, to accelerate the nail and drive it into the block a net force is supplied to the nail by the hammer. However, Newton recognized that a single isolated force (such as the force on the nail by the hammer) cannot exist. Instead, a force in nature always exists in pairs. According to the Newton, the hammer exerts a force on the nail and the nail also exerts force on the hammer. There is clearly a net force on the hammer, because it rapidly slows down after coming into contact with the nail.

Fig 4.8 Driving a nail into a wooden block

Newton described this type of situation in terms of the third law of the motion

If two objects interact, the force exerted on the first object by the second object is equal in magnitude but opposite in direction to the force exerted on second object by the first object.

This law states that forces always exist in pairs or that a single isolated force cannot exist. The force that first body exerts on the second body is sometimes called **action force** and the force of the second body exerts on the first body is called **reaction force**. In all case the action force and the reaction force acts on different objects and must be the same type.

$$F_{12} = - F_{21}$$

Fig 4.9 the force exerted by the object 1 on object 2 is equal to and opposite the force exerted by object 2 on object 1

Let's have a look when a ball is dropped from some height, the earth is applying a force of gravity on that ball Fg and the magnitude of the ball is mg. the reaction of this force of the ball on the earth if Fg′.

$$\text{So} \quad F_g = -F_g{}'$$

The reaction force F_g accelerates the ball towards earth and F_g' accelerates the earth towards ball but the earth has a huge mass as compare to the ball so its acceleration due to the reaction is negligible.

As we all know that the Earth exerts a force F_g on any object. If a mass of 1 kg is placed on floor at rest, the F_g is the force the Earth is exerting on 1 kg mass and F_R is the force that 1 kg mass exerts on the earth. The mass is not accelerating or moving but it is held up by the floor. The floor exerts the reactive force in an upward direction F_R which is the normal force; it balances the mass on the floor and provides equilibrium and the reaction to the F_R is the force of the mass on the floor. Therefore we can conclude that

$$F_g = - F_R$$

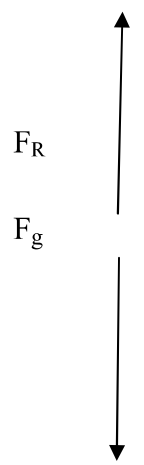

Fig 4.10 The force exerted by the mass on floor is equal to and opposite the force exerted by the floor on mass

4.1.3.1 Force of Friction

When a body is in motion either on a surface or through a fluid (air or water), there is a resistance to the motion because the body interacts with the surroundings. We can call such resistance the force of friction. Force of friction is very important in our daily lives. They allow us to walk, run and necessary for the motion of the wheeled vehicles.

Consider a block on a horizontal table. If we apply an external horizontal force F on the block, acting to the right, the block remains stationary provided the force is small. The applied force F keeps the block moving and the force which is acting in the left direction is called the force of static friction F_s. As long as the block is not moving we can say that $F_s = F$.

As F increases the F_s is also increasing, the body moves when the value of the F becomes greater than the $F_{s.}$ The frictional force arises from the nature of the two surfaces because of their roughness; contact is made only at few points as shown in the magnified view given below. The frictional force is a complicated phenomenon because it involves the study of the surface of bodies at the microscopic level.

Fig 4.1 The direction of the force of friction Fs between a block and a horizontal surface is opposite the direction of the applied force

If we increase the magnitude of F, the block eventually slips, when the block is on the verge of slipping the F_s will be maximum. When F exceeds $F_{s\,max}$, the block will move to the right and accelerates .When the block is in motion, the frictional force become less than $F_{s\,max}$. We call the friction force for an object in motion the force of kinetic friction $F_{k.}$ The unbalanced force in the x-direction F- F_k will produce the acceleration. If the applied force is removed then the frictional force acting to the left accelerates the block in the –x direction and eventually brings it to rest.

Some observations related to the force of friction are given below:

- The magnitude of the force of static friction between any two surfaces in contact have the values

$$F_s \leq \mu_s n$$

Where μ_s is the co-efficient of static friction
Where n is the magnitude of the normal force.

The above equation has the two states, first condition is that F_s is equal to the $\mu_s n$ when the block is at the verge of slipping and the second condition of inequality or less than means that the value of F_s is less than the value of $\mu_s n$

- The magnitude of the force of kinetic friction acting on an object is given by

$$F_k \leq \mu_k n$$

μ_k is the co-efficient of kinetic friction

- The values of μ_k is less than the values of μ_s

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1. Does the force of friction exist when the airplane moves in the sky?

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2. Describe the force of friction when a car is moving back.

