Simple Machines

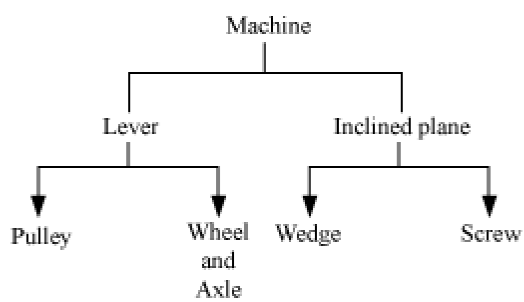
A machine is a device through which we can either overcome a large resistive force present at some point by applying a small force at a specific point in a desired direction or obtain a gain in speed.

These machines have been used for centuries not only to make work easy, but also to make it efficient and safe. As the name suggests, the construction of simple machines are not complicated and they are used for day-to-day simple works. The other characteristic feature of simple machines is that they do not convert energy from one form to another. Complicated machines such as bicycles and screwing machines are made up by combining two or more simple machines.

Simple machines can be broadly classified into two categories.

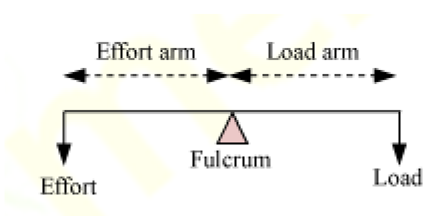
- Lever
- Inclined plane

These two types are further divided into sub-categories, as shown in the given diagram.



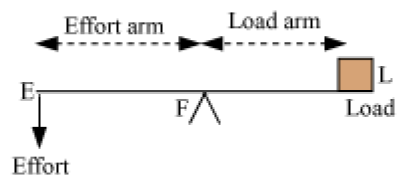
A lever is a rod which moves freely about a fixed point called the fulcrum.

Parts of a Lever

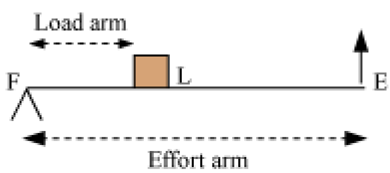


Levers are of three types depending on the position of the fulcrum, load and effort.

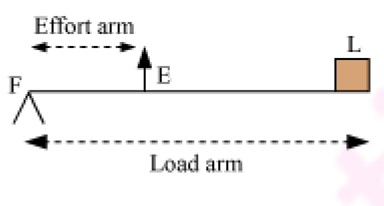
Lever of first order: Fulcrum is situated between the load and the effort. E.g., see-saw, crowbar, beam balance



Lever of second order: Load is situated between the fulcrum and the effort. E.g., mango-cutter, wheel barrow, nut cracker



Lever of third order: Effort is situated between load and the fulcrum. E.g, pair of tongs, fishing rod



An **inclined plane** provides a sloping surface over which heavy things can easily be lifted or rolled down.

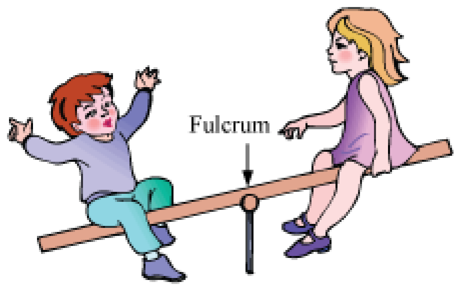
There are certain common terms that are used for almost every simple machine. Let us understand these terminologies first.

Machine Terminology

- **Effort —** The force applied to a machine to do mechanical work is called effort.

- **Load** — The force applied on an object by the machine is called load. When a crow bar is used for lifting an object, the weight of the object is the load, as that is the amount of force the simple machine has to apply to lift the object.

- **Fulcrum** — When a machine does mechanical work by turning on a point, the point of rotation is called the fulcrum. In the given picture, the middle point is the fulcrum of the seesaw.



- **Input Energy —** The work done on a machine or the energy supplied to a machine is called input energy.

- **Output Energy —** It is the work done by the machine or the energy obtained from the machine.

- **Principle of Ideal Machine —** In an ideal machine, the output energy is equal to the input energy. Therefore, mathematically we can express it as $\boxed{\text{Input} = \text{Output}}$. This is called the principle of machine.

- **Mechanical Advantage**— It is the ratio of the force obtained from the machine to that applied to the machine. In simple words, we can say $\boxed{\text{Mechanical Advantage} = \frac{\text{Load}}{\text{Effort}}}$

- **Velocity Ratio**— It is defined as the ratio of the displacement of effort to the displacement of load.

