CHAPTER

3

Machines

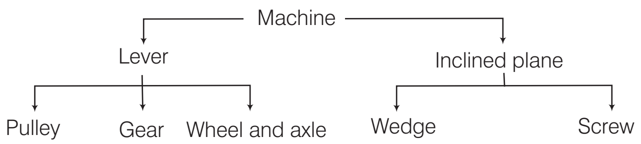
Chapter Objectives

- Ideal and Actual Machine
- Lever
- Pulley
- Gears

Machine is a device which helps us to do the work at one point and deliver it at another point with a view of accomplishing the work easily.

Basically, machines act as **force multiplier**, i.e., the net effort produced by the machine is much more than the effort applied. e.g., A jack is used to lift a bus or car, pulleys are used to lift heavy loads. In all such examples, the effort is much less than the load. So, we can say that machines act as a force multiplier.

Simple machines can be classified (or categorised) into two major classes, one is lever and other is inclined plane. Further it can be classified as shown below.



Classification of Machine

In this chapter, we will be exploring all the functions and terms related to machine, there after lever and inclined plane as important types of simple machine will be studied.

Terms Related to Machine

The terms related to machine are as follows

Load It is the resistive or opposing force against which the machine works. It is denoted by L.

Effort It is the force applied on the machine to overcome the load. It is denoted by E.

Mechanical Advantage (MA) It is the ratio of the load to the effort. It is denoted by MA.

It is expressed as, $\text{MA} = \dfrac{L}{E}$

(i) If MA > 1 (i.e., $L > E$), then machine works as force multiplier.

(ii) If MA < 1 (i.e., $L < E$), then machine gains speed, i.e., machine can help us to achieve greater movement of load by smaller movement of effort, e.g., The blades of a scissors more longer with smaller movement of handles.

(iii) If MA = 1 (i.e., $L = E$), then machine changes the direction of effort, i.e., machine can change the direction of effort to a more convenient direction, e.g., To lift the bucket from well, effort is applied on pulley in downward direction while bucket is pushed in upward direction.

Note Being a ratio of two like quantities (such as both load and effort are some types of forces) MA has no unit.

Velocity Ratio (VR) It is defined as the ratio of velocity of the effort to the velocity of the load. It is denoted by VR.

It is expressed as,

$$\text{VR} = \frac{\text{Velocity of effort } (v_E)}{\text{Velocity of load } (v_L)}$$

In terms of distance moved by a particular force, velocity ratio is the ratio of the distance moved by the effort to the corresponding distance moved by the load.

$$\because \qquad \text{VR} = \frac{v_E}{v_L} = \frac{d_E/t}{d_L/t} = \frac{d_E}{d_L}$$

Here, d_L and d_E are the distances moved in same time t by the load and the effort, respectively.

Note Being a ratio of two like quantities, velocity ratio also has no unit.

Work Input The work done on the machine by the effort is called the work input (W_{input} or W_i). If an effort E causes a displacement d in its own direction, then

$$\text{Work input} = \text{Effort} \times \text{Displacement}$$
$$= E \times d$$

Work Output *The work output (W_{output} or W_o) can be classified into two ways*

(i) **Actual Output** The entire work done by the machine is known as actual output.

If L is the total load (load lifted by the machine and by resistance overcome) displaced through a distance d, then actual output will be treated as

$\Rightarrow$ total load $(L) \times$ distance (d)

i.e., Actual output $= L \times d$.

(ii) **Useful Output** The useful work done by the machine is termed as useful output.

If l is the useful load displaced through a distance d, then useful output will be treated as

$= \text{useful load } (l) \times \text{distance } (d)$

i.e., Useful output $= l \times d$.

Example 1. If a machine is used to lift a load of 50 N such that resistance due to friction and movable part of machine is 15 N, then the total lifted load is 65 N, i.e., (50 + 15) N. If the displacement is caused through 2 m, then find actual and useful output.

Sol. Actual output = total load × distance

$= 65\,\text{N} \times 2\,\text{m} = 130\,\text{J}$

and useful output = useful work × distance

$= 50\,\text{N} \times 2\,\text{m} = 100\,\text{J}$

Note In some problems or descriptions, only the term output is used. Hence, we will use this output as useful output not as actual output.

Efficiency (η) It is defined as the ratio of work done (W_{output}) by the machine to work done (W_{input}) on the machine. It is denoted by η. It is expressed as

$$\eta = \frac{\text{Work done on the load}}{\text{Work done by the effort}} = \frac{W_{\text{output}}}{W_{\text{input}}}$$

But efficiency is usually expressed in percentage, so we may write

$$\text{Efficiency, } \eta = \frac{W_{\text{output}}}{W_{\text{input}}} \times 100\%$$

Ideal and Actual Machine

Ideal Machine or Perfect Machine

Machine works on the principle of conservation of energy. The machine which converts are input work (effort) into output work (load) without any wastage of work is called ideal machine.

Work done (input) = Work done (output)

Thus, an ideal machine can be defined as follows

A machine whose parts are weightless and frictionless such that whatever the energy given to it, is same as the energy produced by it, is called as an ideal machine. The efficiency of an ideal machine is 100%. An ideal machine cannot be made practically because some part of the input is wasted in moving the parts of the machine and in overcoming the friction between the various parts of a machine.

Ideal Mechanical Advantage (IMA)

The ratio between total load moved to the effort (E) applied is called the ideal mechanical advantage. If L_0 is the total load such that L is the useful load and l is the load due to friction and movable parts of the machine, then

$$\text{IMA} = \frac{L_0}{E}, \text{ where } L_0 = L + l$$

Note For an ideal machine, IMA = VR.

Actual Machine

In an actual machine, the output energy is always less than the input energy indicating that there is some loss of energy during its operation, reasons of which are listed below

(i) The moving parts of the machine are neither weightless nor smooth or frictionless.

(ii) Different parts of the machine are not perfectly rigid.

(iii) The elastic materials (string) are not perfectly elastic.

Actual Mechanical Advantage (AMA)

The ratio of useful load (L) moved to the effort (E) applied is called the actual mechanical advantage.

$$\text{AMA} = \frac{L}{E}$$

Key Points

(i) For all practical or actual machines, efficiency is less than 1 (i.e., $\eta < 1$).

(ii) If mechanical advantage is mentioned in a question, it means only the actual mechanical advantage but not the ideal machine advantage.

(iii) A machine of η % efficient means η% of the total energy supplied to the machine and remaining $(100 - \eta)$% of the energy is lost to the surroundings.

(iv) The energy lost in overcoming the frictional force between the moving parts of a machine, is the most common type of loss of energy in it.

Relation between η, MA and VR

Consider a practical machine which overcomes a load L by the application of an effort E in time t. Suppose the displacement of effort be d_E and the displacement of load be d_L.

Now, we can write

Work input (W_{input})

$$= \text{Effort} \times \text{Displacement of effort} = E \times d_E$$

Work output (W_{output})

$$= \text{Load} \times \text{Displacement of load}$$

$$= L \times d_L$$

$$\text{Efficiency, } \eta = \frac{W_{\text{output}}}{W_{\text{input}}} = \frac{L \times d_L}{E \times d_E} = \frac{L}{E} \times \frac{d_L}{d_E} = \frac{L}{E} \times \frac{1}{\frac{d_E}{d_L}}$$

As, we know that

$$\text{MA} = \frac{L}{E} \quad \text{and} \quad \text{VR} = \frac{d_E}{d_L}$$

$$\therefore \quad \eta = \frac{\text{MA}}{\text{VR}} \quad \text{or} \quad \boxed{\text{MA} = \eta \times \text{VR}}$$

For all practical machines, mechanical advantage is always less than velocity ratio,

i.e., $\text{MA} < \text{VR}$

Example 2. An effort of 10 kgf is applied on a machine through a distance of 100 cm, when a load of 100 kgf moves through a distance of 5 cm.

Calculate the

(i) velocity ratio

(ii) mechanical advantage

(iii) efficiency of the machine

Sol. Given, effort, $E = 10$ kgf, load, $L = 100$ kgf

Distance moved by effort, $d_E = 100$ cm

and distance moved by load, $d_L = 5$ cm

(i) Velocity Ratio (VR)

$$= \frac{\text{Distance through which the effort moves } (d_E)}{\text{Distance through which the load moves } (d_L)}$$

$$= \frac{100 \text{ cm}}{5 \text{ cm}} = 20$$

(ii) Mechanical Advantage (MA)

$$= \frac{\text{Load } (L)}{\text{Effort } (E)} = \frac{100 \text{ kgf}}{10 \text{ kgf}} = 10$$

(iii) Percentage efficiency, $\eta = \frac{\text{MA}}{\text{VR}} \times 100$

$$= \frac{10}{20} \times 100 = 50\%$$

Example 3. How is the mechanical advantage related with the velocity ratio for an actual machine? State whether the efficiency of such a machine is equal to 1, less than 1 or more than 1.

Sol. For a machine,

$$\frac{\text{work output}}{\text{work input}} = \frac{L \times d_L}{E \times d_E}$$

or

$$= \frac{\frac{L}{E}}{\frac{d_E}{d_L}} = \frac{\text{Mechanical Advantage (MA)}}{\text{Velocity Ratio (VR)}}$$

For an actual machine,

work output < work input

$$\therefore \quad \frac{\text{MA}}{\text{VR}} < 1$$

or $\text{MA} < \text{VR}$

$$\therefore \quad \text{Efficiency, } \eta = \frac{\text{MA}}{\text{VR}} < 1$$

Thus, for an actual machine, efficiency will always be less than 1.

Example 4. A machine is operated by an effort of 80 N acting downward and moving through a downward displacement of 0.15 m. The load of mass 10 kg, is raised up by 10 cm. Calculate the MA, VR, work input, useful work output and efficiency (Take, $g = 10 \text{ ms}^{-2}$).

