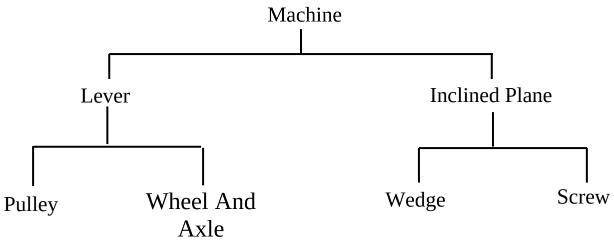
Machine

A machine is a device that helps people to do work against some resistive force. Some machines are powered by engines, motors and even animals, while many others simply use human power. The basis of all complex machines comes from their simple components. The most common simple machines are lever, roller, ramp and pulley.

Machine

Machine is a device, by which we can overcome a resistance or gain speed, by applying comparatively a smaller force at convenient point and in a desired direction. Machines are classified as follows:



Working of Machine

(a) Input:
Work done on the machine (or energy supplied to the machine) is called input. If an effort E causes a displacement D in its own direction, then:
Input = Effort × Displacement = E × D.

(b) Output:
The output can be classified under two headings:

(i) Actual output:
The total work done by the machine is called actual output.
If L is the total load (load lifted by the machine + resistance overcome) displace through a distance d then, actual output = L × d.

(ii) Useful output :
The useful work done by the machine is called useful output. If ℓ is the useful load displaced through a distance d then, useful output = $\ell \times d$.

NOTE : It is not possible to have an ideal machine, because there cannot be a machine, whose parts are weightless or frictionless. However, if we take the view that energy spent by a machine in overcoming resistance, is in a way useful, then any machine can be called perfect machine or ideal machine.

Eg. : If machine is able to lift a load of 30 N, such that resistance due to friction and movable parts of machine is 20N, then total load lifted is (30 + 20) N + 50 N. If the displacement is caused through 1 m.
Then, actual output = 50 N × 1 m = 50 J
Useful output = 30 N × 1 m = 30 J

Terms Related to Machine

(a) Mechanical advantage (MA):

Mechanical advantage literally means advantage given by the machine in terms of effort applied and load lifted by it.
Mechanical advantage can be classified under two classes:

(i) Ikeal mechanical advantage (AMA) :
The ratio between total load moved (or resistance overcome) to the effort applied is called ideal mechanical advantage.

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

(ii) Actual mechanical advantage (AMA) :
The ratio between useful load moved to the effort applied is called actual mechanical advantage.

$$AMA = \frac{\ell}{E}$$

IIIustrations

1. If the mechanical advantage of a machine is 5. Find the effort necessary to lift 100 N.

Sol. Mechanical advantage, MA = 5
Load = 100 N

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

$$Effort = \frac{Load}{MA} = \frac{100}{5} = 20\ N$$

(b) Velocity ratio:
Velocity ratio is the ratio of the velocity at which effort is applied on a machine to the velocity with which load moves.
If D is the displacement caused by an effort in time t such that d is the displacement caused by the load in the same time, then:
Velocity of the effort = D/t
Velocity of the load = d/t

$$\therefore Velocity\ \ ratio\ (VR) = \frac{Velocity\ \ of\ \ effort}{Velocity\ \ of\ \ load}$$

$$VR = \frac{D/t}{d/t}$$

$$VR = \frac{D}{d} = \frac{Displacement\ of\ \ effort}{Displacement\ of\ \ load}$$

(c) Efficiency of machine (η) :
It is given by, $\eta = \frac{Output}{Input}$

$$\%\,\eta = \frac{Output}{Input} \times 100$$

(d) Relation between the efficiency, mechanical advantage and the velocity ratio of a practical machine:
Consider a practical machine which displaces a useful load ℓ through a distance d when an effort E causes a displacement through distance D.
∴ Output = Work done in displacing the load = ℓ × d
Input = Work done by the effort in causing the displacement = E × D

$$\therefore \text{Effidiency}, \eta = \frac{Output}{Input}$$

$$= \frac{\ell \times d}{E \times D} = \frac{\ell}{E} + \frac{D}{d} = MA \div VR, \eta = \frac{MA}{VR}$$

2. A system of levers with a velocity ratio 25 over comes a resistance of 3300 N when an effort of 165 N is applied. Find then the mechanical advantage.