- $\text{Velocity of load } \left(V_L\right) = \frac{d_L}{t}$

  $\text{Velocity of effort } \left(V_E\right) = \frac{d_E}{t}$

  $\therefore \text{Velocity ratio} = \frac{V_E}{V_L} = \frac{d_E/t}{d_L/t} = \frac{d_E}{d_L}$

- **Efficiency —** The ratio of the energy obtained from the machine to that supplied to it is known as the efficiency of the machine. It is obtained by dividing the amount of work done by the machine by the work done on the machine.

$$\boxed{\text{Efficiency} = \frac{\text{Output Energy}}{\text{Input Energy}} = \frac{\text{Work done by the machine}}{\text{Work done to the machine}}}$$

- In an ideal machine, all the input energy is converted into output energy i.e., the efficiency of an ideal machine is 100%. In real life, no machine can have 100% efficiency because some amount of input energy always gets lost to overcome the friction between the different parts of the machine.

- **Relation Between Mechanical Advantage (M.A.) and Velocity Ratio (V.R.):** Assume a machine is doing a work in time *t* to overcome a load *L* by the application of effort *E*. Let the displacement of effort be d_E and of load be d_L.

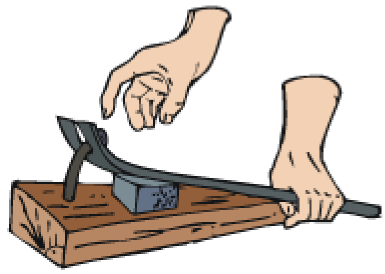
$$\text{Work input} = \text{Effort} \times \text{Displacement of effort} = E \times d_E$$
$$\text{Work output} = \text{Load} \times \text{Displacement of load} = L \times d_L$$
$$\eta = \frac{\text{work output}}{\text{work input}} = \frac{L \times d_L}{E \times d_E} = \frac{L}{E} \times \frac{1}{{}^{d_E}/_{d_L}}$$
$$\frac{L}{E} = M.A. \ and \ \frac{d_E}{d_L} = V.R.$$
$$\therefore \eta = \frac{M.A.}{V.R.}$$
$$M.A. = \eta \times V.R.$$
where, η is the efficiency the machine.

We must take care of machines to minimize its wear and tear. We can take care of machines by:

- Keeping them away from dust and moisture
- Lubricating them properly
- Painting iron parts

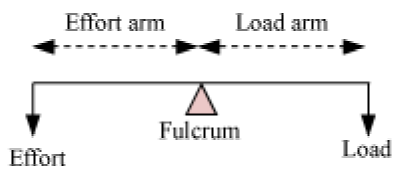
Levers

A lever is a simple machine. It consists of a rigid bar, which is capable of turning around a pivot, which is also called a fulcrum. Generally, we use a rod, which can rotate freely about the fulcrum.



For lever, we generally use two more terms apart from the general terms used for all the machines.

- **Load Arm**— It is the distance between the fulcrum and the point where the load is applied.
- **Effort Arm —** It is the distance between the fulcrum and the point where the effort is put.



The working of all levers is based on a common principle, which is called **principle of lever.**

Principle of lever

Load × Load arm = Effort × Effort arm

If we rearrange the equation, we obtain

$$\frac{\text{Load}}{\text{Effort}} = \frac{\text{Effort arm}}{\text{Load arm}} = \text{Mechanical Advantage}$$

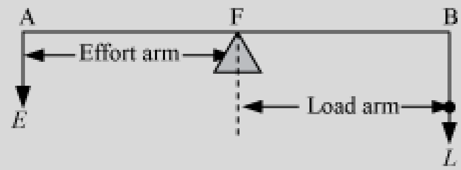
Therefore, the mechanical advantage of a lever is nothing but the ratio of the length of its effort arm to the load arm.

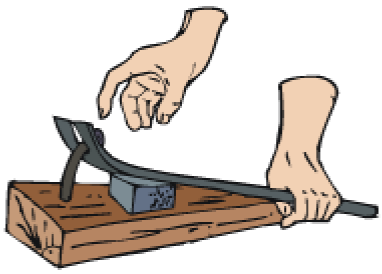
Different Types of Lever

Levers are classified into three types depending upon the positions of load, fulcrum, and effort.