Sol. $\text{MA} = \dfrac{\text{Load } (L)}{\text{Effort } (E)}$ ($L = 10 \text{ kg} = 10 \times 10 = 100$ N, $E = 80$ N)

$= \dfrac{100}{80} = 1.25$

$\text{VR} = \dfrac{d_E}{d_L} = \dfrac{0.15}{0.1} = 1$

Work input $= E \times d_E = 80 \times 0.15 = 12$ J

Useful work output $= L \times d_L = 100 \times \dfrac{10}{100} = 10$ J

Efficiency, $\eta = \dfrac{\text{Output}}{\text{Input}} = \dfrac{10}{12} = 0.833 = 83.3\%$

CHECK POINT 01

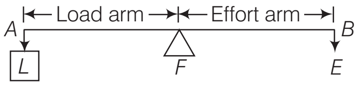
1. Name a device that helps us to do the work at one point and deliver it to the another point.
2. What happens when mechanical advantage (MA) becomes equal to one?
3. Write an expression for calculating the efficiency of a machine.
4. "An ideal machine cannot be made practically.'' Justify the statement.
5. Give one example each of a machine which is used to
   (i) multiply force
   (ii) change direction of application of force.
6. Can a simple machine act as a force multiplier and a speed multiplier at the same time ?
7. State whether in actual machines, the output energy is greater or lesser than input energy. Give reason.

Lever

A lever is a straight or bent rigid rod which can be turned or rotated about a fixed point called fulcrum. It is one of the most common and simple machine.

Principle of a Lever

Consider a lever (i.e., a straight rod) *AB* with balanced point at *F* (fulcrum for the lever). A load *L* acts at point *A* of the lever and effort *E* acts at point *B* as shown in the diagrams.



Lever

The perpendicular distance of the effort from the fulcrum is called the **effort arm** i.e., *BF*. The perpendicular distance of the load from the fulcrum is called the **load arm** i.e., *AF*. For an ideal lever, it is assumed that the lever is weightless and frictionless. A lever works on the principle of moment. In the equilibrium position of the lever, by the principle of moment,

moment of load about the fulcrum

= moment of effort about the fulcrum

The two moments are always in opposite directions. In figure, the moment of load is anti-clockwise while the moment of effort is clockwise. Thus, we can write

$$\boxed{\text{Load} \times \text{Load arm} = \text{Effort} \times \text{Effort arm}}$$

This is also called principle of lever.

or $L \times AF = E \times BF$ or $\dfrac{L}{E} = \dfrac{BF}{AF}$

$\therefore$ Mechanical Advantage (MA), $\dfrac{L}{E} = \dfrac{\text{Effort arm}}{\text{Load arm}} = \dfrac{BF}{AF}$

This relation is known as the **law of levers.**

From the above equation, it is clear that, if

(i) Effort arm = Load arm, MA = 1
(ii) Effort arm < Load arm, MA < 1
(iii) Effort arm > Load arm, MA > 1

Note Mechanical advantage of a lever can be increased either by increasing its effort arm or by decreasing its load arm.

Types of Levers

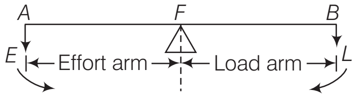
There are three types of levers

(i) Class I lever (ii) Class II lever (iii) Class III lever

Class I Lever

In this type of lever, the effort (*E*) and the load (*L*) are situated on either side of the fulcrum (*F*).

e.g., A pair of scissors, handle of water pump, a catapult and the nodding of the human head, etc.



Class I lever

MA of class I lever $= \dfrac{\text{Effort arm}}{\text{Load arm}}$

VR of class I lever $= \dfrac{d_E}{d_L}$

Characteristics of a Class I Lever

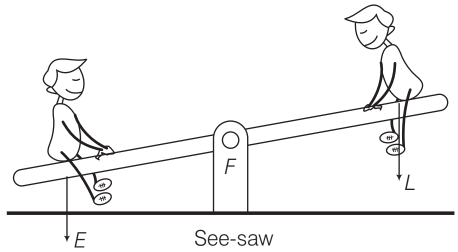
(i) Fulcrum lies in between the load and the effort.
(ii) By moving the fulcrum towards the load, i.e., by decreasing load arm. Mechanical advantage can be increased.
(iii) For class I lever, the mechanical advantage and velocity ratio can have any value either greater than 1 or equal to 1 or less than 1.

e.g.,

(i) The beam of a common balance (MA = 1)
(ii) A crowbar (MA > 1)
(iii) A pair of scissors (MA < 1)

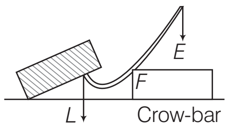
Examples of Class I Lever

(i) **A See-saw** Two boys are playing with a see-saw as shown in the figure. The lighter boy sits far away from the fulcrum as compared to the heavier boy such that the moments of both of them are same.



See-saw

(ii) **A Crow-bar** To have the less effort in lifting the load, longer crow-bar with more fulcrum is required. The reason behind the less effort is increasing mechanical advantage with increasing the effort arm.



Crow-bar

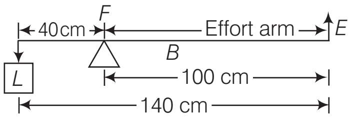
Another examples of class I lever are

(i) a pair of scissors
(ii) pliers
(iii) a claw hammer
(iv) human forearm

Example 5. **A crow-bar of length 140 cm has its fulcrum situated at a distance of 40 cm from the load. Calculate the mechanical advantage of the crow-bar.**

Sol. If fulcrum is situated in the middle of effort arm and load arm, it is a class I lever.

We have length of crow-bar = 140cm



Now,

Mechanical Advantage (MA) of crow-bar

$$= \frac{\text{Effort arm}}{\text{Load arm}} = \frac{100}{40} = \frac{5}{2} = 2.5\,\text{cm}$$

and distance of fulcrum from the load = 40cm

$\therefore$ Load arm = 40 cm

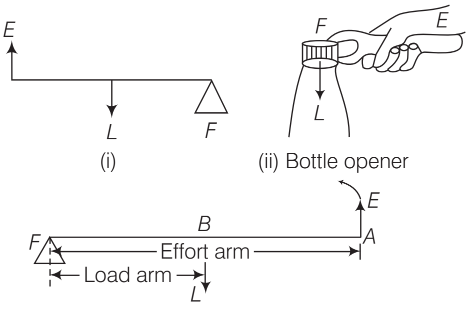
and effort arm = length of crow-bar – load arm

$$= 140 - 40 = 100\,\text{cm}$$

Class II Lever

In this type of lever, the load is situated between fulcrum and effort, e.g., A bottle opener, a wheel barrow, a paper cutter, raising the weight of the human body on toes, etc.

As, effort arm is always greater than the load arm, then MA and VR are always more than 1.



Characteristics of a Class II Lever

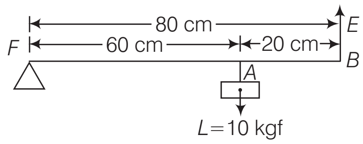
(i) Load lies in between the effort and the fulcrum.
(ii) Mechanical advantage and velocity ratio are always more than one because the effort arm is always longer than the load arm.
(iii) If load is moving towards the fulcrum, then load arm decreases and consequently the mechanical advantage increases.
(iv) Class II levers always act as a force multiplier.

Examples of Class II Lever

Some examples of class II lever are

(i) lemon squeezer (ii) nut cracker
(iii) hinged door

Example 6. The diagram below shows a lever in use.



(i) To which class of lever does it belong?
(ii) If $FA = 60$ cm, $AB = 20$ cm, find its MA.
(iii) Find the value of effort (E).

Sol. (i) From the given figure, it is clear that load lies in between fulcrum (F) and effort (E).

$\therefore$ Lever is of class II.

(ii) From the above figure, MA of lever

$$= \frac{\text{Effort arm }(FE)}{\text{Load arm }(FA)} = \frac{80\text{ cm}}{60\text{ cm}} = \frac{4}{3} = 1.33\,\text{cm}$$

(iii) On balancing the moments, we can write

$$E \times \text{effort arm }(FE) = L \times \text{load arm }(FA)$$

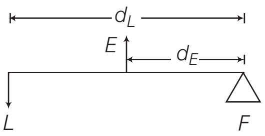
$\Rightarrow$ $E \times 80 = L \times 60$

$\therefore$ $E = L\left(\frac{60}{80}\right)$

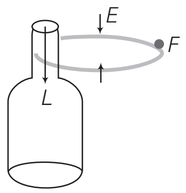
$$= 10 \times \frac{3}{4} = \frac{30}{4}\,\text{kgf} = 7.5\,\text{kgf}$$

Class III Lever

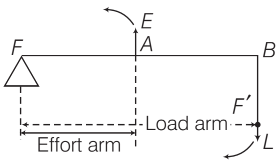
In this type of lever, effort is situated between the load and the fulcrum. As effort is situated between the load and the fulcrum, then MA and VR is always less than 1.
e.g., Sugar tongs, foot treadle, etc.



(i)



(ii) Sugar tongs



(iii) Class III lever

Characteristics of Class III Lever

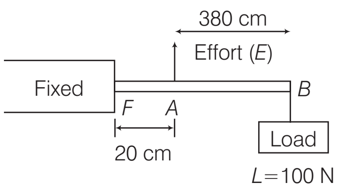
(i) Effort lies in between the fulcrum and the load.
(ii) Mechanical advantage and velocity ratio are always less than one, because the effort arm is always smaller than the load arm.
(iii) These class III levers are called speed multiplier as the load moves through a larger distance as compared to the effort.

