UNIT 5

SIMPLE MACHINES

Unit outcomes: After completing this unit you should be able to:

- ✓ understand concepts related to simple machines.
- ✓ develop skill of manipulating numerical problems related to simple machines.
- ✓ appreciate the interrelatedness of all things.
- ✓ use a wide range of possibilities for developing knowledge of the major concepts with in physics.

Introduction

Do you recall the different types of simple machines from your science courses?

Activity 5.1

Group the following devices as machines or not machine: knife, scissors, screw, computer, bottle opener, axel, typewriter, electric motor, lever, pulley and wedge.

In science there is no difference between machines and tools or devices. They mean the same thing. In this unit you will learn about some machines which help you make your work easier and be done conveniently. You will also learn about the purposes of some simple machines interms of their velocity ratio, mechanical advantage and efficiency.

To understand the purposes of machines, you need to revise the concepts of force, work, weight, ratio and percentage, because you often use them in this chapter.

5.1 Definition of Machines

Activity 5.2

i. As a student you use daily a sharpener, or a cutter or a blade to sharpen a pencil. Describe what advantage you get by using these devices.
ii. From your daily experience mention some devices or tools which help people make their life easier. Discuss with your friends how they make their work easier.
iii. What are machines? Can we call the above tools as machines? Why?
iii. Write the names of tools that you think are not machines.

Had there been no blade, cutter or sharpener, what would you use to sharpen your pencil? You might use your teeth or knife to sharpen your pencils. This idea is inconvenient for work. We use different tools in our daily activities to make our work easier.

Knife, scissors, screw, bottle opener, axel, lever, pulley and wedge, etc. are some machines or tools which make our work easier.

A machine is any device which helps us to do work easier.

Machines are energy transforming devices. Actually machines do not create energy or change one form of energy into another. They simply transfer mechanical energy involving a small force into mechanical energy involving a large force.

Machines act as force or speed multipliers. They are used to make work easier.

Why do we use machines?

Activity 5.3

Discuss the following questions with your friends or parents.

i. Why do people use inclined plane to raise different objects on a truck? (Hint is it to decrease the required force or to increase the speed?)

ii. Why do people use a bicycle instead of walking or running on feet? (Hint is it to save energy? or to decrease the required force? or, to be faster?)

iii. Why do we use a fixed single pulley to take water from a deep well?

Effort is the force you exert on the machine.

Load is the force exerted by the machine.

While you discuss the questions in Activity 5.3., you need to use the terms **effort** and **load**,

Effort (E) is the force exerted on a machine by an external body like a human being.

Load (L) is the force exerted by a machine on an object to be lifted or moved. It is the force with which the machine does work against resisting force like a weight and a friction force.

Having this in mind, think why people use a bicycle, an inclined plane and fixed single pulley. People use machines at least for one of the following purposes. These are:

1. to multiply force.
2. to multiply speed (distance)
3. to change the direction of force.

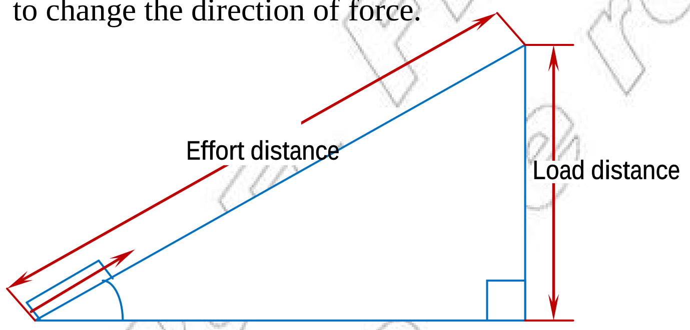


Fig 5.1 Inclined plane

Let us take an inclined plane shown in Fig 5.1. The force exerted by an external body to pull or push a block along the inclined plane is an **effort**. The distance moved by the effort is **effort distance.**

The block is lifted to certain height using the inclined plane.
The weight of the block is the **load;** while the distance raised is called the **load distance**.

In an inclined plane a small effort is used to lift the heavy load. Hence the inclined plane is used to multiply a force. It is a force multiplier machine.