Lever of first order

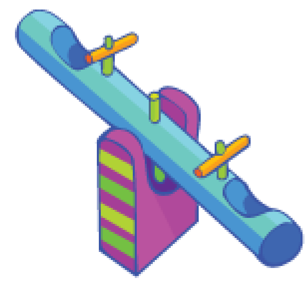
When the fulcrum is situated between load and effort, we call it a lever of first order. For example, beam balance, a crowbar, a seesaw.





Crowbar

Beam Balance



Seesaw

Mechanical advantage of a lever of first order

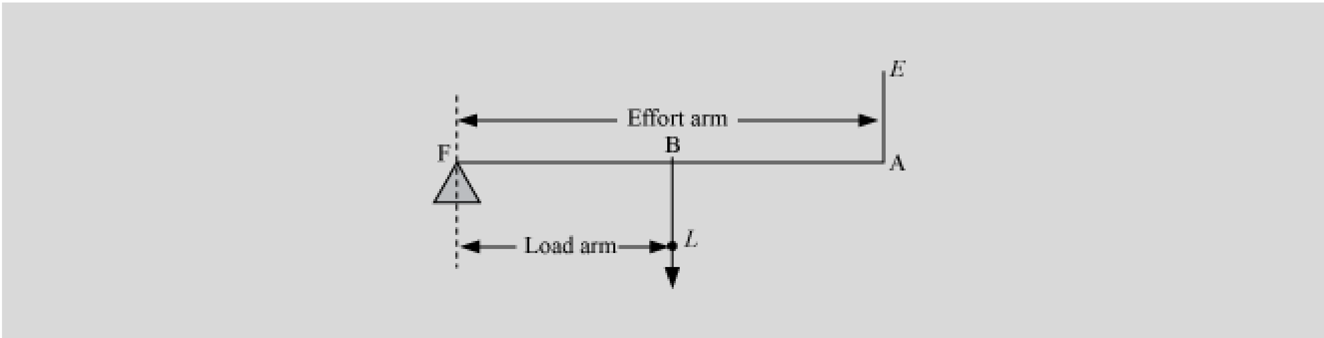
In case of First order lever Mechanical advantage can be equal to 1 or greater than or less than 1.It depends on the position of the fulcrum between effort arm and load arm. In case of levers of first order, we try to keep the load arm smaller than the effort arm i.e., **effort arm > load arm**. Therefore, a big load can be shifted by using small effort with the help of a lever of first order. As the effort arm is larger than the load arm,

$$\text{Mechanical Advantage} = \frac{\text{Effort arm}}{\text{Load arm}} > 1$$

When effort arm is less than load arm then mechanical advantage is less than 1.When Effort arm is equal to load arm then mechanical advantage is equal to 1.

Lever of second order

When the fulcrum and effort are situated at the two opposite ends of the lever and a load is placed in between them, we call it a lever of second order. For example, a nutcracker, a wheel-barrow, etc.



Wheel-Barrow

Nutcracker

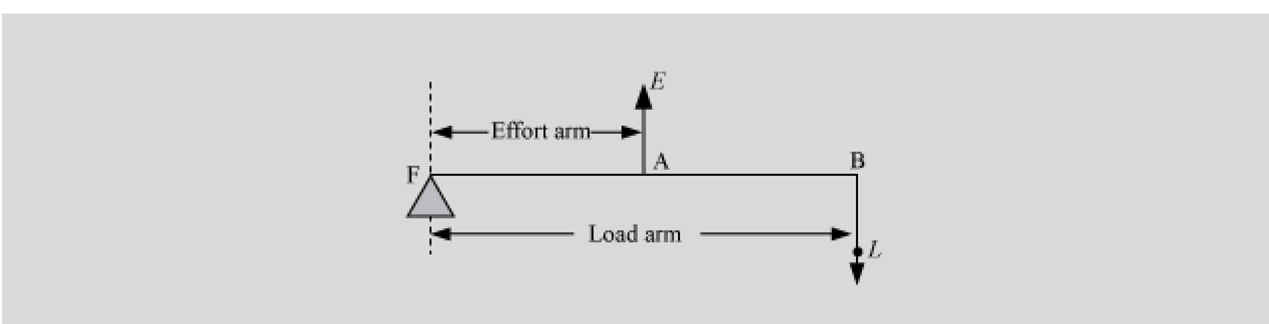
Mechanical advantage of a lever of second order