Examples of Class III Lever

Some examples of class III levers are

(i) arms used to lift weight (ii) baseball bat
(iii) broom (iv) doors
(v) fishing rod (vi) sling
(vii) tweesers (viii) stapler

Example 7. The diagram below shows the use of a lever



(i) State the principle of moments as applied to the above lever.
(ii) Give an example of this class of lever.
(iii) If $FA = 20$ cm, $AB = 380$ cm, then calculate the mechanical advantage and minimum effort required to lift the load.

Sol. (i) Principle of moment for the given lever can be applied as

$$\text{Effort} \times AF = \text{Load} \times BF$$

or $$E \times (20) = (100)\,(AB + AF)$$

$\therefore$ $$20\,E = (100)\,(400) \quad \text{...(i)}$$

(ii) Fire tongs class III lever has effort in between F and L.

(iii) From Eq. (i), we can write

$$E = \frac{100 \times 400}{20} = 100 \times 20 = 2000\,\text{N}$$

Here, effort arm, $FA = 20\,\text{cm}$

Load arm, $BF = FA + AB = 20\,\text{cm} + 380\,\text{cm} = 400\,\text{cm}$

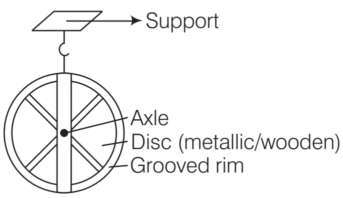
$$\therefore \quad \text{MA} = \frac{\text{Effort arm}}{\text{Load arm}} = \frac{20\text{ cm}}{400\text{ cm}} = \frac{1}{20} = 0.05$$

CHECK POINT 02

1. For a lever, if effort arm becomes equal to load arm, then what effect can be seen in the value of mechanical advantage (MA)?
2. State any two characteristics of lever of class I?
3. Fill up: a scissors is a ……… multiplier.
4. Give one example each of class I lever, where the mechanical advantage is
   (i) equal to 1 (ii) more than 1.
5. Which class of a lever always act as a force multiplier?
6. Give an example of lever of third order.
7. Which type of levers have mechanical advantage always less than 1? Give reason. Why are they then used?

Pulley

Pulley is a wheel on an axle that is designed to support movement and change the direction of a cable or belt along its circumference. A set of pulleys assembled so that they rotate independently on the same axle to form a block is called **pulley system**.



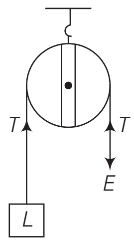
Pulley

Single Fixed Pulley

A pulley which has its axis of rotation fixed in position is called single fixed pulley.
Mechanical Advantage

$$(\text{MA}) = \frac{\text{Load}}{\text{Effort}} = \frac{T}{T} = 1$$

($\because$ load, $L = T$, effort, $E = T$, if pulley is not rotating)



Single fixed pulley

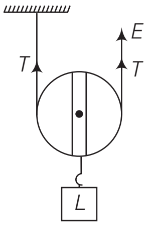
$$\text{Velocity Ratio (VR)} = \frac{d_E}{d_L} = \frac{d}{d} = 1$$

$$(d_E = d \text{ and } d_L = d)$$

$$\text{Efficiency } (\eta) = \frac{\text{MA}}{\text{VR}} = 1 \text{ or } 100\%$$

Single Movable Pulley

A pulley whose axis of rotation is not fixed in position is called a movable pulley.



Single movable pulley

Load is balanced by

$$T + T = 2\,T \qquad (\because \text{Load} = 2T)$$

$$\text{Mechanical Advantage (MA)} = \frac{\text{Load}}{\text{Effort}} = \frac{2T}{T} = 2$$

$$(\because L = T + T = 2T \text{ and } E = T)$$

$$\text{Velocity Ratio (VR)} = \frac{d_E}{d_L} = \frac{2d}{d} = 2 \;(\because d_E = 2d \text{ and } d_L = d)$$

$$\text{Efficiency } (\eta) = \frac{\text{MA}}{\text{VR}} \times 100 = \frac{2}{2} \times 100 = 100\% \text{ or } 1$$

Example 8.

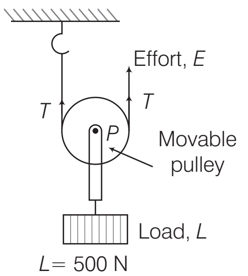
(i) Name the type of single pulley that can act as a force multiplier. Draw a labelled diagram of the above named pulley.

(ii) A pulley system has a velocity ratio of 4 and an efficiency 80%. Calculate

(a) the mechanical advantage of the system .

(b) the effort required to raise a load of 500 N by the system.

Sol. (i) Single movable pulley acts as a force multiplier.



(ii) Given, velocity ratio of a pulley system (VR) = 4

Efficiency of the pulley system (η) = 90%

We know that,

(a) Efficiency, $\eta = \dfrac{\text{Mechanical Advantage (MA)}}{\text{Velocity Ratio (VR)}}$

$$\Rightarrow \quad 80\% = \frac{\text{MA}}{4} \quad \Rightarrow \quad \text{MA} = \frac{80}{100} \times 4 = 3.2$$

(b) Load, $L = 500$ N, MA = 3.2 and effort, E = ?

$$\text{MA} = \frac{L}{E} \;\Rightarrow\; E = \frac{L}{\text{MA}} = \frac{500\text{ N}}{3.2} = 156.25\text{ N}$$

Difference between a Single Fixed Pulley and a Single Movable Pulley

Single Fixed Pulley	Single Movable Pulley
It is fixed to a rigid support.	It is not fixed to a rigid support.
Its Ideal Mechanical Advantage (IMA) is 1.	Its Ideal Mechanical Advantage (IMA) is 2.
Its Velocity Ratio (VR) is 1.	Its Velocity Ratio (VR) is 2.
The weight of pulley itself does not affect its mechanical advantage.	The weight of pulley itself reduces its mechanical advantage.
It is used to change the direction of effort from upwards to downwards.	It is used as a force multiplier.
Load moves in a direction opposite to that of effort.	Load moves in the direction of effort.

Combination of Pulleys

The combination can be made in two ways

(i) Using one fixed pulley and several movable pulleys.

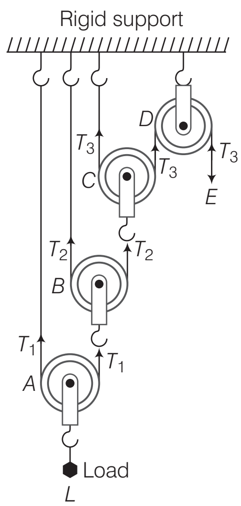
(ii) Using several fixed pulleys in two blocks known as block and tackle system.

Using One Fixed Pulley and Other Movable Pulleys

If there are n movable pulleys with one fixed pulley, then the mechanical advantage of this system is

$$\text{MA} = 2^n$$

So, mechanical advantage of system which has one fixed pulley and three movable pulleys $= 2^3 = 8$



If there are n movable pulleys connected to a fixed pulley, then velocity ratio of this system is

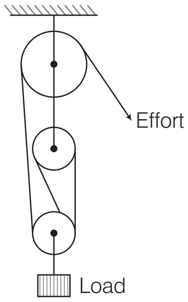
$$\text{VR} = 2^n$$

So, velocity ratio of system which has one fixed pulley and three movable pulleys $= 2^3 = 8$

Efficiency of this combination is

$$\eta = \frac{\text{MA}}{\text{VR}} = \frac{2^n}{2^n} = 1 \text{ or } 100\%$$

Example 9. Diagram given in below is representing a pulley system having a velocity ratio 3 and an efficiency of 80%. Calculate the mechanical advantage and efficiency.



Sol. Since, Mechanical Advantage,

$$\text{MA} = \frac{\text{Load}}{\text{Effort}} = \text{VR} \times \eta = 3 \times \frac{80}{100} = 2.4$$

$$\text{or efficiency} = \frac{\text{load}}{2.4} = \frac{300}{2.4} = 125\,\text{N}$$

Using Several Fixed Pulleys in Two Blocks (Block and Tackle System)

In this system, two blocks of pulleys are used, while usually upper block is fixed and the lower block is movable. If the total number of pulleys used in both the blocks is n and the effort is being applied in the downward direction.

In this case,

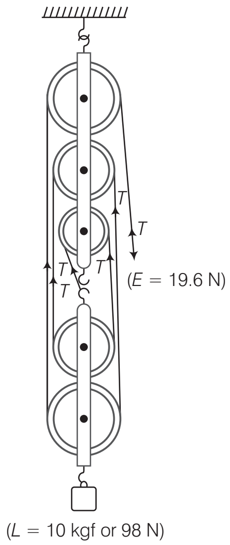
$$\text{Load} = nT \quad \text{and} \quad \text{Effort} = T$$

Mechanical Advantage (MA)

$$= \frac{\text{Load}}{\text{Effort}} = n$$

In a block and tackle system, if the load moves up through a distance d, the effort end moves through a distance nd because each section of the string supporting the load is loosened by a length d, i.e., if $d_L = d$, then $d_E = nd$

$$\therefore \quad \text{Velocity ratio} = \frac{nd}{d} = n$$



Block and tackle for five pulleys

Effect of Weight of Pulleys on MA, VR and η

But, if total weight of pulleys in the lower block be w,

$$L + w = nT, E = T$$

$$L = nT - w, E = T$$

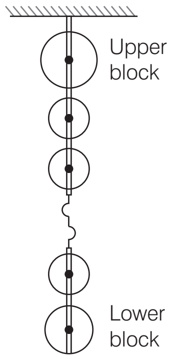
$$\text{Mechanical Advantage (MA)} = n - \frac{w}{E}, \text{ VR} = n$$

$$\text{Efficiency, } \eta = \frac{\text{MA}}{\text{VR}} = \frac{(n - w/E)}{n} = 1 - \frac{w}{nE}$$

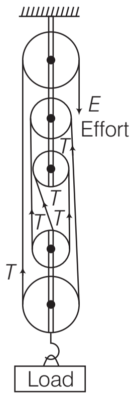
Example 10. The diagram below shows a system of 5 pulleys.