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Activity 3

Force of Friction

Material Required:

Two 1-meter long strings, two small carts (if not available then use any two similar baskets or cans), four 0.2 kg masses.

Procedures and Observations

1. Tie the two 1 meter strings to the back of the carts and attach 0.2 kg masses at the other end of the strings. Hang the masses over the end of a table in such a position that the masses are just above the floor. Place the two masses in the carts separately. Give the carts a little push, what will happen?

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2. If no masses are present in the carts, what will be the movement?

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3. If the masses in the carts will be double, will the speed of the motion reduce?

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Key Points

1. A push force moves something away from you and the pull force moves something closer to you.
2. Forces can be categorized into two types, one is the contact force and the other is the non-contact force.
3. The world around the object that exerts the force on object is called the environment.
4. Each and every force has a particular, identifiable cause which is called agent.
5. According to the first law of motion “An object with no motion will keep the position of rest or an object moving with some velocity will continue to move along a straight line with constant speed, if the net external force acting on that object is zero”.
6. Newton discovered that objects will continue to do what they are doing until a net, or unbalanced force, acts on the object.
7. Inertia is the tendency of an object to resist change of its rest position or the moving position. If an object is at rest it will remain at rest, if it is moving at constant velocity it tends to move at the same speed continuously.
8. The second law of motion “the acceleration of an object is directly proportional to applied net force and inversely proportional to its mass”.
9. **$\Sigma F = ma$**
10. The force exerted by the earth on an object is the gravitational force Fg . The magnitude of the gravitational force is called the weight of the object.
11. The SI unit of weight is Newton (N), which is actually the force exerted by the Earth on an object.
12. Weight has both magnitude and direction and the mass has only magnitude but no direction.
13. The third law of the motion” If two objects interacts; the force exerted on the first object by the second object is equal in magnitude but opposite in direction to the force exerted on second object by the first object”.
14. The force that first body exerts on the second body is sometimes called action force and the force of the second body exerts on the first body is called reaction force.
15. Force of friction is very important in our daily lives. They allow us to walk, run and necessary for the motion of the wheeled vehicles.
16. The magnitude of the force of static friction between any two surfaces in contact have the values $F_s \leq \mu_s n$
17. The magnitude of the force of kinetic friction acting on an object is given by $F_k \leq \mu_k n$.

16. The values of μ_k is less than the values of μ_s

Self Assessment Exercise 4.1

Q.1 Fill in the blanks:

i. ---------------------- is commonly defined as a push or a pull
ii. A ------------ force moves something away from you
iii. A ------------ force moves something closer
iv. Forces can be categorized into ------------ types, one is the contact force and the other is the non-contact force.
v. Force has both ---------------- and the -----------------.

Q.2 Answer the following questions:

i. A book pushed across the desk by your hand, what are the forces acting on it?
ii. A book pulled across the table by a string, what are the forces present?

4.2 Pressure

Imagine that you are standing on the surface of road, your feet exerts force on the earth. The area under your shoe bears the force of your body. The ratio of the applied force to the area is called pressure. When you talk about a high heel, the high heel exerts more pressure on earth than the shoe, because the area is small but the force is same. For example a man is sitting on a ground; the weight is the force which is acting on the surface of Earth. The force (weight of man) acted upon the area he covers while sitting cause the pressure of the man on the Earth. But a man is standing applies the same force (weight) with different area in contact with the surface and therefore exert a different pressure.

Fig 4.13 Different Area in contact will give different value of the pressure

Pressure is defined as force per unit area.

It is usually more suitable to use pressure rather than force to describe the fluid behavior. The standard unit for pressure is the Pascal, which is a Newton per square meter.

$$P = F / A$$

Where: P is the pressure,
F is the normal force,
A is the area of the surface area on contact

There are many common physical examples where pressure is the most important variable. If you peel some apple, you actually apply pressure on the apple with the help of a knife. As the knife edge is sharp you have to apply less force, because the area of contact of the apple and the knife is small.

If you visit a doctor and he advises you to get an injection. The sharp needle can pass the right pressure as compare to a dull one. The smaller area of contact involves less force for the needle to push through the skin.

As we all know that the fluids exert pressure. The individual molecules of the fluid, however, are in constant random motion. In the fluids, there are extremely huge amount of molecules and because the movement of the particular molecules is random in every direction so we do not specify the motion.