Machines are said to be *force multipliers* when they enable us to lift big load by applying small effort. Load is greater than effort.

For example, if you raise a load of 400N by an effort of 40N using a machine, you are able to exert 10 times the original effort. In such cases the machine is a force multiplying tool.

Let us take another type of machine called a bicycle. People prefer to ride a bicycle rather than to walk on their feet. (Fig 5.2)

In a bicycle, the small distance moved by a person on a pedal is multiplied by the wheels of the bicycle and a long distance is covered during the same time. Hence a bicycle is called a speed multiplier or a **distance multiplier.**

Machines are said to be distance multipliers when they enable people to lift a load through a large distance by moving the effort through a small distance

Fig 5.2 Bicycle

Thus the distance moved by the effort is less than the distance moved by the load.

Example

Suppose in a machine an effort moves 1m in one second to lift a load, and the load moves 5m at the same time. The speed with which the effort moves would be 1m/s and that of the load is 5m/s. Here the speed of the effort is multiplied by five. In such cases the machine is used as a speed multiplier or a distance multiplier.

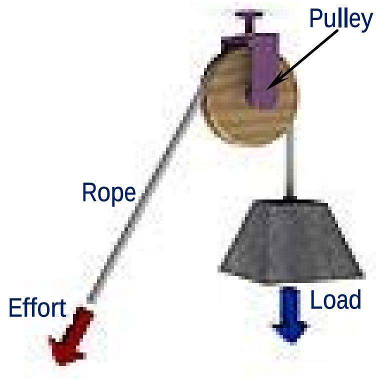


Fig 5.3 Single fixed pulley

Activity 5.4

Does a machine multiply a force and distance at the same time? Discuss your reason with friends.

A pulley is another example of a machine. A single fixed pulley is shown in Fig 5.3. It is used to raise a load like a pail of water from a deep well or turned over car from a ditch.

To raise a load upward a downward effort is applied. The effort applied is of the same magnitude as the load, but opposite in its direction. Thus, a fixed single pulley is a direction changing machine.

Check point 5.1

1. What is a machine?
2. Describe three purposes of using simple machines.
3. Can a machine be a force and distance multiplier at the same time?
4. Define the terms
   a) effort
   b) load

5.2. Mechanical Advantage, Velocity Ratio and Efficiency of Machines

a) Mechanical Advantage (MA)

Activity 5.5

i. Can you measure the advantage of a given machine? How?
ii. Consider a load of 120N is moved by applying an effort of 30N to the machine. What is the advantage that you obtain by using the machine?
iii. What is the term used to describe the advantage of a machine?

From activity 5-5(ii) you observed that to move a load of 120N the applied effort is only 30N. Here you can say that the machine multiplied the applied effort. Hence the advantage you obtain by using the machine is, four times the original force. The advantage you get from a machine is called **mechanical advantage (MA)**.

The Physical quantity which is used in describing the advantage of a machine is known as Mechanical Advantage MA. It tells us the number of times a machine multiplies the effort.

For any machine the mechanical advantage is the ratio of load to effort.

i.e. $MA = \frac{\text{Load (L)}}{\text{Effort (E)}} = \mathbf{MA} = \frac{L}{E}$

What can you say about the unit of MA from the above expression?

Worked Example 5.1

A load of 360N is moved by applying an effort of 60N to a machine, What is the mechanical advantage of the machine?

Given	Required	Solution
L = 360N E = 60 N	MA = ?	MA = L/E = 360N/60N = 6

This means the machine is used to multiply the applied force by 6. From the above example it is clear that MA is a dimensionless physical quantity. i.e. it has no unit.

There are two kinds of Mechanical Advantage

a. Actual Mechanical Advantage - the mechanical advantage that the machine provides in a real situation (with friction).

b. Ideal Mechanical Advantage is the mechanical advantage that the machine provides without friction.

Note: The MA of a machine depends on the friction between the load and the machine.

b) Velocity Ratio

Activity 5.6

Discuss with your friends.

i. What will happen to the MA if the machine is totally frictionless?

ii. Does the machine require more effort or less?

From your discussion in activity 5.6, it is understood that the effort required will be less as the machine is frictionless. i.e. There is no resistant force required to be overcome.