(i) Copy the diagram and complete it by drawing strings around the pulleys. Mark the position of load and effort.

(ii) If the load is raised by 2 m, through what distance will the effort move?



Sol. (i) *Complete diagram is shown in the given figure*

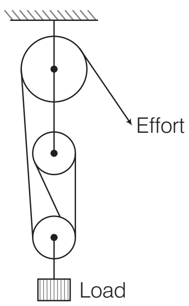


(ii) In block and tackle system, if the load moves through a distance d, the effort moves through a distance nd, where, n is the total number of pulleys in both blocks.

Here, as the load is raised by 2 m, the effort will move through a distance of $5 \times 2 = 10\,\text{m}$.

Example 11. A pulley system has a velocity ratio 4 and an efficiency of 70%. Draw a labelled diagram of this pulley system. Calculate the mechanical advantage of the system and the value of the effort required to raise a load of 400 N.

Sol. Labelled diagram of the pulley system is shown in figure. Given, velocity Ratio (VR) = 4, efficiency, η = 70%, load, L = 300 N



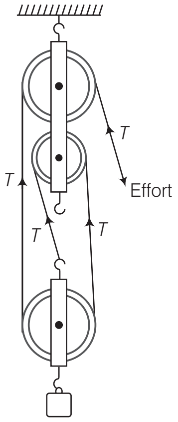
Mechanical Advantage (MA)= ? and effort, E = ?

$$\text{MA} = \frac{\text{Load}}{\text{Effort}} = \text{VR} \times \eta$$

$$= 4 \times \frac{70}{100} = 2.8$$

$$\text{and} \quad \text{effort} = \frac{\text{load}}{2.8} = \frac{500}{2.8} = 178.57$$

Example 12. A block and tackle system has the velocity ratio 4, labelled diagram of the system indicating the point of application and the directions of load and effort is given below. A man can exert a pull of 500 N. What is the maximum load he can raise with this pulley system if its efficiency is 80%?



Sol. Given, VR = 4

Efficiency, $\eta = 80\% = \frac{4}{5}$

$$MA = VR \times \eta$$

$$MA = 4 \times \frac{4}{5} = \frac{16}{5} = 3.2$$

But, $MA = \frac{L}{E}$

$\Rightarrow$ $3.2 = \frac{L}{500\text{ N}}$

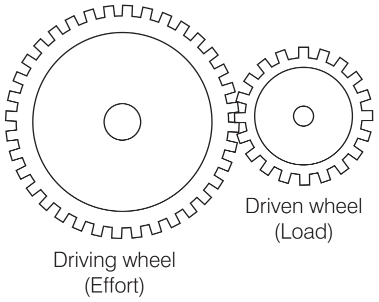
$\Rightarrow$ $L = 500 \times 3.2$

$\Rightarrow$ $L = 1600\text{ N}$

The maximum load can be raised is 1600 N.

Gears

Gears are a set of toothed wheels arranged together in a machine to vary the speed of rotation and/or to transmit power from one part to another. The gear wheel closer to the source of power is called driving gear while the gear wheel which receives motion from the driver is called a driven gear.



(i) The number of teeth on a sheel depends on its circumference and hence on it's radius i.e., $\frac{N_D}{N_d} = \frac{r_o}{r_d}$.

(ii) Gear ratio is the ratio of number of teeth on the driving wheel (N_D) to that on the driven wheel (N_d)

i.e., Gear ratio $= \frac{N_D}{N_d}$

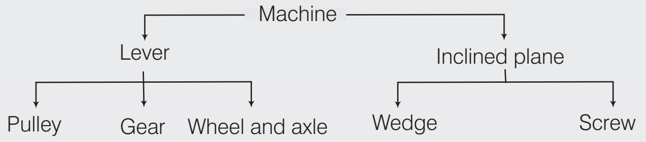
Note The mechanical advantage of an inclined plane is given by,
$MA = \frac{l}{h}$, where l = length of inclined plane
and h = height of inclined plane.

CHECK POINT 03

1. Name a machine which can be used to change the direction of force applied.
2. Define the term ''single fixed pulley''. State its mechanical advantage and velocity ratio.
3. Name the type of single pulley that has a mechanical advantage greater than one.
4. Why do we use single fixed pulley?
5. What is the value of ideal mechanical advantage of a single fixed pulley?
6. In the case of a single movable pulley, state whether the load moves in the direction of effort or opposite to effort ?
7. How many combination of pulleys are there? Name them.
8. Define gear ratio.

SUMMARY

- Machine is a device which helps us to do the work at one point and deliver it at another point with a view of accomplishing the work easily.



Classification of Machine

- Functions performed by machines are
  (i) as a force multiplies
  (ii) to increase or decrease speed
  (iii) in changing, the direction of effort
  (iv) to change the point of application of effort.
- Load It is the resistive or opposing force against which the machine does the work. It is denoted by L.
- Effort It is the force applied on the machine to overcome the load. It is denoted by E.
- Mechanical Advantage (MA) It is the ratio of the load to the effort. It is denoted by MA.
- Efficiency (η) It is the ratio of the work done on the load by the machine to the work put into the machine by the effort.
- Velocity Ratio (VR) It is the ratio of the distance moved by the effort d_E to the corresponding distance moved by the load d_L.
- For an ideal machine, η is 100%.
- In actual machine, the output energy is always less than the input energy.
- Relation between η, MA and VR If η is expressed as efficiency percentage, then $\eta = \frac{\textbf{MA}}{\textbf{VR}} \times \textbf{100}$
- A lever is a straight or bent rod which can be turned or rotated about a fixed point called fulcrum.
- In class I lever, the effort (E) and the resistance (load, L) are situated on either side of the fulcrum (F) . e.g., A pair of scissors, handle of water pump, a catapult and the nodding of the human head, etc.
- In class II lever, the load is situated between fulcrum and effort. e.g., A bottle opener, a wheel barrow, a paper cutter, raising the weight of the human body on toes, etc.
- In class III lever, effort is situated between the load and the fulcrum. e.g., Sugar tongs, foot treadle, etc.
- Three classes of levers are found in the human body (i) class I lever in the action of nodding of head (ii) class II lever in raising the weight of the body on toes (iii) class III lever in raising a load by forearm.
- Pulley is a wheel on an axle that is designed to support movement and change the direction of a cable or belt along its circumference. A set of pulleys assembled so that, they rotate independently on the same axle to form a block is called pulley system.
- A pulley which has its axis of rotation fixed in position is called single fixed pulley. For this pulley MA = 1, VR = 1, η = 100%.
- A pulley whose axis of rotation is not fixed in position is called a movable pulley.
  For this pulley MA = 2, VR = 2, η = 100%.
- For combination of pulleys using one fixed pulley and other movable pulley MA = 2^n, VR = 2^n, η = 100%.
- For block and tackle system MA = n, VR = n with weight of pulley, MA = $n - \frac{W}{E}$, VR = n, $\eta = 1 - \frac{W}{nE}$.
- A gear is a wheel with teeth around its rim. A gear wheel closer to the source of power is called the driver (or the driving gear), while the gear wheel which receives motion from the driver is called the driven gear.
  For this,
  gear ratio = $\frac{N_A}{N_B}$, gain in torque = $\frac{N_B}{N_A} = \frac{r_B}{r_A}$ and gain in speed = $\frac{n_B}{n_A} = \frac{N_A}{N_B}$
- The inclined plane is a sloping surface that behaves like a simple machine whose mechanical advantage is always greater than 1.

$$\text{MA} = \frac{1}{\sin\theta}, \ \text{VR} = \frac{l}{h}$$

EXAM PRACTICE

a 2 Marks Questions

1. Write two functions of a machine.

Sol. *Two functions of a machine are given below*

(i) A machine can be used to lift a load in one direction by applying effort in convenient direction.

(ii) It can be used to overcome a load at some point by applying an effort at a convenient point. *[1+1]*

2. With reference to the terms mechanical advantage, velocity ratio and efficiency of a machine, name and define the term that will not change for a machine of a given design. *[2016]*

Sol. From the given variables, velocity ratio of a machine will not change for a machine of a given design. It is the ratio of the velocity of effort to the velocity of load. *[2]*

3. When does a machine act as

(i) a force multiplier?

(ii) a speed multiplier?

Sol. (i) A machine having MA > 1 works as force multiplier, e.g., Crow-bar. *[1]*

(ii) A machine having $MA < 1$ works as speed multiplier, e.g., A pair of scissors. *[1]*

4. Why cannot a machine be 100% efficient?

Sol. Due to the weights of different parts of machine and friction between its different parts the MA is less than the VR (i.e., MA < VR). Hence, a machine can never be 100% efficient. *[2]*

5. (i) What is meant by an ideal machine?

(ii) Write a relationship between the mechanical advantage (MA) and velocity ratio (VR) of an ideal machine.

Sol. (i) A machine having 100% efficiency is called an ideal machine. *[1]*

(ii) The relation between MA and VR is given by

$$MA = VR \qquad (\because \eta = 100\%)$$ *[1]*

6. What is a lever? State its principle.

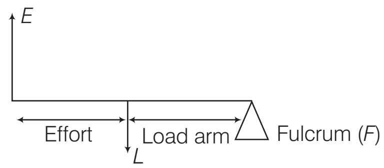
Sol. A simple machine that can rotate (capable of turning) freely about a point or axis is called lever. The principle of lever is *[1]*

$\Rightarrow$ effort $\times$ effort arm length = load $\times$ load arm length. *[1]*

7. Which class of lever will always have MA > 1 and why? *[2017]*

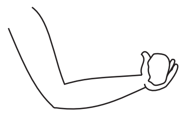
Sol. In class II lever, an effort arm is always greater than the load arm and the load is situated between fulcrum and effort. In this lever, the mechanical advantage and velocity ratio are always more than 1.