If we fill a container with some fluid (either gas or liquid), we can detect a pressure in the fluid from the molecules, which have a collision with the walls of container. We can put the gas in the container , and the force per unit area (the pressure) is the same. Similarly, pressure acts in all directions at a point inside a fluid. At the surface of a fluid, direction of the pressure acts at right angle to the surface. Pressure is the effect of a force applied to a surface. Pressure is a scalar quantity. The transmission of pressure from the fluid to the solid boundaries is always perpendicular to that surface at every point.

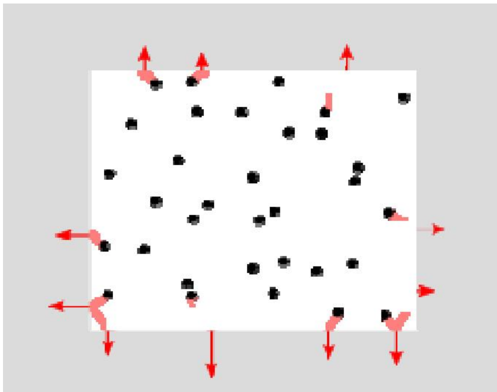

Fig 4.14 Pressure as exerted by particle collisions inside a closed container

Absolute Pressure

The absolute pressure is measured relative to the absolute zero pressure. Absolute pressure is pressure that would occur at absolute vacuum, or zero pounds per square inch (PSI). All calculations concerning the gas laws have need of pressure, and temperature in absolute units. Absolute pressure is actually referred as 'total systems pressure'. To differentiate it from gauge pressure, the term 'abs' is usually placed after the unit. The absolute pressure, Pabs is measured relative to the absolute zero pressure .It is the pressure that would occur at absolute vacuum. All calculation involving the gas laws requires pressure (and temperature) to be in absolute units.

$$P_{abs} = P_g + P_{atm}$$

Gauge Pressure

A gauge pressure is often in use to measure the difference between a system pressure and its environment (surrounding) pressure. The gauge pressure actually has shown on the dial of a gauge gives record of the pressure relative to atmospheric pressure. For example if a pressure gauge gives the reading of zero value, it does not mean that there is no pressure acted upon the fluid , actually it means that there is no pressure in addition of to the atmospheric pressure. This pressure is often called the gauge pressure and can be expressed a

Pg = Pabs - Patm

Where Pg = gauge pressure
Ps = Absolute pressure
Patm = atmospheric pressure

Atmospheric pressure

Atmospheric pressure can be defined as the force exerted by the weight of air just above that surface per unit area applied against that surface. Think in terms of air molecules, if the quantity of the air molecules above a surface increase, so there are more number of molecules to exert a force on that surface and in this way the pressure automatically increases. The case will be opposite; when there is a reduction in the quantity of air molecules above that surface will give low pressure in result.

Fig 4.15 The relationship among the absolute, atmospheric and gauge pressure

Atmospheric pressure is measured with an instrument called a "barometer", that is why atmospheric pressure is also called as barometric pressure.

Units for Pressure

- The SI unit for pressure is Pascal (Pa), equal to one Newton per square meter (N/m^2 or $kg \cdot m^{-1} \cdot s^{-2}$).
- The British system measures pressure in pounds per square inch .
- The CGS unit of pressure is the barye (ba), equal to 1 $dyn \cdot cm^{-2}$ or 0.1 Pa. Pressure is sometimes expressed in grams-force/cm^2, or as kg/cm^2.

- The standard atmosphere is approximately equal to typical air pressure at earth mean sea level and is defined as follows:
  Standard atmosphere = 101,325 Pa = 101.325 kPa

Example Problem 01

A woman has 550 N weight and she wears the high heel shoes that come into contact with the ground over an area of 425 cm^2.

a) What will be the value of the average pressure exerted by the shoes in kPa over the floor?
b) How much pressure will be exerted by the woman if she stands up on her one foot?
c) What will be the value of the pressure if she puts all her weight on the heel of one of his shoe with the area of the high heel of 0.5 cm^2?

Known:

$F = 550$ N

$A_{shoes} = 425\ cm^2$

$A_{shoe1} = 212.5\ cm^2$

$A_{of\ high\ heel} = 0.5\ cm^2$

Unknown;

$P_{shoes} =?$

$P_{shoe1} =?$

$P_{of\ high\ heel} =?$

Formula:

$\mathbf{P} = F/A$

Calculation:

1. $A_{shoes} = 425\ cm^2 = 412 / (100)^2 = 0.0425\ m^2$
   So $P_{shoes} = 550 / 0.0425 = 12914\ N/m^2$ = 12 kilo Pascal