The velocity ratio (VR) characterizes the frictionless mechanical advantage of a machine. Velocity ratio is also called ideal mechanical advantage (IMA).

Velocity ratio of any machine is defined as the ratio of the distance moved by the effort to the distance moved by the load. i.e.

$$\mathbf{VR} = \frac{\text{Distance moved by the effort}}{\text{Distance moved by the load}} \frac{(S_E)}{(S_L)}$$

$$\mathbf{VR = S_E/S_L}$$

Velocity ratio of a machine has no unit.

Velocity ratio of a particular machine is constant. When you reduce friction, the actual mechanical advantage is closer to the ideal mechanical advantage. If frictional force is zero then VR = MA.

Worked Example 5.2

A machine raises a load to 2m, when the effort is moved by 8m. What is the velocity ratio of the machine?

Given	Required
$S_E = 8m$ $S_L = 2m$	VR = ?

Solution

$$VR = \frac{S_E}{S_L}$$

$$= \frac{8m}{2m} = 4$$

This means that the effort moves four times faster than the load or the effort distance is four times that of the load distance.

c) Efficiency (η)

Activity 5.7

i. How could you describe the terms 'input work' and 'output work'?
ii. What is wastage energy?
iii. Explain both 'efficiency' and 'wastage energy' for a machine. How are they related?

Efficiency has many meanings in everyday life. In science it has a specific meaning related to output and input work.

i. **Input work (W_i)** is the work done on the machine by the effort. It is equal to the product of the effort (E) and distance moved by the effort (S_E).

$$W_i = E \times S_E$$

ii. **Output work (W_o):** is the work done by the machine on the load (object). It is equal to the product of the load (L) and distance move by load (S_L).

$$W_o = L \times S_L$$

When you apply a force on a machine, you do work on it (input work). At the same time the machine also does work on the load (output work). In actual case the output work is less than the input work. Can you give reason why it should be less?

Worked Example 5.3

Suppose, a force of 80N is applied through a distance of 5m in pulling 300N box up an inclined plane whose upper end is 1m above ground level.

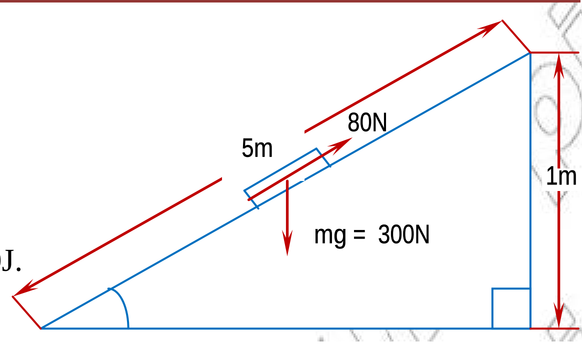


Fig 5.4 The efficiency of an inclined plane

The input work is 80N×5m = 400J. The output work is effectively the raising of the 300N box a distance of 1m or 300N×1m= 300J. The 300J is sometimes called **useful work**.

The difference between the input work and the output work (useful output work) 100 J is the work done against friction. It is called **wastage** energy.

The phrase "efficiency of a machine" refers to the performance of a machine. It denotes how much energy the machine transfer or change to the output work.

Efficiency of a machine is defined as the ratio of the output work to the input work. Multiplying the ratio by 100 means that the efficiency is written as a percentage

$$\text{Efficiency} = \frac{\text{Output work}}{\text{Input work}} \times 100\%$$

$$\Rightarrow \eta = \frac{W_o}{W_i} \times 100\%$$

Where η is efficiency, W_o is output work, and W_i is input work.
The Greek letter η is read as eta.

Note: If there is no friction, the efficiency of a machine is 100% i.e, η=1 and MA = VR. A machine with efficiency of 100% is called an **ideal machine**.

Challenging question

Can a machine with efficiency of 100% or more be produced in this world? Explain your answer.