The sketch of such lever is shown below

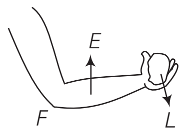


[1+1]

8. Copy the diagram of the forearm given below, indicate the positions of load, effort and fulcrum. *[2008]*

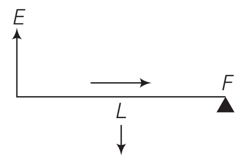


Sol. The below diagram shows the position of load (L), effort (E) and fulcrum (F).



[2]

9. The diagram below shows a lever in use



(i) To which class of levers does it belong?

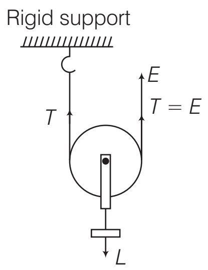
(ii) Without changing the dimensions of the lever, if the load is shifted towards the fulcrum what happens to the mechanical advantage of the lever? *[2018]*

Sol. (i) It belongs to class II lever because load is situated between fulcrum and effort. *[1]*

(ii) If load is shifted towards the fulcrum, then mechanical advantages will increase. *[1]*

10. Draw a diagram to show how a single pulley can be used so as to have its ideal MA = 2. *[2014]*

Sol.



[2]

11. A type of single pulley is very often used as a machine even though it does not give any gain in mechanical advantage. *[2013]*

(i) Name the type of pulley used.

(ii) For what purpose is such a pulley used?

Sol. (i) The pulley which is used in the arrangement is single fixed pulley. **[1]**

(ii) Single fixed pulley is used only to change the direction of the force applied. **[1]**

12. Give two reasons why the efficiency of a single movable pulley system is less than 100%.

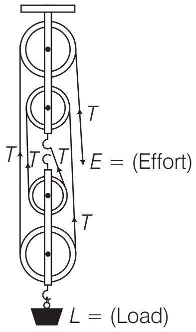
Sol. *We consider the following reasons*

(i) The friction in the pulley bearings or at the axle.

(ii) The weight of pulley and string, the mechanical advantage will be less than 2 and efficiency will be less than 100%. **[1+1]**

13. A block and tackle system of pulleys has a velocity ratio 4. Draw a labelled diagram of the system indicating clearly the points of application and directions of load and effort.

Sol. *The labelled diagram of the system is shown as below*



[2]

14. State the fundamental principle of gear tooth action.

Sol. The fundamental principle of gear and tooth action depends upon the Velocity Ratio (VR). Velocity ratio is also defined as the ratio of speed of rotation of driver gear to the speed of rotation of driven gear. **[1]**

$$\text{VR} = \frac{\text{Speed of rotation of driver gear } (v)_{\text{driver}}}{\text{Speed of rotation of driven gear } (v)_{\text{driven}}}$$ **[1]**

15. An effort is applied on the bigger wheel of a gear having 32 teeths. It is used to turn a wheel of 8 teeths. Where is it used? *[2016]*

Sol. If an effort is applied on the bigger wheel of gear having 32 teeths to turn a wheel of 8 teeths, it acts as speed multiplier. And it is used in bicycles and car to gain speed. **[2]**

b 3 Marks Questions

16. Derive a relationship between MA, VR and η of a machine. *[2014]*

Sol. Refer to theory (Page 45).

17. What step could be taken to increase the mechanical advantage of a lever?

Sol. As we know, $\text{MA} = \frac{\text{load}}{\text{effort}}$, to increase MA, length of effort arm should be greater than load arm, because

$$E \times E_d = L \times L_d$$

or $$\text{MA} = \frac{\text{effort arm}}{\text{load arm}}$$ **[3]**

18. (i) State the class of levers and the relative positions of load (L), effort (E) and fulcrum (F) in each of the following cases:

(a) A bottle opener (b) Sugar tongs

(ii) Why is less effort needed to lift a load over an inclined plane as compared to lifting the load directly? *[2012]*

Sol. (i) (a) A bottle opener is a class II lever. In this case, the load is in between the fulcrum and the effort.

(b) Sugar tongs is a class III lever. In this case, the effort is in between the fulcrum and the load. **[1+1]**

(ii) Less effort is needed to lift a load over an inclined plane as compared to lifting the load directly, as the mechanical advantage increases. **[1]**

19. Assume that a pair of scissors and a pair of pliers belong to the same class of levers.

(i) Which one has mechanical advantage less than one?

(ii) What is the usefullness of a machine whose mechanical advantage is less than one?

Sol. (i) A pair of scissors and a pair of pliers both belong to class I levers.

For class I levers, $\text{MA} > 1$ or $\text{MA} = 1$ or $\text{MA} < 1$

As, we know that

$$\text{Mechanical advantage} = \frac{\text{Load } (L)}{\text{Effort } (E)} = \frac{\text{Effort arm}}{\text{Load arm}}$$ **[1]**

In a pair of scissors effort arm is less than the load arm.

∴ Mechanical advantage of a pair of scissors is less than one. **[1]**

(ii) The machines with MA < 1 can help us to apply the effort at a more convenient point or to gain in speed. **[1]**

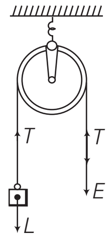
20. With the help of a diagram of a single fixed pulley, obtain expressions for its

(i) mechanical advantage

(ii) velocity ratio

(iii) efficiency in the ideal case.

Sol. *The diagram of a single fixed pulley is shown alongside.* Suppose, T is the tension in each of the string and in the ideal case string is massless and there is no friction in the pulley bearings, then in equilibrium,



$$E = T \text{ and } L = T$$

(i) Mechanical advantage $= \dfrac{L}{E} = \dfrac{T}{T} = 1$ **[1]**

(ii) If the effort E moves a distance d downwards, then load L moves the same distance d upwards.

So, velocity ratio $= \dfrac{d_E}{d_L} = \dfrac{d}{d} = 1$ **[1]**

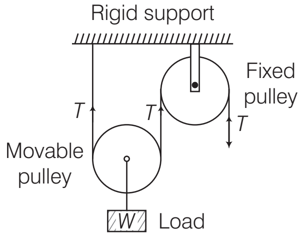
(iii) Efficiency $= \dfrac{\text{MA}}{\text{VR}} = \dfrac{1}{1} = 1$ (or 100%) **[1]**

21. A pulley system comprises two pulleys, one fixed and the other movable.

(i) Draw a labelled diagram of the arrangement and show clearly the directions of all the forces acting on it.

(ii) What change can be made in the movable pulley of this system to increase the mechanical advantage of the system?

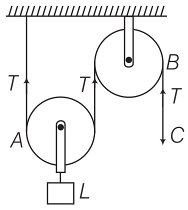
Sol. (i) *The labelled diagram of the above arrangement is as shown below*



[2]

(ii) To increase the mechanical advantage of the system we need to reduce the friction between the string and the movable pulley. **[1]**

22. From the diagram given below, answer the questions that follow:



(i) What kind of pulleys are A and B?

(ii) State the purpose of pulley B.

(iii) What effort has to be applied at C to just raise the load L = 20 kgf? (neglect the weight of pulley A and friction) **[2016]**

Sol. (i) According to questions,
A is a movable pulley while B is a fixed pulley. **[1]**

(ii) The purpose of pulley 'B' is to change the point of application of effort and load in the same direction. **[1]**

(iii) Given, load = 20 kgf, MA = 2 and we know that,

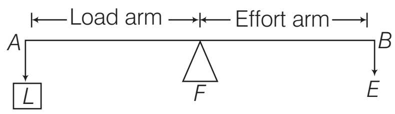
$$\text{MA} = \frac{\text{Load}}{\text{Effort}}$$

$$\therefore \quad \text{Effort} = \frac{20}{2} = 10 \text{ kgf}$$ **[1]**

C 4 Marks Questions

23. State and explain the working principle of a lever with proper diagram.

Sol. Consider a lever (for a straight rod) AB with balanced point at F (fulcrum for the lever), a load L acts at point A of the lever and effort E acts at point B as shown in the diagrams. **[2]**



A lever works on the principle of moment. In the equilibrium position of the lever, by the principle of moment,

moment of load at about the fulcrum
= moment of effort about the fulcrum **[1]**

The two moments are always in opposite directions.

In figure, the moment of load is anti-clockwise while the moment of effort is clockwise. Thus, we can write

$$\text{load} \times \text{load arm} = \text{effort} \times \text{effort arm}$$

This is also called principle of lever.

or $$L \times AF = E \times BF$$ **[1]**

24. Write the class of levers to which following belongs.

(i) A physical balance	(ii) A see-saw
(iii) An oar of a boat	(iv) Human-arm
(v) Pliers	(vi) A claw-hammer
(vii) Rowing of a boat	(viii) A fire tongs
(ix) Sugar tongs	(x) A pair of scissors
(xi) Wheel barrow	(xii) Nut cracker
(xiii) Forearm used for lifting a load.	

Sol. *Above mentioned levers belong to the following classes*

(i) Class I	(ii) Class I
(iii) Class II	(iv) Class III
(v) Class I	(vi) Class I
(vii) Class II	(viii) Class III
(ix) Class III	(x) Class I
(xi) Class II	(xii) Class II
(xiii) Class I	

[1/3 ×12]

25. Draw a diagram consisting of 4 pulleys in block and tackle arrangement.

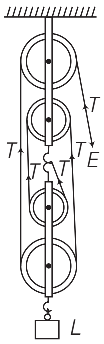
(i) State how many strands of tackle support the load?

(ii) Draw arrows to represent tension in each strand.

(iii) Find the mechanical advantage of the system stating the assumptions made.

(iv) If load is pulled up by a distance of 1 m, how much does the effort arm move?

Sol. The adjacent diagram shows a block and tackle system of 4 pulleys.



(i) Four strands of tackle support the load.

