

Machines – Summary Notes

- A machine is a device to overcome a large resistive force by applying a small force, or to gain speed or to gain speed or to change the direction and the point of application of the force.
- A machine does not work itself. When energy is supplied to it or work is done on it, the machine does some useful work.
- **Functions of a Machine**
 - It is used to multiply force, i.e., used as a force multiplier.
 - It makes a force applied at one point available at some other desired point.
 - It changes the direction of force applied.
 - It increases the speed.
- Energy supplied or work done on the machine by the effort is called input or work input.
- Energy obtained or work done by the machine on the load is called output or work output.
- For a perfect (an ideal) machine, Output = Input

But in any practical machine,

$$\text{Work Output} < \text{Work Input}$$

AS some of the energy is wasted in overcoming friction between different moving parts of the machines.

- **Terms Related to a Machine**

Load: The resistive force to be overcome by a machine is called load (L). The point where energy is obtained by overcome the load is called the load point.

Effort: The force applied on a machine to overcome the resistive force is called effort (E). The point at which the energy is supplied to the machine by the resistive force is called the effort point.

Mechanical Advantage: It is the ratio of the load (resistive force overcome by machine) to the effort (the force applied to the machine).

$$\text{Mechanical advantage (MA)} = \frac{\text{Load}}{\text{Effort}}$$

Since it is the ratio of two similar quantities, the mechanical advantage has no unit.

Velocity Ratio: It is the ratio of the distance travelled by the effort to the distance travelled by the load in the same interval of time. It can also be defined as the ratio of the velocity of effort to the velocity of load.

$$\text{Velocity ratio (VR)} = \frac{\text{Distance travelled by effort}}{\text{Distance travelled by load}}$$

$$\text{or Velocity} = \frac{\text{Velocity of effort}}{\text{Velocity of load}}$$

Since it is the ratio of two similar quantities, velocity ratio has no unit.

- **Efficiency:** It is the ratio of useful work done by a machine (work output) to the total work done on the machine (work input). It is usually expressed as a percentage. It has no unit.

$$\text{Efficiency } (\eta) = \frac{\text{Work Output}}{\text{Work Input}}$$

$$\text{or } (\eta) = \frac{\text{Work Output}}{\text{Work Input}} \times 100$$

The efficiency of an ideal machine is 100%. In practice, however, no machine is 100% efficient due to some reasons, such as:

- Smoothness in moving parts: The moving parts of a machine are not perfectly smooth.
- Elasticity of the string (if any): The string is not perfectly elastic.
- Rigidity of parts: The different parts are not perfectly rigid.
- Weight of moving parts: Moving parts of a machine are not weightless.
- **Relation between MA, VR and η :**

$$\text{MA} = \text{VR} \times \eta$$

$$\text{or } \eta = \frac{\text{MA}}{\text{VR}}$$

$$\text{or } \eta\% = \frac{\text{MA}}{\text{VR}} \times 100$$

For an ideal machine, the efficiency is equal to 1. So from the above formula, the mechanical advantage is equal to the velocity ratio (VR).

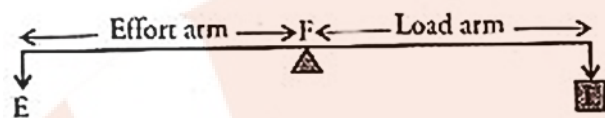
- In actual practice, the mechanical advantage for all machines is always less than the velocity ratio, and the efficiency is less than 1.
- **Lever:** A lever is a rigid bar, straight or bent, which is capable of rotating about a fixed point or axis of rotation, called its fulcrum.
- **Principle of a Lever:** For an ideal lever: Load $\times$ Load arm = Effort $\times$ Effort arm

$$\text{Mechanical advantage of a lever} = \frac{\text{Effort arm}}{\text{Load arm}}$$

This relation is known as the law of levers.

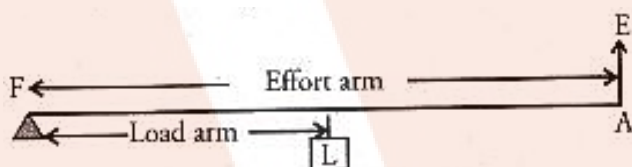
- **Class-I levers:** In this type of levers, the fulcrum (F), is in between the load (L) and the effort (E). For this type of levers, the mechanical advantage is greater than or less than or equal to 1.

Examples: A seesaw, a claw hammer, pliers, crowbar, a spade, a spoon used to open a lid, a handpump, etc.