Worked Examples 5.4

1. What is the efficiency of a machine that has an input work of 4200J and produces an output work of 3200J?

Given	Required	Solution
Work in put = 4200J	$\eta = ?$	$\eta = \frac{\text{work out put}}{\text{work in put}} \times 100\%$
Work out put= 3200J		$\eta = \frac{3200J}{4200J} \times 100\%$
		$\eta = 76.2\%$

2. A certain machine is used to lift a load of 250N. When an effort of 50N is applied to the machine, the load is raised by 1m and the effort is move by 6m. Calculate
   a) work done on the load
   b) work done on the machine
   c) the efficiency of the machine.
   d) wastage energy.

Given	Required	Solution
L = 250N	a. W_o=?	a. Wo=L × S_L= 250N x 1m = 250J
E = 50N	b. W_i= ?	b. W_i= E × S_E= 50N × 6m=300J
S_L= 1m	c. η=?	c. $\eta = \frac{W_o \times 100\%}{W_i} = \frac{250J \times 100\%}{300J}$ =83.3%
S_E= 6m	d. wasted energy = ?	d. W.E= W_i-W_o=300J-250J=50J

Check point 5.2

1. Define a) Mechanical Advantage (MA)
   b) Velocity Ratio (VR)
   c) Efficiency
2. What is a) work output?
   b) Work input?
3. What is the effect of friction on the efficiency of a machine?

5.3. Types of Simple Machines

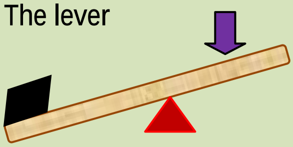
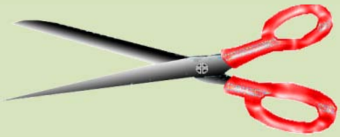
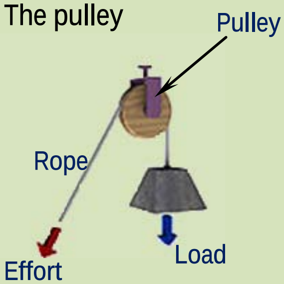
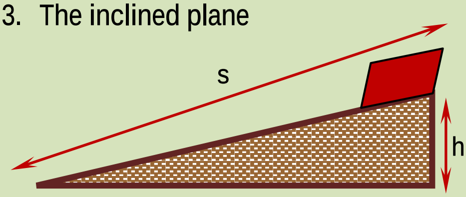
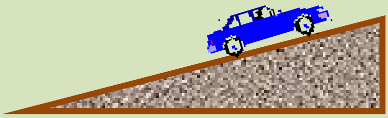
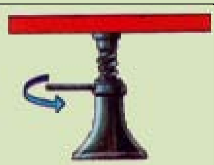
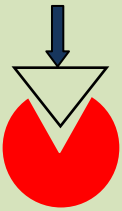
Types of simple machines	Practical Examples
1. The lever 	
2. The pulley 	
3. The inclined plane 	
4. Wheel and axle 	
5. The screw 	
6. The wedge 	

Fig 5.5 Six types of machines

Challenging questions

Explain what the practical examples in Fig 5.5 illustrate and where they are used.

Give other examples from your locality for each type of simple machines.

Activity 5.8

i. Observe Fig 5.5 and state the six types of simple machines.

ii. List at least two additional examples for each type of simple machine used in your locality.

There are two groups of machines in general:

i. **Simple machine** is a device that changes the direction or magnitude of a force. A simple machine uses single applied force (effort) to do work against single load force. Ignoring friction, the work done on the load is equal to the work done by the applied force.

Simple machines do not contain a source of energy, so they cannot do more work than they receive from the input force. When friction is ignored, the work output (that is done on the load) is equal to the work input (from the applied force).

Simple machines are of six types. They are;

1. The lever
2. The pulley system
3. Inclined plane
4. Wheel and axle,
5. The wedge,
6. Screw and gears

ii. **Compound machines** are machines made by combining two or more simple machines together. For example lawn mowers, typewriters and automobiles are compound machines.

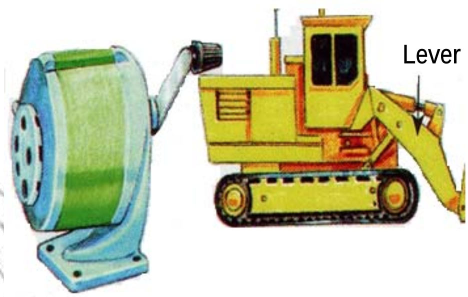


Fig 5.6 Compound machines

At this level you will focus only on common simple machines like lever, pulley and inclined plane.