(ii) The tension in each strand is shown by the arrows marked as T.

(iii) If we neglect the friction of the pulleys and weight of the pulleys in the lower block, then

$$L = 4T \text{ and } E = T$$

$$\therefore \quad MA = \frac{L}{E} = \frac{4T}{T} = 4$$

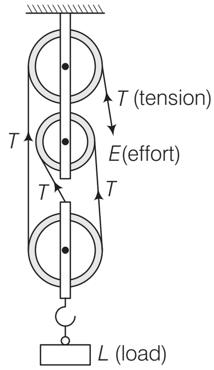
(iv) If load is pulled up by a distance 1 m, the effort end moves by 4 m. ***[1 × 4]***

26. (i) Draw a diagram to show a block and tackle pulley system having a velocity ratio of 3 marking the direction of load (L), effort (E) and tension (T).

(ii) The pulley system drawn lifts a load of 150 N when an effort of 60 N is applied. Find its mechanical advantage.

(iii) Is the above pulley system an ideal machine or not? ***[2018]***

Sol. (i) *The labelled diagram of the system is shown below*



[2]

(ii) Given, load (L) = 150 N

Effort (E) = 60 N

We know that, mechanical advantages

$$(MA) = \frac{\text{Load}}{\text{Effort}} = \frac{150}{60} = 2.5$$ ***[1]***

(iii) No, the above pulley system is not an ideal machine because velocity ratio ($VR = 3$) is not equal to mechanical advantages. ***[1]***

27. (i) Name a machine which can be used to change the direction of force applied.

(ii) Draw a labelled diagram of a block and tackle system of pulleys with two pulleys in each block. Indicate the directions of the load, effort and tension in the string.

(iii) Write down the relation between the load and the effort of the pulley system.

Sol. (i) Pulley is a machine which can change for direction of force applied. ***[1]***

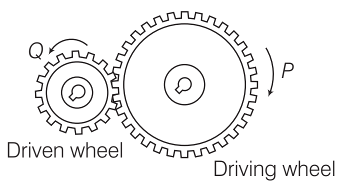
(ii) Refer to the Q. No. 26. ***[1½]***

(iii) Refer to the Q. No. 26. ***[1½]***

28. Explain how a gear system can be used to obtain

(i) gain in speed (ii) gain in torque.

Sol. (i) **Gain in Speed** Consider the figure shown in which the wheel P is used as driving gear and the wheel Q as the driven gear, i.e., if $N_P = 24$ and $N_Q = 12$, the velocity ratio will be $\frac{24}{12} = 2$ or gain in speed.



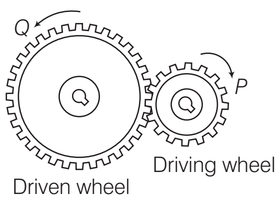
e.g., A toy motor car having a key and spring on the axle fitted with a driving gear having more teeth which engages the driven gear having less teeth to gain speed.

Gain in speed

$$= \frac{\text{Number of teeth in driving wheel } (N_P)}{\text{Number of teeth in driven wheel } (N_Q)}$$

[2]

(ii) **Gain in Torque** A gear system can be used to increase the turning effect when the smaller wheel drives the bigger wheel, i.e. the driven gear has more number of teeth than the driving gear, (i.e., $N_Q > N_P$) the ratio of number of teeth in driven gear to the number of teeth in driving gear gives gain in torque. ***[2]***



29. (i) Write a relation expressing the mechanical advantage of a lever.

(ii) Write an expression for the mechanical advantage of an inclined plane.

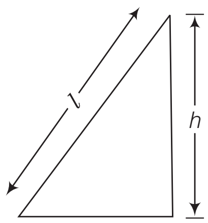
(iii) Give two reasons as to why the efficiency of a single movable pulley system is always less than 100%. ***[2010]***

Sol. (i) The relation expressing mechanical advantage of a lever is given by

$$\text{MA} = \frac{\text{Effort arm}}{\text{Load arm}}$$

[1]

(ii) The expression for the mechanical advantage of an inclined plane is given by



$$\text{MA} = \frac{l}{h}$$

where, l is the length of inclined plane and h is the height of inclined plane. ***[1]***

(iii) (a) The weight of movable pulley with its frame is not negligible.

(b) The frictional force between pulley and string is not negligible. $(\because \eta = 100\%)$ ***[1×2]***

Numerical Based Questions

30. A crow-bar of length 150 cm has its fulcrum situated at a distance of 50 cm from the load. Calculate the mechanical advantage of crow-bar.

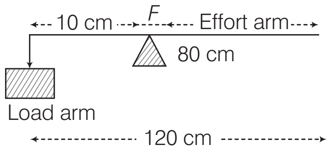
Sol. $\text{MA} = \frac{\text{Length of effort arm from fulcrum}}{\text{Length of the load arm from fulcrum}}$ ***[1]***

i.e., $= \frac{150-50}{50} = 2$ ***[1]***

31. A crow-bar of length 80 cm has its fulcrum situated at a distance of 10 cm from the load. Calculate the mechanical advantage of the crow-bar.

Sol. MA of crowbar,

$$\text{MA} = \frac{\text{Effort arm}}{\text{Load arm}} = \frac{80}{10} = 8$$

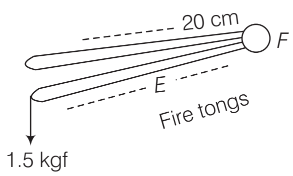


[2]

32. A fire tongs has its arms 30 cm long. It is used to lift a coal of weight 2 kgf by applying an effort at distance 20 cm from the fulcrum. Find
(i) the mechanical advantage of fire tongs and
(ii) the effort needed.

Sol. (i) MA = ?

Effort arm = 20 cm



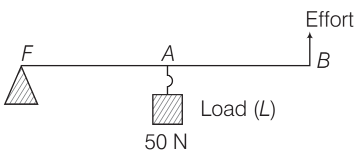
Load arm = 30 cm

$$\text{MA} = \frac{\text{Effort arm}}{\text{Load arm}} = \frac{20}{30} = \frac{2}{3} = 0.66$$

[1]

(ii) $\text{Effort} = \frac{\text{Load}}{\text{Mechanical Advantage}} = \frac{2 \text{ kgf}}{2/3} = 3 \text{ kgf}$ ***[1]***

33. The diagram below shows a lever in use.



If $FA = 40$ cm, $AB = 60$ cm, then find the mechanical advantage of the lever. ***[2011]***

Sol. Effort arm $= FA + AB = 40 + 60 = 100$ cm

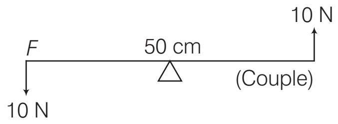
Load arm $= FA = 40$ cm **[1]**

$$\therefore \quad MA = \frac{\text{Effort arm}}{\text{Load arm}}$$

$$= \frac{FB}{FA} = \frac{100}{40} = 2.5$$ **[1]**

34. Two forces each of 10 N act vertically upwards and downwards, respectively on the two ends of a uniform meter rule which is placed at its mid-point as shown in the diagram. Determine the magnitude of the resultant moment of these forces about the mid-point.

Sol.

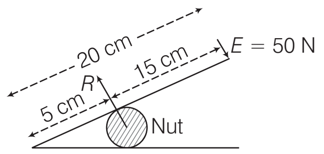


$$M = F \times d \text{ (or) } F \times s$$ **[1]**

$$\therefore \quad M = 10 \times \frac{50}{100} \text{ m}$$

$$= 10 \times 0.5 = 5 \text{ N-m}$$ **[1]**

35. In the diagram shown below, calculate the resistance (R) offered by the nut, when an effort of 50 N is applied.



Sol. Load arm $= 5$ cm

Effort arm $= 15 + 5 = 20$ cm **[1]**

As we know that,

load × load arm = effort × effort arm

$$\Rightarrow \quad R \times 5 \text{ cm} = 50 \text{ N} \times 20 \text{ cm} \Rightarrow R = 200 \text{ N}$$ **[1]**

36. A cook uses a fire tong of length 28 cm to lift a piece of burning coal of mass 250 g. If he applies his effort at a distance of 7 cm from the fulcrum, what is the effort in SI unit? (Take, $g = 10 \text{ m/s}^2$)

Sol. Given, mass, $m = 250 \text{ g} = 0.25$ kg

Load, $L = 0.25 \times 10 \text{ N} = 2.5$ N **[1]**

Distance of load, $L_d = 28 \text{ cm} = 0.28$ m

Distance of effort, $E_d = 7 \text{ cm} = 0.07$ m

Effort, $E = ?$

According to the principle of moment, we have **[1]**

$$E \times E_d = L \times L_d$$

$$\Rightarrow \quad E = \frac{L \times L_d}{E_d} = \frac{0.25 \times 10 \times 0.28}{0.07} = 10 \text{ N}$$ **[1]**

37. A force of 10 kgf is required to cut a metal sheet. A shear used for cutting a metal sheet has its blades 10 cm long, while its handle is 20 cm long. What effort is needed to cut a sheet?

Sol. Length of blades = Load arm $= 10 \text{ cm} = \frac{10}{100}$ m

Load, $L = 10$ kgf, effort needed, $E = ?$ **[1]**

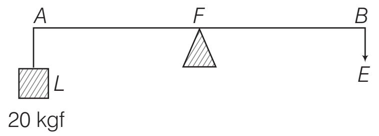
Length of handle = Effort arm $= 20 \text{ cm} = \frac{20}{100}$ m

$\therefore E \times$ effort arm $= L \times$ load arm

$$\Rightarrow \quad E \times \frac{20}{100} = 10 \times \frac{10}{100}$$ **[1]**

$$\Rightarrow \quad E = \frac{100}{20} = 5 \text{ kgf}$$ **[1]**

38. The diagram below shows a lever in use.



(i) To which class of lever does it belong?