1. $A_{shoe1} = 212.5\ cm^2 = 212.5 / (100)^2 = 0.0212\ m^2$
   So $P_{shoe1} = 550 / 0.02212 = 24864\ N/m^2$ = 24.86 Kilo pascal

2. $A_{of\ high\ heel} = 0.5\ cm^2 = 0.5 / (100)^2 = 0.00050\ m^2$
   So $P_{of\ high\ heel} = 550 / 0.00050 = 1100000\ N/m^2$ = 110 kilo pascal

Key Points

1. Pressure is defined as force per unit area. . The standard unit for pressure is the Pascal, which is a Newton per square meter.

$$P = F / A.$$

2. Pressure is a scalar quantity.
3. Absolute pressure is pressure that would occur at absolute vacuum, or zero pounds per square inch (PSI). Absolute pressure is also referred to as 'total systems pressure'. $P_{abs} = P_g + P_{atm}$
4. The pressure actually shown on the dial of a gauge that registers pressure relative to atmospheric pressure
5. Atmospheric pressure is defined as the force per unit area exerted against a surface by the weight of the air above that surface.

Self Assessment Exercise 4.2

Q.1 Fill in the blanks:

i. The ratio of the______________________ to the____________ is called pressure.

ii. The standard unit for pressure is the _______________, which is a Newton per square meter.

iii. Pressure is a______________ quantity.

iv. Atmospheric pressure can be defined as the force exerted by the weight of air just _______________that surface per unit area applied against that surface.

v. Atmospheric pressure is measured with an instrument called a ______________

4.3 Gravitational Force

As we all know that the fall of an apple made Newton to think on the subject of the motion of the planets. He recognized that the apple falls on the surface of Earth only because of the Earth attraction towards the apple. He was in doubt whether this force of attraction could extend beyond the tree to cloud, to moon and even beyond the moon.

He thought that the force on the apple must be directly proportional to its mass . In addition, according to his own third law of motion, the apple would also attract towards Earth. Similarly, the force of attraction is also proportional to the mass of earth and the mass of the object. Another factor involved is the distance between the apple and the Earth. He concluded that this force of attraction is inverse of the distance between them. This attractive force between objects and the Earth is called the **Gravitational force**.

Newton was so confident about his governing laws of motion on Earth, that he suggested that this force would work anywhere in the universe. He assumed that the same force of attraction would act between two masses m_A and m_B.

The law of Gravitation states

The gravitation between two bodies is proportional to the product of their masses and inversely proportional to the square of the distance between them.

He proposed his law of gravitation, which is represented by the following equation:

$$F \propto m_A \, m_B$$
$$F \propto 1/d^2$$

Law of Universal Gravitation $$F = \frac{G \, m_A \, m_B}{d^2}$$

In the above equation, d = distance between the centers of the two objects

G= Universal Constant

m_A, m_B = Masses of two objects

Fig 4.16 Different objects exerts the force according to their masses

How large is the constant G? As you know that the force of gravitational attraction between two objects on earth is small. You can't feel the slightest attraction even between two huge objects. It took about 100 years after the Newton's law of motion.

4.3.1 Henry Cavendish Experiment

In 1797 AD, a scientist from Britsih, Henry Cavendish had first performed experiment to measure the gravitnational force between two masses in the laboratory. He was the first to give accurate values results about the gravitational constant. He used the equipment given below in the figure 4.17. The apparatus consisted of a torsion balance made of a six-foot (1.8 m) wooden rod suspended from a wire, with a 2-inch (51 mm) diameter 1.61-pound (0.73 kg) lead sphere attached to each end. Two 12-inch (300 mm) 348-pound (158 kg) lead balls were located near the smaller balls, about 9 inches (230 mm) away, and held in place with a separate suspension system. The experiment measured the giant gravitational attraction between the small balls and the larger ones. The two large balls were positioned on alternate sides of the horizontal wooden arm of the balance. Their mutual attraction to the small balls caused the arm to rotate, twisting the wire supporting the arm.

Figure 4.17 Apparatus of the Henry Cavendish Experiment

The arm was stopped rotating when it arrived at an angle where the rotating force of the wire balanced the combined gravitational force of attraction between the large and small lead spheres. By measuring , the angle of the rod, and with the known value of twisting force (torque) of the wire, Cavendish determined the force of attraction between the pairs of masses. Since the gravitational force of the Earth on the small ball could be measured directly by weighing it, the ratio of the two forces allowed the density of the earth to be calculated, using Newton's law of gravitation.