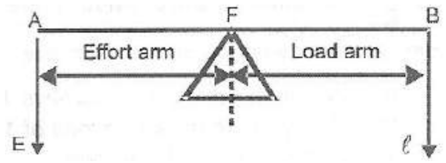
Sol. L = 3300 N, E = 165 N, VR = 25

$$MA = \frac{L}{E} = \frac{3300}{165} = 20$$

Lever

A lever is a rigid bar that rests on a fulcrum (fixed point).

Expression for the mechanical advantage of a lever:



Load × Load arm = Effort × Effort arm

$\ell \times BF = E \times AF$

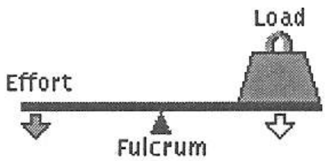
$$\frac{\ell}{E} = \frac{AF}{BF}$$

$$\text{Mechanical advantage}\,(MA) = \frac{AF}{BF} = \frac{\text{Effort arm}}{\text{Load arm}}$$

$$\left[\therefore \frac{\ell}{E} = \text{Mechanical advantage}\,(MA)\right]$$

(a) Class-1 Lever :

A class-1 lever has its fulcrum located somewhere between the effort and the load.



Eg.: Crowbar, Scissors, Water-pump, etc.

Characteristics of class-1 lever:

(i) Fulcrum is in between load and effort.

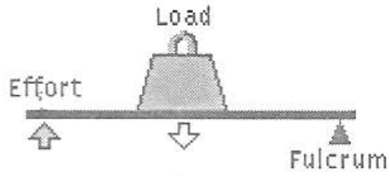
$$(ii)\ \text{mechanical advantage} = \frac{\text{Effort arm}}{\text{Load arm}}$$

(iii) By moving fulcrum towards load, the mechanical advantage can be increased.

(iv) By keeping the load constant the effort applied decreases, if the fulcrum is moved towards the load.

(b) Class-2 Lever:

A lever in which the fulcrum is at one end, the effort is at the other end and the load is in the middle is called as class-2 lever.



Eg. : Screw driver, Bottle opener, Nut cracker, etc.

Characteristics of class-2 lever:

(i) Load is in between the effort and the fulcrum.

(ii) Mechanical advantage of lever is the ratio between effort arm and load arm.

(iii) Mechanical advantage is always more than one, because the effort arm is always longer than the load arm.

(iv) By moving the load towards the fulcrum, the load arm decreases and consequently the mechanical advantage increases.

(c) Class-3 Lever :

The fulcrum is at one end and the effort is applied between the fulcrum and the load.

Eg. : Hockey sticks, Tennis rackets, Forceps, Hair plucker, Fire tong etc.

Characteristics of class-3 lever:

(i) Effort is in between the fulcrum and the load.

$$(ii)\ \text{mechanical advantage} = \frac{\text{Effort arm}}{\text{Load arm}}$$

(iii) MA > 1 as the effort arm is always smaller than the load arm.

(iv) The class-3 lover is called speed multiplier as the load moves through a larger distance as compared to the effort.

3. A cook uses a 'fire tong' of length 35 cm to lift a piece of burning coal of mass 200g. If he applies his effort at a distance of 7 cm from the fulcrum, then the effort in SI unit is : [Take g = 10 ms^{-2}]

Sol. Length of fire tong = 35 cm

Load (Weight of coal) = 200 gwt = 2N

Effort arm = 7 cm, Laod arm = 35 cm

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

$$\Rightarrow Effort = \frac{Load\ (\text{Load arm})}{\text{Effort arm}} = \frac{2 \times 35}{7} = 10\ N$$

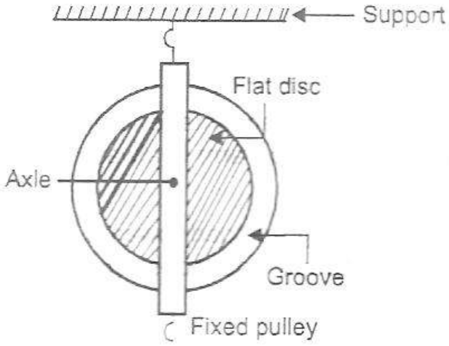
4. A uniform plank of sea-saw is 8m long and is supported in the centre. A boy weighing 50kgf sits at a distance of 2.5 m from the fulcrum. Where must another boy weighing 40kgf sit, so as to balance the plank?