(ii) If $AB = 4$ m, $AF = 0.8$ m, find its mechanical advantage.

(iii) Find the value of E.

Sol. (i) It belongs to lever of class I.

(ii) We can write, $MA = \frac{FB}{FA} = \frac{4.0 - 0.8}{0.8} = \frac{3.2}{0.8} = 4$

(iii) Applying the law of moment,

$$20 \times 0.8 = E \times 3.2$$

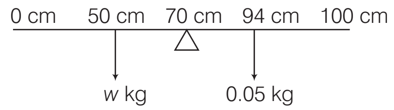
or $$E = \frac{20 \times 0.8}{3.2} = \frac{160}{32} = 5 \text{ kgf}$$ **[1+1+1]**

39. A uniform meter scale can be balanced at the 70.0 cm mark, when a mass of 0.05 kg is hung from the 94.0 cm mark.

(i) Draw a diagram of the arrangement.

(ii) Find the mass of the meter scale. **[2011]**

Sol. (i) *The diagram of the above arrangement is shown as below* **[1]**



(ii) Let w be the weight of the scale.

By principle of moments, we get

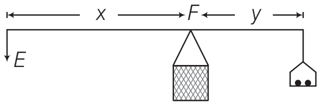
$$w \times (70 - 50) = 0.05(94 - 70)$$ **[1]**

$$\Rightarrow \quad w \times 20 = 0.05 \times 24$$ **[1]**

$$\Rightarrow \quad w = \frac{0.05 \times 24}{20} = 0.06 \text{ kg}$$ **[1]**

40. (i) Calculate the mechanical advantage of the lever shown in figure.

(ii) How do you define mechanical advantage of a machine?



Sol. (i) Clockwise moment $= y \times L$

and anti-clockwise moment $= x \times E$

According to the principle of moment,

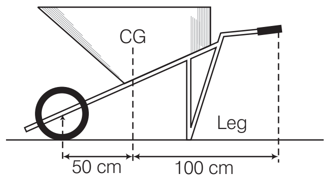
clockwise moment = anti-clockwise moment

$\therefore \quad y \times L = x \times E \quad \text{or} \quad \frac{L}{E} = \frac{x}{y}$ ***[1]***

(ii) Mechanical advantage is the ratio of the load lifted to the effort applied.

Hence, in figure, $\text{MA} = \frac{L}{E} = \frac{x}{y}$ ***[1]***

41. If the weight of wheel barrow is 10 kgf and the weight of sand in it is 50 kgf, with the help of information given in figure. Calculate the minimum effort required to keep the leg just off the ground.



Sol. Total load of wheel barrow $= 50 + 10$ kgf

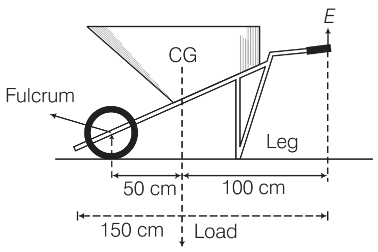
Load = 60 kgf

Load arm = 50 cm

Effort = ?

Effort arm = 150 cm ***[1]***

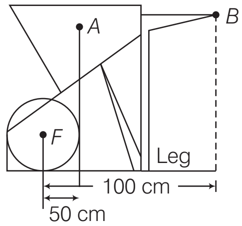
Load × Load arm = Effort × Effort arm



[1]

$\Rightarrow \quad 60 \times 50 = E \times 150 \quad \Rightarrow E = \frac{60 \times 50}{150} = 20 \text{ kgf}$ ***[1]***

42. In the diagram of a stationary wheel barrow, the centre of gravity is at *A*. The wheel and the leg are in contact with the ground. The horizontal distance between *A* and *F* is 50 cm and that between *B* and *F* is 150 cm.



(i) What is the direction of the force acting at *A*? Name the force.

(ii) What is the direction of the minimum force at *B* to keep the leg off the ground? What is this force called?

(iii) The weight of the wheel barrow is 15 kgf and it holds sand of weight 60 kgf. Calculate the minimum force required to keep the leg off the ground.

Sol. (i) The direction of the force acting at *A* is vertically downwards. This force is named as load. ***[1/2]***

(ii) The direction of the minimum force at *B* to keep the leg off the ground is acting vertically upwards. This force is called effort. ***[1/2]***

(iii) Given, weight of wheel, $w_E = 15$ kgf

Weight of sand, $w_S = 60$ kgf

Minimum force, $E = ?$

Total load, $L = w_E + w_S$

$= 15 + 60 = 75$ kgf

Effort arm, $\quad E_a = 50 + 100$ ***[1]***

$= 150 \text{ cm} = 1.5 \text{ m}$

Load arm, $\quad L_a = 50 \text{ cm} = 0.5 \text{ m}$

Applying the principle of lever,

load × load arm = effort × effort arm

$\Rightarrow \quad L \times L_a = E \times E_a$

$\Rightarrow \quad E = \frac{L \times L_a}{E_a} = \frac{75 \times 0.5}{1.5}$

$= 25$ kgf ***[1]***

43. In a single movable pulley system a load of 300 kgf is lifted by an effort of 200 kgf. Find the percentage efficiency of system.

Sol. We know that, VR of single movable pulley = number of supporting segments of string = 2

MA of single movable pulley $= \frac{L}{E} = \frac{300}{200} = \frac{3}{2}$ ***[1]***

Therefore, efficiency is $\eta = \frac{\text{MA}}{\text{VR}} = \frac{3}{2 \times 2} = \frac{3}{4}$

$= 0.75 = 75.00\%$ ***[1]***

44. A pulley system has a velocity ratio of 4 and an efficiency of 90%. Calculate

(i) the mechanical advantage of the system.

(ii) the effort required to raise a load of 300 N by the system.

Sol. Given, velocity ratio, VR = 4

Efficiency, $\eta = 90\%$

(i) Mechanical Advantage, $\text{MA} = \text{VR} \times \frac{\eta}{100}$

$$= 4 \times \frac{90}{100} = 3.6 \qquad \left(\because \eta = \frac{\text{MA}}{\text{VR}}\right)$$ **[1]**

(ii) Effort, $E = ?$, load, $L = 300$ N

$$E = \frac{L}{\text{MA}} = \frac{300}{3.6} = 83.33 \qquad \left(\because \text{MA} = \frac{L}{E}\right)$$ **[1]**

45. A pulley system has four pulleys in all and is 75% efficient. Calculate

(i) MA

(ii) effort required to lift a load of 1000 N.

Sol. Given, $\eta = 75\%$,

VR = 4 (as the system has 4 pulleys)

(i) Since, $\eta = \frac{\text{MA}}{\text{VR}}$

$$\therefore \quad \text{MA} = \eta \times \text{VR} = \frac{75}{100} \times 4 = 3$$ **[1½]**

(ii) Also, $\text{MA} = \frac{\text{Load}}{\text{Effort}}$

$$\text{Effort} = \frac{\text{Load}}{\text{MA}} = \frac{1000}{3} = 333.33 \text{ N}$$ **[1½]**

46. A pulley system has three pulleys. A load of 120 N is overcome by applying an effort of 50 N. Calculate the mechanical advantage and efficiency of this system. **[2016]**

Sol. According to question, load = 120 N

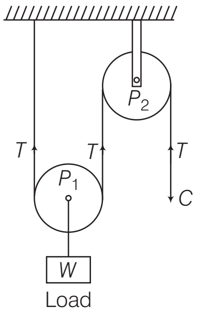
Effort = 50 N

$$\therefore \text{Mechanical Advantage} = \frac{\text{Load}}{\text{Effort}} = \frac{120}{50} = 2.4$$ **[1]**

$$\text{Now, \% efficiency} = \frac{\text{MA}}{\text{VR}} \times 100$$

$$\Rightarrow \quad = \frac{2.4}{3} \times 100 = 80\%$$ **[2]**

47. Consider the combination of a movable pulley P_1 with a fixed pulley P_2 used for lifting a load W.



(i) What is the function of the fixed pulley P_2?

(ii) If the free end of the string moves through a distance y, find the distance by which the load W is raised.

(iii) Calculate the force to be applied at C to just raise the load $W = 30$ kgf, neglecting the weight of the pulley P_1 and friction.

Sol. (i) From the given diagram, it is clear that applying effort in the upward is very difficult, if no fixed pulley P_2 is used.

The fixed pulley changes the direction of effort from upwards to downwards, making the application of the effort more convenient and easier. **[1]**

(ii) As, the movable pulley doubles the effort,

$\therefore$ Force, $L = 2T$

i.e., $W = 2T$

Mechanical Advantage, $\text{MA} = \frac{2T}{T} = 2$

$$\text{VR} = \frac{\text{Distance travelled by effort}}{\text{Distance travelled by load}} = \frac{2y}{y} = 2$$

The distance travelled by load is half the distance moved by effort $= \frac{y}{2}$. **[1]**

(iii) Since, $W = 2T$

or $30 \text{ kgf} = 2T$.

Here, T = Effort

$$\therefore \text{Effort applied} = \frac{30}{2} = 15 \text{ kgf}$$ **[1]**

48. A block and tackle system of pulleys has a velocity ratio 4. What is the value of the mechanical advantage of the given pulley system, if it is an ideal pulley system?

Sol. Given, velocity ratio,

$$VR = 4, \text{ load } L = 4T \text{ effort} = T$$

$$\therefore \quad MA = \frac{\text{Load}}{\text{Effort}} \quad \textit{[1]}$$

$$= \frac{4T}{T} = 4 \quad \textit{[1]}$$

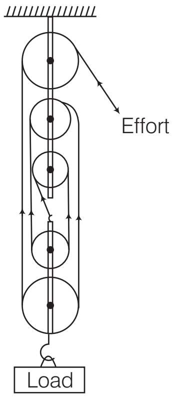
49. The pulley system shown in the figure is used to raise 500 kgf object. What is the mechanical advantage and what force is exerted?