4.3.2 Weight & Weightlessness

The accelaration of objects due to earth's gravitation can be found by using Newton's law of universl gravitation and second law for a free falling object. Lets the force between the Earth nad an object paced on Earth is given by

$$F = \frac{G\, m_E\, m}{d^2} \quad \text{.............1}$$

We know $F = ma$ ………………….2

Combining equation 1 and equation 2

On the earth surface the distance between will be d= Re , so the above equation will become

As the distance is increasing then the value of the g will be reducing according to the inverse square relationship. You have seen the photos of the Astronauts that feel the condition of weightlessness of space shuttle. This situation is called "zero-g". The shuttle distance from the surface of Earth is only 400 km. At that distance the value of "g" is 8.6 m/s^2, thus the gravitational force is certainly not zero in the shuttle.

The Astronauts have the weight because the gravitational force is exerted on them, but they don't have apparent force. Remember that you sense weight when something such as floor or your chair exerts force on you. But if you, your chair and the floor are accelerating towards Earth together, then no contact forces exerted on you. Your apparent weight is zero and you are experiencing the condition of weightlessness.

Example Problem 2

There are two 5.0 kg masses, which are 2.5 meter apart from their centers. Determine the force of attraction between them?

Known

M1 = 5.0 kg

M2 = 5.0 kg

d= 2.5 meter

G= 6.67×10^{-11} N m^2 / kg^2

Unknown **Force of attraction** =?

Formula: $F = \frac{G\, m_A\, m_B}{d^2}$

Calculation:

$$F = \frac{6.67 \times 10^{-11}\ N\, m^2 / kg^2 \times 5.0\ kg \times 5.0\ kg}{(2.5)^2\ m^2}$$

F= 26.68×10^{-11} N

Two 1.0 kg masses have their centers 1.0 meter apart. What is the force of attraction between them?

Key Points

1. The law of Gravitation states "the gravitation between two bodies is proportional to the product of their masses and inversely proportional to the square of the distance between them".

$$F = \frac{G\, m_A\, m_B}{d^2}$$

2. If the mass of one object is double than the force would be double.
3. Similarly if the distance between them is reduced to half, the force will be of the four times the actual force between them.
4. Henry Cavendish, a British scientist did the first experiment to measure the force of gravity between two masses in the laboratory and give the specific value of the gravitational constant.
5. Forces can be categorized into two types, one is the contact force and the other is the non-contact force.
6. The Astronauts that feel the condition of weightlessness of space shuttle. This situation is called "zero-g".

Self Assessment Exercise 4.3

Q.1 Answer the following questions:

i. If the Earth weight was as twice as massive but remained the same size, what will be the value of "g" will be?

ii. The moon and the Earth are attracted to each other by the Gravitational force. The massive Earth attracts the moon with a greater force than the moon attracts the earth, why?

4.4 Simple Machines

We do not know exactly, when and what kind of machine was first made and used by human beings. From the study of the Stone Age period, we know that they used wood, bone, stone to make tools such as axes, hammers, knives, and pins and needles. After the invention of pulley and lever, the creation of the wheel revolutionized the transportation without which our modern machinery would be impossible.

Everyone uses a number of machines every day, some are simply the tools, such as bottle opener and screwdrivers and some are complex machines such as automobile, bicycles etc. Machines, whether power-driven by engines or by the people, they make task easier. A **machine** reduces load by modifying either the quantity or the direction of the force as it transmits energy to the task. So we can say that the machines serve any of the three following purpose:-

i) They increased speed; examples are egg beater, drive wheel of a bicycle.
ii) They increase force; example car jack, screwdriver etc.
iii) They change the direction of the force; example pulley.

As you have noticed that machines you use in every day, perform the three kinds of tasks mentioned above. These machines do not produce energy but made use of the energy supplied to them.

Consider the case of bottle opener, when you use the bottle opener, you actually lift the handle, in this manner you do work on the bottle opener. The opener raises the cap by doing work on it. The work you do is called the input work Wi and the work that machines does is called the output work Wo. As you know that work is done when some force applied and as a result some displacement occurs. Another definition of the work is that the transfer of energy by the mechanical resources. You put the work on the machine and as a result it does the work. In the current example, the machine used is the bottle opener.

You give energy to the opener. In response to the energy applied by your hand, the opener does work on the bottle cap and transfer energy to cap. The source of energy is not the opener but the source is your hand. The cap is not receiving much energy that you put into an opener, but the outcome is the greater force. The machine simply helps to transfer energy from your hand to the bottle cap. In general, simple machines provide mechanical advantage.