1. The lever

Activity 5.9

Observe Fig 5.7 and Fig 5.8 answer the following questions

i. What is lever? Name the different parts of a lever.

ii. Give some examples of lever, which are used in your daily activities.

iii. Are levers force multipliers or speed multipliers?

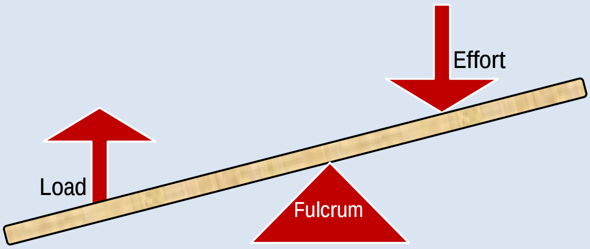


Fig 5.7The three important parts of a lever

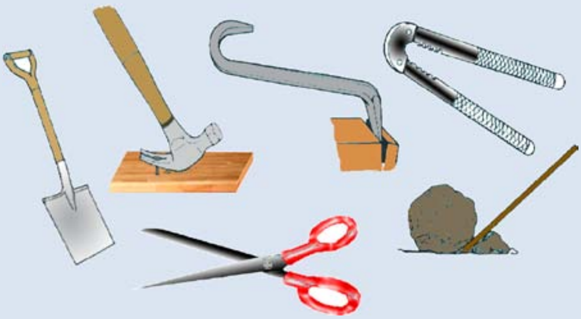


Fig 5.8 Examples of a lever

When we use a spoon to put sugar into a glass of tea, the spoon is used as a lever. Similarly, when we also use a crowbar to lift a heavy load we use it as a lever. Have you seen people rowing a boat in a lake? The bar of wood that they use for rowing is used as lever.

The scissors, the forearm and the spade are some additional examples of levers. Generally there are different levers which we use in our daily life.

Lever is a rigid bar of wood or metal that is free to turn about the supporting point which is called fulcrum (F). Lever also consists of effort point (E) and load point (L) in addition to the fulcrum (F).

Fig 5.7 shows the three important points on a lever. They are **effort**, **load** and **fulcrum**. The distance between load and fulcrum is called **load-arm** and the distance between effort and fulcrum is called **effort- arm.**

"Give me a place to stand, and I shall move the earth with a lever"

Fig 5.9 Archimedes

There are three orders (classes) of levers. They are classified into three depending on the position of the fulcrum in relation to the load and the effort. (see Fig 5.10)

i. **First order**: The fulcrum is located between the effort and the load. For example, a crowbar and a pair of scissors.
ii. **Second order**: The load is situated between the fulcrum and the effort, For example, a wheelbarrow and a nutcracker.
iii. **Third order**: The effort is applied between the fulcrum and the load, For example, a nail clipper and tongs.

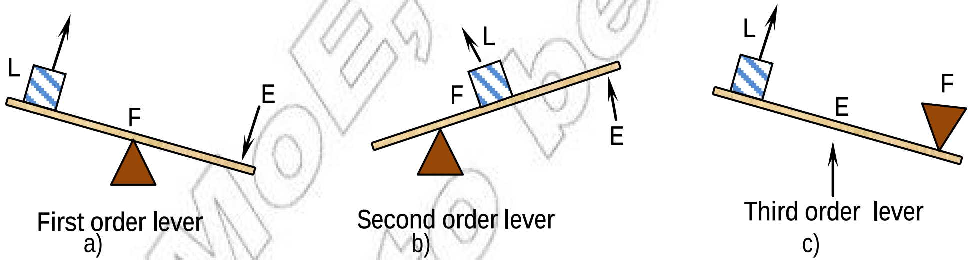


Fig 5.10 Three types of a lever

Mechanical advantage of a lever

The MA of a lever is the ratio of the load to the effort.

$$\therefore MA = \frac{F_L}{F_E}$$

A lever is a force multiplying machine if the fulcrum is near to the load. It is a speed multiplying machine, if the fulcrum is near to the effort.