Sol. Given, MA = number of segments holding the load = 5

Load, $L = 500$ kgf

Effort, $E = ?$

We know that, $MA = \frac{\text{Load}}{\text{Effort}}$



or $\quad \text{Effort} = \frac{\text{Load}}{MA} = \frac{500}{5} = 100 \text{ kgf}$ *[1 +1]*

50. A boy uses a single fixed pulley to lift a load of 50 kgf to same height. Another boy uses a single movable pulley to lift the same load to the same height. Compare the effort applied by them. Give a reason to support your answer. *[2017]*

Sol. In first case, the pulley is single fixed,

$$MA = 1$$

But, $\quad MA = \frac{L_1}{E_1}$

$$\Rightarrow \quad 1 = \frac{50}{E_1}$$

$$\Rightarrow \quad E_1 = 50 \text{ kgf} \quad \textit{[2]}$$

In second case, the pulley is single movable,

$$\therefore \quad MA = 2 \Rightarrow 2 = \frac{50}{E_2}$$

$$\Rightarrow \quad E_2 = 25 \text{ kgf}$$

$$\Rightarrow \quad \frac{E_1}{E_2} = \frac{50}{25} = \frac{2}{1} \quad \textit{[2]}$$

51. A pulley system with VR = 4 is used to lift a load of 175 kgf through a vertical height of 15 m. The effort required is 50 kgf in the downward direction. (Take, $g = 10$ N/kg).

Calculate

(i) distance moved by the effort

(ii) work done by the effort

(iii) MA of the pulley system

(iv) efficiency of the pulley system *[2017]*

Sol. (i) We known that, $VR = \frac{\text{distance moved by effort } (D_E)}{\text{distance moved by load } (E_L)}$ *[1]*

$$4 = \frac{D_E}{15} \Rightarrow D_E = 60 \text{ m}$$

(ii) Work done by the effort = Force × displacement

$$= 50 \times 10 \times 60 = 30000 \text{ J} \quad \textit{[1]}$$

(iii) $MA = \frac{L}{E} = \frac{175}{50} = 3.5$ *[1]*

(iv) Efficiency, $\eta = \frac{MA}{VR} = \frac{3.5}{4}$

$$= 0.875$$

$$= 87.5\% \quad \textit{[1]}$$

52. A block and tackle with five pulleys is found to have a MA of 3, when a load of 10 N is raised by it. Calculate (i) the effort applied (ii) VR (iii) efficiency and (iv) the total resistance R due to friction.

Sol. Number of pulleys in the block and tackle = 5

$$MA = 3, L = 10 \text{ N}, E = ?$$

Total resistance, $R = ?, \eta = ?$

(i) Now, we know that velocity ratio of a pulley block and tackle is equal to the total number of pulleys.

$$\therefore \quad E = \frac{L}{MA} = \frac{10}{3} = 3.33 \text{ N} \quad \textit{[1]}$$

Also, $L + R = VR \times E = 5 \times 3.33 = 16.65$

(ii) $VR = n = 5$ *[1]*

(iii) $\text{Efficiency} = \frac{MA}{VR} \times 100$

$$= \frac{3}{5} \times 100 = 60\% \quad \textit{[1]}$$

(iv) Resistance due to friction,

$$R = 16.65 - L = 6.25 - 10 = 6.65 \text{ N} \quad \textit{[1]}$$

CHAPTER EXERCISE

2 Marks Questions

1. Write an expression to show the relationship between mechanical advantage, velocity ratio and efficiency for a simple machine. ***[2007]***

2. Which class of levers has a mechanical advantage always greater than one? What change can be brought about in this lever to increase its mechanical advantage? ***[2007]***

3. What is the relationship between the mechanical advantage and the velocity ratio for
(i) ideal machine (ii) practical machine ?

4. To use a machine as a force multiplier, what types (class) of lever should preferably be used? Draw a sketch of such a lever.

5. Why is the mechanical advantage of a lever of third order is always less than 1? Give one example of this class of lever.

6. Draw a diagram of a class III lever. Give one example of this kind of lever.

7. Give two reasons why the efficiency of a single movable pulley system is not 100%.

8. A block and tackle pulley system has a velocity ratio 3. ***[2007]***
(i) Draw a labelled diagram of this system. In your diagram, indicate clearly the points of application and the directions of the load and effort.
(ii) Why should the lower block of this pulley system be of negligible weight?

3 Marks Questions

9. Name the type of single pulley that can act as a force multiplier. Draw a labelled diagram of the above named pulley. ***[2006]***

10. Draw a labelled sketch of a class II lever. Give one example of such a lever.

11. A pair of scissors and a pair of pliers belong to the same class of levers.
(i) Which one has mechanical advantage less than one?
(ii) State the usefullness of such a machine whose mechanical advantage is less than 1.

12. What is the relationship between the mechanical advantage and the velocity ratio for
(i) an ideal machine
(ii) a practical machine.

13. (i) Which simple machine is used by the labourers to load heavy barrels, etc., on a truck?
(ii Does a single fixed pulley help us to multiply the force? In what way is it useful?

4 Marks Questions

14. Draw diagrams to illustrate the positions of fulcrum, load and effort in each of the following.
(i) A common balance (ii) A see-saw
(iii) Forceps (iv) A nut-cracker

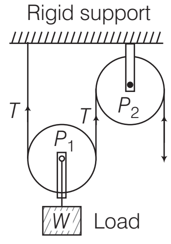
15. Define the following.
(i) Machine
(iI) Efficiency

Numerical Based Questions

16. A woman draws water from a well using a fixed pulley. The mass of the bucket and water together is 6.0 kg. The force applied by the woman is 70 N. Calculate the mechanical advantage. (Take, $g = 10\ m/s^2$) ***[2007]***

Ans. $6/7 = 0.857$

17. The alongside figure shows the combination of a movable pulley P_1 with a fixed pulley P_2 used for lifting up a load W. ***[3]***



(i) State the function of the fixed pulley P_2.
(ii) If the free end of the string moves through a distance x, find the distance by which the load W is raised.
(iii) Calculate the force to be applied at C to just raise the load $w = 20$ kgf, neglecting the weight of the pulley P_1 and friction.

Ans. (i) to change direction, (ii) $x/2$, (iii) Effort needed = 10 kgf

18. The radius of the driving wheel of a set of gears is 18 cm. It has 100 teeth and rotates at a speed of 30 rpm. The driven wheel rotates at a speed of 150 rpm. Calculate

(i) the gear ratio.

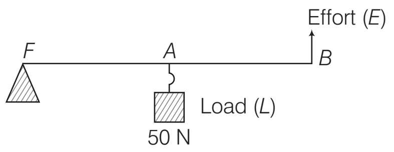
(ii) the number of teeth on the driven wheel.

(iii) the radius of the driven wheel.

Ans. (i)1:5, (ii) 20, (iii) 3.6 cm

19. A block and tackle system has VR = 5. Draw a neat labelled diagram of a system indicating the direction of its load and effort. Rohan exerts a pull of 200 kgf. What is the maximum load he can raise with this pulley system, if its efficiency 75%? ***Ans.*** 750 N

20. The diagram below shows a lever in use.



(i) Which class of lever does it belong?

(ii) If $FA = 30$ cm, $AB = 50$ cm, then find the mechanical advantage of the lever. ***Ans.*** 2

21. A crow-bar of length 100 cm has its fulcrum situated at a distance of 25 cm from the load. Calculate the mechanical advantage of crow-bar. ***Ans.*** 3

22. A pulley system has a velocity ratio of 3 and an efficiency of 80%. Calculate

(i) the mechanical advantage of the system.

(ii) the effort required to raise a load of 480 N by the system. ***Ans.*** (i) 2.4, (ii) 200 N

23. A boy draws water from a well using a fixed pulley. The mass of the bucket and water together is 5 kg. The force applied by the boy is 60 N. Calculate the mechanical advantage. (Take, $g = 10$ m/s^2)

Ans. 0.832

24. A cook uses a fire tong of length 30 cm to lift a piece of burning coal of mass 500 g. If he applies his effort at a distance of 10 cm from the fulcrum, what is the effort in SI unit? (Take, $g = 10$ m/s^2) ***Ans.*** 15 N

25. (i) A see-saw 8 m long is balanced in the middle. Two children of mass 30 kg and 40 kg are sitting on the same side of fulcrum at a distance of 1.5 m and 3.5m, respectively. Where must a man of mass 60 kg sit from the fulcrum so as to balance the see-saw?

Ans. 3.08 m

(ii) A block and tackle system of 5 pulleys is used to raise a load of 500 N steadily through a height of 20 m. The work done against friction is 2000 J. Calculate

(a) the displacement of the effort applied.

(b) the efficiency of the system. ***Ans.*** 80% (4 m)

26. The mechanical advantage of a machine is 4 and its efficiency is 60%. It is used to lift a load of 300 kgf to a height of 15 m. Calculate

(i) the effort required.

(ii) the work done on the machine.
(Take, $g = 10$ m /s^2) ***Ans.*** (i) 75kgf, (ii) 75000 J

27. A block and tackle system has VR = 5.

(i) Draw a neat labelled diagram of a system indicating the directions of its load and effort.

(ii) Shyam exerts a pull of 200 kgf. What is the maximum load he can raise with this pulley system, if its efficiency 80%? ***Ans.*** 800 kgf

28. A pulley system has a velocity ratio 5. Draw a neat labelled diagram of the pulley system to lift a load by applying the effort in a convenient direction. Mark the tension in your diagram.

(i) If the efficiency of the system is 80%, find its mechanical advantage.

(ii) If a load of 10 kgf is pulled up by a distance of 2 m in 10 s, calculate the power developed by the effort. (Take, $g = 10$ m/s^2) ***Ans.*** 200 W