Sol. Let the distance of 40 kgf boy from fulcrum is χ, then 50 kgf × 2.5 m = 40 kgf × χ

$$\therefore \chi = \frac{50 \times 2.5}{40} = 3.125m$$

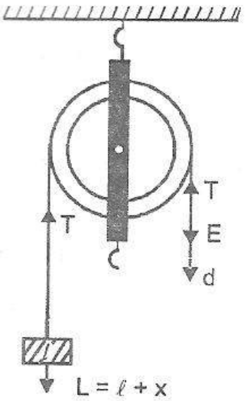
Pulley

Pulley is flat circular disc, having a groove in its edge and capable of rotating about a fixed point passing through its centre and is commonly called axis.



Single fixed Pulley system:

A pulley that is attached to a structure is called a fixed pulley.



Single fixed pulley system consists of a single pulley. It is attached to some high platform and around its groove passes a rope. One end of rope is attached to the load and the effort is applied at the other end.

Let ℓ be useful load lifted by an effort E, such that effort acts downward through a distance d. Let × be the load due to resistance and weight of pulley itself. If L is the total load lifted by pulley then :

L = ℓ ÷ x

When the pulley is in equilibrium, a tension T acts as shown in above figure.

$$\therefore L = T$$

E = T [When pulley is not rotating)

$$Mechanical\ advantage = \frac{Load}{Effort} = \frac{L}{E} = \frac{T}{T} = 1$$

When the effort acts through a distance d in the downward direction, load also maves through a distance d in the upward direction.

$$\therefore Velocity\ ratio = \frac{d}{d} = 1$$

$$\because Efficiency\ of\ pulley = \frac{MA}{VR} = \frac{1}{1} = 100\%$$

The mechanical advantage calculated above is ideal mechanical advantage as the load due to friction and movable parts of machine, is considered useful.

However, if we consider only useful load then:

$$\frac{L}{E} = 1$$

$$or\ \frac{\ell + x}{E} = 1 \{\because L = \ell + x\}$$

$$\frac{\ell}{E} = 1 - \frac{X}{E}$$

$$AMA = 1 - \frac{X}{E}$$

As $\frac{X}{E}$ has some positive value, therefore, actual mechanical advantage is less then one.

5. A single string system has 5 pulleys. If an effort of 50 kgf is required to raise a load of 150 kgf, then find the efficiency of the system.

Sol. Number of pulleys = 5 = velocity ratio (VR)

Effort = 50 kgf, Load = 150 kgf

We know, Mechanical advantage

$$(MA) = \frac{Load}{Effort} = \frac{150}{50} = 3$$

$$\%\ Efficiency\ , \eta = \frac{MA}{VR} \times 100 = \frac{3}{5} \times 100 = 60\%$$

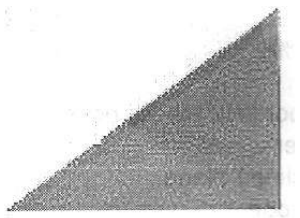
Wheel and Axle

A wheel and axle is a simple machine made up of two circular objects of different size. The axle (a small wheel) is attached to the center of a larger wheel. All wheels need an axle. The wheel and axle must move together to be a simple machine. A wheel and axle lift or move load.

Effort applied to the wheel turns the axle, or effort applied to the axle turns the wheel. They move together when effort is applied to the wheel, the wheel and axle spreads the force over a greater distance.

Inclined Plane

An inclined plane is a flat surface set at an angle (other than a right angle) against a horizontal surface.



Expression for Mechanical Advantage when effort acts parallel to the surface of Inclined Plane:

Let E be the effort applied along the inclined plane from B to A, when a load L rises up through a vertical height CA.

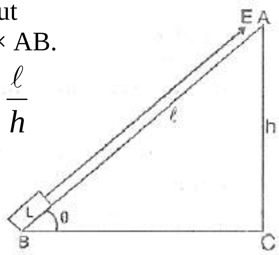
Work done on inclined plane (input) = E × AB.

Work done by inclined plane (output) = L × AC.

Output = Input

L × AC = E × AB.

$$\frac{L}{E} = \frac{AB}{AC} = \frac{\ell}{h}$$



$$\therefore MA = \frac{Length\ of\ inclined\ \ plane}{Height\ of\ \ plane} = \frac{\ell}{h}$$

The above expression is true only, if there is no friction on the surface of inclined plane.

Also, $MA = \frac{\ell}{h} = 1 \div \sin\theta = \frac{1}{Sin\,\theta}$

Thus, $MA = \frac{1}{Sin\,\theta}$

6. A frictionless inclined plane is 8 m long. A barrel of 400 N is raised up the inclined plane by an effort of 20 N. Calculate (;) the height through which barrel rises, (ii) gradient of inclination of inclined plane.