Worked Example 5.5

1. Refer to the lever in the fig 5.10 (a). A load of 400N is lifted by applying a force of 160N on the lever. If the load is 20cm from the fulcrum and the effort is 80cm from the fulcrum, calculate:
   a) The VR of the machine
   b) The MA of the machine

Given	Required	Solution
L = 400N	a. VR = ?	a. $VR = \frac{S_E}{S_L} = \frac{80cm}{20cm} = 4$
E = 160N	b. MA = ?	b. $MA = \frac{\mathbf{L}}{\mathbf{E}} = \frac{\mathbf{400N}}{\mathbf{160\ N}} = \mathbf{2.5}$
S_E = 80cm S_L = 20cm		

Worked Example 5.6

2. A simple lever starts in a horizontal position and moves to the position shown in Fig 5.11.

Calculate:

a. The work input
b. The work output
c. The efficiency

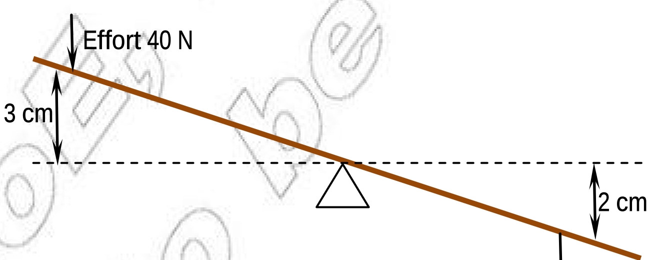


Fig 5.11 Simple lever

Given	Required	Solution
L= 60N	a. work in put	a. Work in put = E × S_E
S_L= 2 cm = .02m	b. work out put	= 40N × 0.03m = 1.20J
E = 40N	c. η = ?	b. Work out put = L × S_L
S_E = 3cm = (0.03m)		= 60 N×0.02m = 1.20J
		c.$\eta = \frac{\text{Work out put}}{\text{Work in put}} \times 100\% = \frac{1.20J}{1.20J} \times 100\%$
		= 100%

2. The Pulleys

A Pulley is a circular body (wheel) with groove surface and is free to rotate about its center. The effort is applied to a rope which passes over the pulleys groove.

A pulley:
- changes direction of force.
- multiplies the effort.

Basically there are two types of pulley systems.

a) **Single Fixed pulley:** is a pulley that does not move together with the load. That is the axle is ''fixed'' or "anchored" in places.

b) **Single Movable pulley:** is a pulley that moves together with the load. It has a free axle.

a. The single fixed pulley

The force on the rope is called a **tension.** From, Newton's third law, the load is the same as the weight (action and reaction forces). The force on the rope turns around the wheel with the same magnitude but opposite in direction. This means the load and the effort are equal in magnitude but opposite in direction.

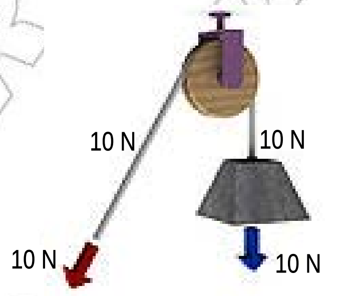


Fig 5.12 Single fixed pulley

- It is used to change the direction of the effort.
- The tension is the same throughout the rope, Neglecting the weight of the rope, wheel and any friction in the pulley bearing, we have

Load (L) = Effort (E)

$\therefore$ MA= $\frac{L}{E}$ = 1 and VR= $\frac{S_E}{S_L} = 1$

i.e, A single fixed pulley has a mechanical advantage of 1. This means that there is no multiplication of effort.

b. The single movable pulley

The tension on the rope is equal to the effort applied. The total upward pull on the pulley is equal to the load. This means that the effort is half of the load or the load is twice the effort.

$$\therefore \text{ Mechanical advantage} = \frac{\text{load}}{\text{Effort}} = \frac{L}{E} = 2$$

i.e. The single moveable pulley has a mechanical advantage of 2.