Listed below are the four classical simple machines:

◊ Lever
◊ Pulley
◊ Screw
◊ Gear

These simple machines fall into two classes:

(i) The inclined plane, wedge, screw characterized by the vector resolution of forces and movement along a line.

(ii) The lever, pulley, wheel and axle characterized by the equilibrium of torques and movement around a pivot.

A simple machine is an elementary device that has a specific movement (often called a mechanism), which can be combined with other devices and movements to form a machine.

4.4.1 Lever

Try to displace a heavy stone with hand, can you do this easily? To do this you only need block of wood and a strong rod or a wooden plank. The wooden block is placed under the plank. The stone is placed on one end of the lever and on other side you applied the force in the downward direction. The stone will be lifted in the upward direction.

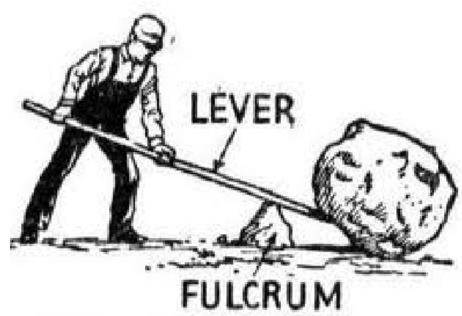

Fig 4.18 a man lifting a stone by lever

The supporting block provides the pivot point called the fulcrum of lever. The distance on the plank from the fulcrum to the end of the plank is called the force arm. Two force arms are present on the lever. One arm is towards the man who is lifting the weight and the other arm is towards the weight. The greater the force arm, the man will require less push and more load/weight will be loaded.

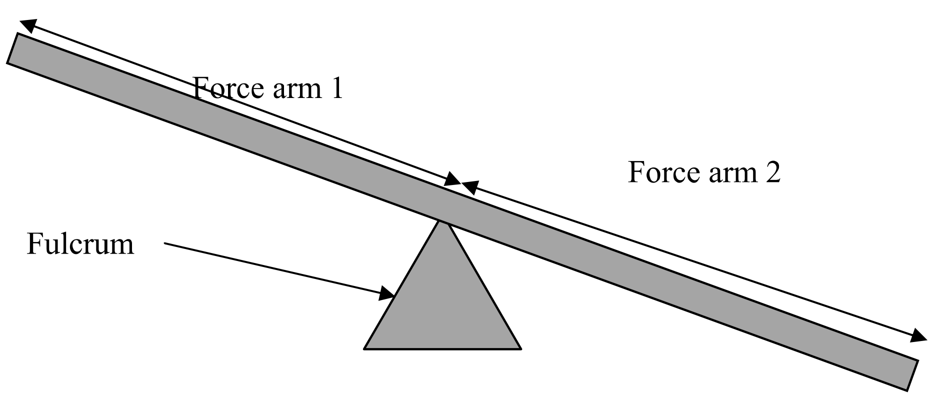

Fig 4.19 a lever parts: force arms and fulcrum

Another example of lever is the hammer. When hammer is used to pull a nail, its long handle makes it possible for the user to exert a strong pull. The hammer is a bent lever. The nail offers the resistance and the point of contact of hammer with wood is the fulcrum. The pull of the hand holding the hammer serves as the force.

Principle of lever

In all types of lever, the moment of effort is always equivalent to the moment of load provided it is in equilibrium state. Hence,

Effort x Effort arm = Load x load arm

Mechanical Advantage of Lever

A typical lever is shown in the fig. The "X" is the effort arm whereas "Y" is the load arm.
According to principle of lever

Effort x Effort arm = Load x load arm

E x X = L x Y

L / E = X / Y

As

Fig. 4.20

Mechanical Advantage = load / Effort

M.A = L / E

Mechanical Advantage of lever = X / Y

Mechanical Advantage of lever = Effort Arm / Load Arm

4.4.2 Pulley

Pulley is a wheel with groove through which a string is passed. The pulley can rotate freely about its axis. What advantage we get from it? Let us perform an experiment, take a bucket full of water and lift it up. Can you lift easily? Now suspend a pulley by a string as shown in fig. 4.20. Pass long string over it. Tie bucket with one end of the string and pull the other end of the string downward. Is the load being lifted up easily? Pulley is also used to draw water from a well. Thus we see that the pulley helps to apply the effort more easily in the suitable direction. By pulling the string downward the load can easily be lifted up to sufficient height.

Fig. 4.21 a fixed or stationary pulley.

The fixed pulley does not increase the force but makes it more conveient to apply. The combination of pulleys, in which one or more pulleys actually moves called a compound pulley. They are used in moving heavy objects. The more pulleys are present, the less force is required to pull the weight.