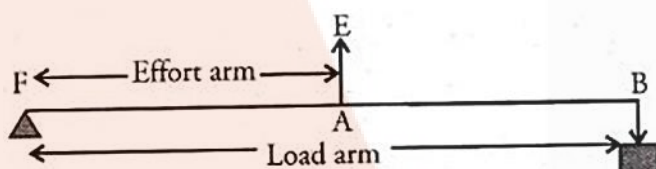
Class-II levers: In this type of levers, the load (L) is in between effort (E) and fulcrum (F). For this type of levers, the mechanical advantage is always greater than 1.

Examples: A nutcracker, a wheelbarrow, a foot bellows, a lemon squeezer, an oar of a boat, etc.



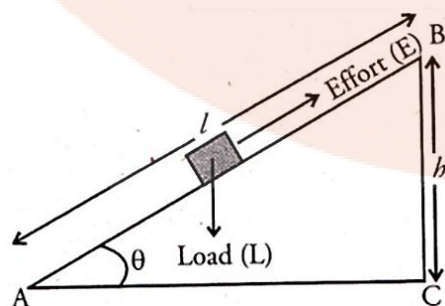
Class-III levers: In this type of levers, the effort (E) is in between load (L) and fulcrum (F). In this type of levers, the mechanical advantage is always less than 1.

Examples: Human forearms, fire tongs, foot treadle, fishing rods, etc.



- **Inclined Plane:** It is a sloping surface which behaves like a simple machine having mechanical advantage greater than 1.

Examples: Sloping planks that are used to load a truck, ramps or stairs on an inclined plane and roads on hills.



MA of an inclined plane = $\frac{1}{\sin \theta} = \frac{l}{h}$ where l = length of the inclined plane and h = height of the inclined plane.

- **Pulley:** It is a flat circular disc having a groove in its rim and is capable of revolving around a fixed point passing through its centre commonly called axle.
- **Single Fixed Pulley:** It consists of a single pulley fixed to a support attached to some high platform so that its axis of rotation remains fixed. In this pulley, the mechanical advantage is 1 for an ideal case. In this arrangement, there is no gain in mechanical advantage. It is used only to change the direction of the force applied.
- **Single Movable Pulley:** A pulley which can change its axis of rotation is called a movable pulley. In this pulley, the mechanical advantage is 2 for an ideal case. In this arrangement, the load can be lifted by applying an effort equal to half the load (in ideal situation).
- **Direction of Tension in the String:** When a load is supported by a string held in a support, the tension in the string acts equally in both the directions downward and upward.
- **Block and Tackle System (Combination of Pulleys):** In this system, two blocks of pulleys are used: one block (upper) is fixed to a rigid support and another is movable (lower). The load is always hung to the lower block. The number of pulleys used in the movable lower block is either equal to or one less than the number of pulleys in the upper fixed block.
 - In ideal case when the weight of the lower block is considered negligible, the mechanical advantage is equal to the number of pulleys in both the blocks.
 - In this system, the velocity ratio is always equal to the number of strands of tackle, or sections of the string, supporting the load.
- For greater efficiency, the pulleys in the lower block should be as light as possible and the friction in pulleys should be minimized by using lubricants.
- **Gears:** Gears are a set of toothed wheels working together to transfer rotational motion from one gear to the other.
- The gear wheel closer to the source of power is called the driver or driving gear. The gear wheel which receives motion from the driver is called the driven gear.
- If both the gears make:
 - External contact, they rotate in the opposite directions.
 - Internal contact, they rotate in the same direction.
- The ratio of the number of teeth on the driving wheel to that on the driven wheel is called gear ratio.

If N_A and N_B are the number of teeth in the driving gear and the driven gear respectively, then:

$$\text{Gear ratio} = \frac{N_A}{N_B}$$

- The ratio of the number of rotations per unit time of the driving gear to the number of rotations per unit time of driven gear is called velocity ratio (VR) of a pair of gears.

$$\text{VR} = \frac{\text{No. of rotations per unit of driving gear}}{\text{No. of rotations per unit of driven gear}}$$

$$\text{VR} = \frac{\text{Speed of rotation of driver } (n_A)}{\text{Speed of rotation of driven gear } (n_B)}$$

- Gain in speed = $\frac{\text{Speed of rotation } (n_B) \text{ of driven gear}}{\text{Speed of rotation } (n_A) \text{ of driver gear}}$
- Gain in torque (turning effect) = $\frac{N_B}{N_A}$, where N_A = Number of teeth in driving gear
 N_B = number of teeth in driven gear