Fig 5.13 Single movable pulley

Project Work

Construct a single fixed and single movable pulley and determine their purposes.

Apparatus:- Two piece of penstocks, (pulley from science kit) two thin wire (paper-clips), two 50cm strings, ruler, and stand.

Procedure:-

1. Insert the wires (paper-clips) in each penstock or pulley.
2. Suspend the paper –clip on the stand or on the table as shown in Fig 5.3 to make a fixed pulley.
3. Tie the load with string and pass it over the fixed pulley
4. Measure the height of the load and effort above some reference frame (ground or table).
5. Apply a force to lift the load.
6. Measure the new height after applying a force and compare distance moved by load and effort.
7. Tie the other paper- clip with the stand or table and pass it over the pulley as shown in Fig 5.13 to make it a movable pulley.
8. Suspend the load on the pulley as shown in fig 5.13.
9. Measure height of load an effort above some reference frame (ground or table).
10. Apply a force to lift the load.
11. Measure the new height after applying a force and compare the distance moved by load and the effort.
    i. Which distance is grater for fixed pulley? Is it S_E or S_L.
    ii. What is the purpose of single fixed pulley?
    iii. Which distance is greater for simple movable pulley "Is it S_L or S_E.
    iv. What is the purpose of single movable pulley?

3. The inclined plane

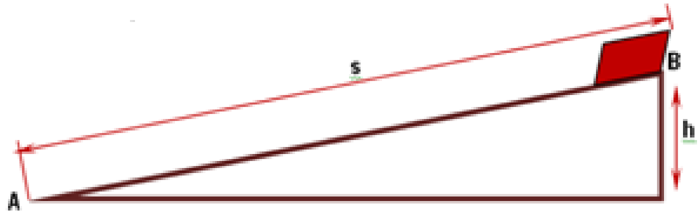


Fig 5.14 Inclined plane

When an object is heavy and difficult to lift on a car, people usually put a plank (heavy wooden board) and incline it on the car and then pull or push the object up along the plank easily.

An inclined plane is a sloping surface or ramp which allows a load to be raised more gradually using a smaller effort than the load if it were lifted vertically upwards.

Inclined plane is a plane whose angle to the horizontal plane is less than 90^0.
In Fig 5.14 an object of a certain weight is raised by pulling it along the inclined surface. As the load is drawn up from A to B, the effort is applied over a distances s while the load is raised vertically a height h. Thus:

i. Velocity Ratio = $\frac{\text{Distance moved by effort}}{\text{Distance moved by load}}$

$$VR = \frac{\text{length of inclined surface}}{\text{height of inclined plane}}$$

$$\Rightarrow VR = \frac{s}{h}$$

For a frictionless inclined plane, output work = input work,

ii. Mechanical Advantage = $\frac{\text{load}}{\text{effort}} = \frac{L}{E}$

The mechanical advantage of a frictionless inclined plane is the ratio of the length of the sloped surface to the height it spans.

Activity 5.10

i. Which distance, S_E or S_L is greater in an inclined plane?
ii. What is the purpose of using inclined plane? Is it to multiply speed or force?

Worked Example 5.7

In Fig 5.14, the length of the plane is 4m and the height is 1m. What will be the velocity ratio of the incline plane?

Given	Required	Solution
s = 4m	VR = ?	$VR = \frac{s}{h} = \frac{4\cancel{m}}{1\cancel{m}} = 4$
h = 1m		

It implies that if there is no friction this incline plane multiplies the effort by 4.

Torque

Activity 5.11

A father and a son are playing a see saw.

i. Do they balance each other?

ii. Who should sit nearer to the fulcrum to balance?

iii. What are the conditions for them to balance?

Torque is the action of a force to turn things around. Torque measures the effectiveness of the force in turning an object about a given axis. Torque is the product of force and a perpendicular distance as shown in Fig 5.15. It is a vector quantity; it has both a magnitude and direction. Torque = force × perpendicular distance from the axis.

The direction of a torque is either clockwise or anti-clockwise.

An object is said to be balanced when the clockwise torque is equal to the anti clockwise torque. In such condition there is no motion (or no turning effect).