Pulleys can be used in two ways:

i. Single Fixed Pulley
ii. Single Movable Pulley

i. Single Fixed Pulley

In order to lift up the load of construction material single fixed pulleys are used.
In a single fixed pulley,the block of pulley is attached with some strong support.

Mechanical Advantage Of Single Fixed Pulley

We know that
Effort moment arm = load moment arm
From figure L x OA = E x OA
As OA = OB
Therfore L = E

Mechanical Advantage = M.A = L / E = 1
In reality,due to friction ,the mechanical advantage of single fixed pulley is less than "1". Although in single fixed pulley,an effort is applied equivalent to load. Our work becomes easy as we have to apply effort downwards in order to lift up the weight.

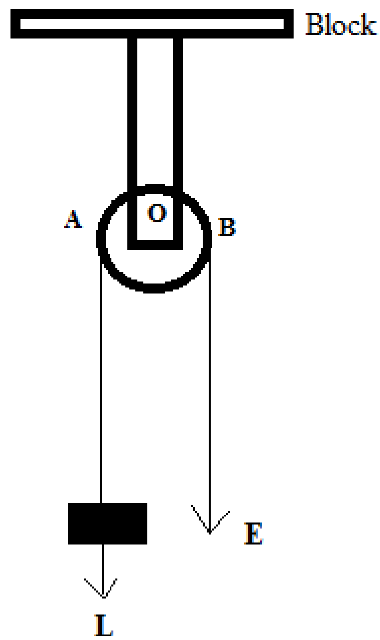

Fig. 4.22 Single Fixed Pulley

ii. Single Movable Pulley

In a single movable pulley, one end of string is fixed with some strong support.the effort is applied to some other end. The load is attached to the block of pulley.

Mechanical Advantage Of Single Movable Pulley

At every part of the string,effort "E" is the same. As both of the parts of the string lift up the load in upward direction. Therfore the effort acting on the load "L" is "2E". Neglecting weight and friction, then

Load = 2 x Effort

L = 2 x E

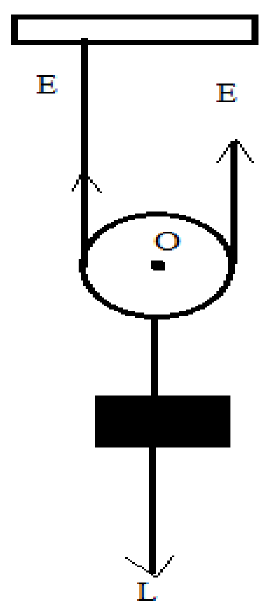

Fig. 4.23 Single Movable Pulley

Mechanical Advantage = L / E = 2
Thus, the mechanical advantage of single movable pulley is 2. As compare to effort, the two times weight can be lifted up.By applying another single fixed pulley,the direction of effort can be changed. In this way work can be made more simple.

4.4.3 Screw Jack

Screw is a machine that changes rotational motion into linear motion. The most familiar type consists of a cylindrical shaft with helical grooves or ridges called threads around the outside. The screw passes through a hole in another object or medium, with threads on the inside of the hole that mesh with the screw's threads. When the shaft of the screw is rotated relative to the stationary threads, the screw moves along its axis relative to the medium surrounding it; for example rotating a wood screw forces it into wood.

In order to replace the punctured tyre, there is need to lift up vehicle body. And to do this, the machine which is used is called screw jack. The weight to be lifted rests on the screw head. As the screw is turned, it twists out of the base and elevates the load resting on it.

A screw jack is a kind of simple machine. It consists of two main parts:

a. Bolt which is a strong cylinder made up of metal. The outer surface of bolt contains thread.
b. Nut is the second part .the inner surface of the nut contains threads similar to the outer surface of the bolt.

Pich is the vertical distance covered by completing one cycle.

Mechanical Advantage of a Screw Jack

Assume the length of handle is “l”. On one end, effort E is applied. The handle covers a distance $2\pi l$ in one cycle. Hence,
Input = Effort x distance moved by the effort
Input= E x $2\pi l$
Aassume the bo;t lifts the load “L” upwardd covers a vertical distance “h” in one cycle. Now the,
Output = load x distance moved by the load
Output = Lx h
We are ignoring friction, then
Output = input
$L \times h = E \times 2\pi l$
$L/E = 2\pi l / h$
Mechanical Advantage = load/ Effort = L/E
M.A = $2\pi l / h$

The mecahnical advantage of the screw jack is always greater than 1 because the lentgh of the handle l is always larger than the pitch of the bolt h.