Sol. (i) Load (L) = 400 N

Effort (E) = 20 N

Length of inclined plane (ℓ) = 8 m

Height of inclined plane (h) = ?

$$\frac{L}{E} = \frac{\ell}{h}$$

$$\frac{400}{20} = \frac{8}{h} \qquad \Rightarrow h = \frac{20 \times 8}{400} = 0.4\,m$$

(ii) Gradient of inclination

$$\sin\theta = \frac{h}{\ell} = \frac{0.4}{8} = \frac{1}{20} = 1:20$$

7. A load of 20 kgf is to be pulled on an inclined plane making an angle of 30^0 with the horizontal.

Find The effort required.

Sol. Load = 20 kgf.

Angle of inclined plane, θ= 30^0

We know, Mechanical advantage.

$$MA = \frac{1}{\sin\theta} = \frac{1}{\sin 30^0} = 2$$

Also, $MA = \frac{Load}{Effort}$

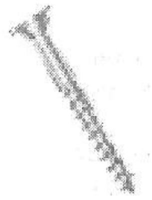
$$\Rightarrow effort = \frac{Load}{MA} = \frac{20}{2} = 10\,kgf$$

Wedge

The wedge is like an inclined plane. Actually, a wedge is two inclined plane joined together back to back. Examples of a wedge are an axe, nail, knife etc.

Screw

An inclined plane wrapped around a cylinder is another type of simple machine called the screw.



EXERCISE

1. To calculate mechanical advantage divide the resistance force by the :

(A) friction

(B) ideal mechanical advantage

(C) work

(D) effort force

2. A baseball bat would be an example of a :

(A) first order lever (B) second order lever

(C) third order lever (D) inclined plane

3. A pair of nut crackers is 20 cm long and when a nut is placed 2.5 cm from the hinge, a force of 2 kgf is sufficient to crack it. What force would be required to crack a similar nut if placed at a distance of 3.0 cm from the hinge?

(A) 2 kgf (B) 2.4 kgf

(C) 3 kgf (D) None of these

4. An Effort of 50 kgf is applied through a distance of 40 cm, if the efficiency of the machine is 90% and the load moves through a distance of 4 cm then the velocity ratio would be :

(A) 10 (B) 15

(C) 20 (D) 25

5. A pulley system consisting of a single string has a velocity ratio of 3 and an efficiency of 80% How many pulleys should be used ?

(A) 1 (B) 2

(C) 3 (D) 4

6. A 30 kg. boy is at a distance of 1.2 m from the fulcrum of a see-saw. How far from the fulcrum must a 20 kg girl sit in order to balance the see-saw ?
(A) 1.5 m (B) 1.8 m
(C) 2 m (D) 2.2 m

7. A third order lever has……………….in the middle.
(A) fulcrum (B) effort force
(C) resistance force (D) pivot point

8. What is an inclined plane wrapped around a cylinder?
(A) Lever (B) Screw
(C) Wedge (D) Wheel and axle

9. A sloping surface used to raise objects is called a/an:
(A) inclined plane (B) wedge
(C) Wheel and axle (D) screw

10. Wedge is a kind of :
(A) inclined plane (B) Lever
(C) Both (A) and (B) (D) None of these

11. A car develops a force of 500 N and climbs up a vertical distance of 200 m. If the load due to the car is 12500 N, the length of the road covered by the car would be :
(A) 2 km (B) 5 km
(C) 2.5 km (D) 4 km

12. A man of weight 60 kgwt, takes a body of mass 15 kg at a height 10 m on a building in 3 minutes. The efficiency of man is :
(A) 10% (B) 20%
(C) 30% (D) 40%

13. The door knob of the house is an example of :
(A) lever
(B) inclined plane
(C) wedge
(D) wheel and axle arrangement

14. Which of the following is not a function of a machine?
(A) To make our work convenient
(B) To enable us lift more load with less force
(C) To enable us make the measurement correctly
(D) To make our work faster

15. A beam balanced is an example of:
(A) inclined plane
(B) lever of first order
(C) lever of second order
(D) lever of third order

16. The proper care and maintenance of machines require:
(A) to make them good looking
(B) for preserving them for future
(C) for their efficient and longer use
(D) none of these

17. A force applied to a machine to do mechanical work is called :
(A) effort (B) load
(C) efficiency (D) output

ANSWER – KEY

SIMPLE MACHINE

Q.	1	2	3	4	5	6	7	8	9	10
A.	D	C	B	A	C	B	B	B	A	A
Q.	11	12	13	14	15	16	17			
A.	B	B	A	C	B	C	A			