Anti clockwise torque = clockwise torque

$$F_1 \times r_1 = F_2 \times r_2$$

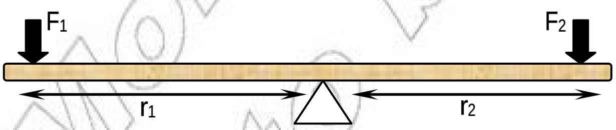


Fig 5.15 Torque

Worked Example 5.8

A 5m long lever is used to balance a load of 1200 N by a force of 80 N, when the fulcrum is located at a distance of 2m from the load and 3m from the effort.

a) What is the clockwise torque?
b) What is the anticlockwise torque?
c) What is the MA of the lever?
d) What is the VR of the lever?

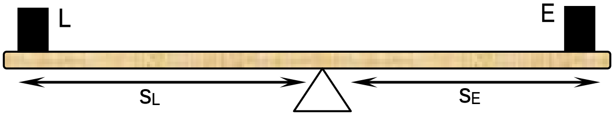


Fig 5.16 Computing a torque

Given	Required
L = 120 N	a) Clockwise torque = ?
E = 80 N	b) Anti clockwise torque = ?
S_L = 2m	c) MA = ?
S_E = 3m	d) VR = ?

Solution

a) Clokwise torque = E × S_E = 80N × 3m = 240 Nm
b) Anticlockwise torque = L × S_L = 120N × 2m = 240 Nm
c) MA = $\frac{L}{E} = \frac{120N}{80N}$ = 1.5
d) VR = $\frac{S_E}{S_L} = \frac{3m}{2m} = \mathbf{1.5}$

Check point 5.3

1. Mention and describe the types of simple machines.
2. What is the significance of simple machines in your daily life?
3. Explain how you can calculate MA, VR and η for
   a) Lever b) Inclined plane c) Pulley
4. What is a torque?

Summary

In this unit you learned that:

- machines are devices which help us do our work easier. We use machines to multiply distance (speed), multiply force or to change direction of a force.
- effort is a force applied on a machine.
- load is a force exerted by the machine.
- a machine is said to be force multiplier if Load > Effort, speed multiplier if $S_E < S_L$.
- M.A of a machine is defined as the ratio of load to effort.
- V.R of a machine is defined as the ratio of S_E to S_L.
- efficiency of a machine is defined as the ratio of output work done to input work done.
- lever is a rigid bar that is free to turn about the supporting point called the fulcrum.
- pulley is a wheel and it is free to rotate about an axis through its center. The simplest form of a pulley is single fixed pulley and single movable pulley.
- inclined plane is a slope or ramp which allows a load to be raised more gradually by a small effort.
- Torque is the turning effect of a force.

Review Questions and Problems

I. Choose the best answer.

1. Which one of the following is not the purpose of machines?
   a. Multiplying force c. Transfering energy
   b. Multiplying speed d. Multiplying energy
2. Which of the following machines is not an example of a lever?
   a. Wedge b. Spade c. Forearm d. Hammer
3. Velocity ratio of a single fixed pulley is always equal to
   a. 2 b. 1 c. 3 d. 4
4. The Velocity ratio of a single movable pulley is always equal to
   a. 2 b. 1 c. 3 d. 4

II. Fill in the blank with the appropriate word or phrase.

1. A device that changes only the direction of force is known as ________
2. ___________is a force applied on a machine.
3. The ratio of effort distance to load distance is called _______.
4. __________ is the ratio of load to effort.
5. The Output work divided by input work for a machine is called _______.

III. Short answer questions.

1. Is there any real machine where its efficiency is 100%? Why?
2. Can you explain the three main important reasons why we use machines?

IV. Work out problem

1. Group the basic simple machines lever, pulley and inclined plane as force multiplier, speed multiplier, and change direction of effort.

Force multiplier	Speed multiplier	Change direction of effort

2. If a load of 24N is moved by applying an effort of 6N to the machine, what is the M.A of the machine?
3. A 500N car is pulled up to 20m plank to a flat from 5m above the ground by an effort of 150N parallel to the plank. Calculate:
   a. VR of the machine
   b. MA of the machine
   c. input work
   d. output work
   e. efficiency