A screw is essentially a coiled plane. In fact, the screw is the combination of the two simple machines, a wheel and the axle and an inclined plane.

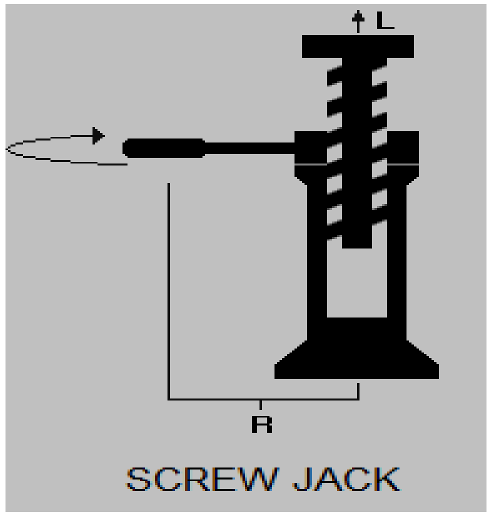

Fig. 4.24 A screw jack.

4.4.4 Gears

Power can also be transmitted from one wheel to another by equipping the wheels with

Fig. 4.25 A Gear

Intermeshing teeth's. Such wheels are called gears or gear wheels (which together with their mounting), are variants of the wheel and axle. A gear is a teethed wheel use in rotating machinery. The teeth of the one gear mesh with another toothed gear in order to pass on the torque. More than two gears working in tandem are called a transmission and can produce a mechanical advantage through a gear ratio and thus may be considered a simple machine. The basic purpose of gears is to change the speed, direction, and torque of a power source. Commonly in machines the situation is for a gear to engage with another gear. The purpose of the gears like other machines is to increase force, or change the direction of the force.

Key Points

a) A **machine** reduces load by modifying either the quantity or the direction of the force as it transmits energy to the task.
b) Machines do not produce energy but made use of the energy supplied to them.
c) The simple machines fall into two classes:
   (i) The inclined plane, wedge, screw characterized by the vector resolution of forces and movement along a line.
   (ii) The lever, pulley, wheel and axle characterized by the equilibrium of torques and movement around a pivot.
d) Pulley is a wheel with groove through which a string is passed. The pulley can rotate freely about its axis.
e) Screw is a machine that changes rotational motion to linear motion.
f) Power can also be transmitted from one wheel to another by equipping the wheels with intermeshing teeth's. Such wheels are called gears or gear wheels (which together with their mounting), are variants of the wheel and axle. A gear is a teethed wheel uses in rotating machinery.

Self Assessment Exercise 4.4

Q.1 Select the best answer:
   i. What do Simple Machines do?
      a) has the fulcrum between the effort and the load
      b) fixed point of a lever
      c) a twisting or turning as a result of a push or pull
      d) change size or duration of the force
   ii. Effort force
      a) force you put into a simple machine
      b) a twisting or turning as a result of a push or pull
      c) how well a machine changes force to work
      d) fixed point of a lever
   iii. Inclined Plane
      a) a large wheel attached to a smaller wheel or rod
      b) flat surface that has one end higher than the other
      c) basic machines that make up other machines
      d) twisting or turning as a result of a push or pull
   iv. Fulcrum
      a) increases effort force
      b) a large wheel attached to a smaller wheel or rod
      c) fixed point of a lever
      d) force you put into a simple machine
   v. Lever
      a) Force you put into a simple machine
      b) result of a force moving an object through distance

c) a bar that turns around a fixed point
d) how well a machine changes force to work

Answers of Self Assessment Exercises

Exercise 4.1
Q.1
i. Force
ii. Push
iii. Pull
iv. Two
v. Magnitude, Direction

Q.2
i. A book pushed across the desk by your hand, four forces are present, 1. The earth gravitational pull, 2. Reaction of the desk on the book, 3. The force exerted by you 4. Force of friction offered by the desk
ii. Same force of answer in 1 except push of hand is converted into the pull of the string.

Exercise 4.2
i. Applied force, area
ii. Pascal
iii. Scalar
iv. Above
v. Barometer

Exercise 4.3
i. If the Earth weight was as twice as massive but remained the same size, the value of "g" will be double, because double the mass of earth the force of gravitation will be double. So as the value of "g".
ii. The moon and the Earth are attracted to each other by the Gravitational force. The massive Earth attracts the moon with a greater force than the moon attracts the earth, because the greater mass produces more attraction

Exercise 4.4
i. d
ii. a
iii. b
iv. c
v. c

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