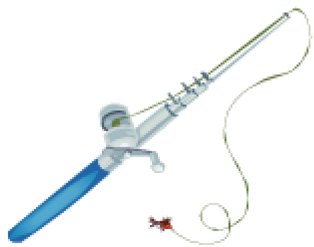
In case of levers of second order, the load arm is always smaller than the effort arm i.e., **effort arm > load arm**. Therefore, a big load can be shifted by using small effort with the help of a lever of second order.As the load arm is larger than the effort arm,

$$\text{Mechanical Advantage} = \frac{\text{Effort arm}}{\text{Load arm}} > 1$$

Lever of third order

When the fulcrum and load is situated at the opposite ends of the lever and an effort is applied somewhere between them, we call it a lever of third order. For example, a pair of tongs, a fishing rod, etc.





Fishing Rod

Tongs

Mechanical advantage of a lever of third order

In case of levers of third order, the effort arm is always smaller than the load arm i.e., **load arm > effort arm**. As the load arm is larger than the effort arm,

$$\text{Mechanical Advantage} = \frac{\text{Effort arm}}{\text{Load arm}} < 1$$

Although we do not obtain mechanical advantage from a lever of third order, we use it for several reasons.

- We use lever of third order where other two kinds of lever cannot be used.
- In case of lever of third order, we always obtain bigger displacement of load by the minimum displacement of the applied force. That is why we use a lever of third order in fishing rod.

Order of Levers found in Human Body

(1) First order lever: Nodding of head
(2) Second order lever: Raising the weight of the body on toes
(3) Third order lever: Raising a load by forearm

Can you say why we use a fire tong or tweezers although we do not get any mechanical advantages from them?

Pulley and Wheel–Axle

Pulley

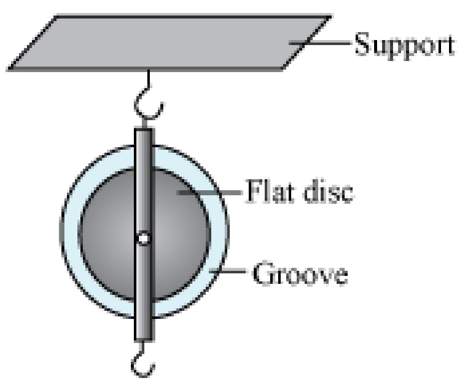
Nisha goes to her native village. There she sees women lifting water from a well. She notices that the rope, by which the women are drawing the water bucket, passes over a circular disc. Do you know why the circular disc is used?

The wheel has a groove on it. This keeps the rope passing over it from slipping. This rope is, in turn, tied to a bucket. Now, when the rope is pulled downwards, the rotation of the wheel brings the bucket upwards.

The whole arrangement is called pulley system. A pulley system is used for lifting heavy loads easily.

Do you know why we use pulley system to lift heavy load?

It is sometimes easier to apply force in one direction than the other. For example, it is always easier to apply force in the downward direction than in the upward direction. The primary purpose of a pulley is to change the direction of the force. It is made up of a circular disc or a wheel, which can rotate about a fixed axis that passes through its centre. The disc has a groove in its edge to provide better grip to the rope passed over it.



You must have seen at any construction site that large cranes have a pulley system fixed at the top of their long arms and some ropes are passed over them to lift heavy loads.

Mechanical Advantage of pulley

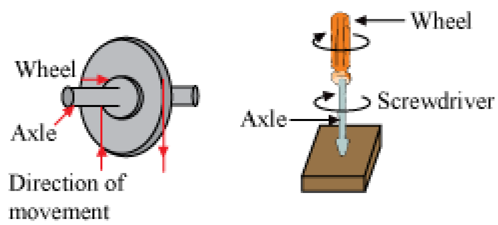
The effort applied is equal to the load to be lifted in case of an ideal pulley.

∴ Mechanical advantage = Load/Effort = 1

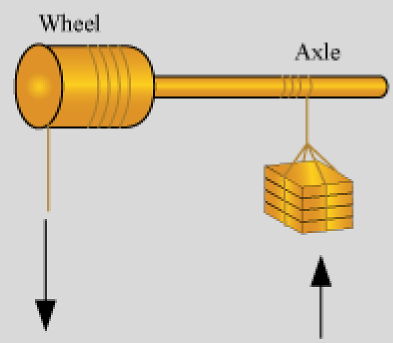
Whereas the mechanical advantage is less than 1 in case of an actual pulley which means that the effort is more than the load.

Wheel–Axle

As the name suggests, wheel and axle comprise of a wheel and a rod (axle) passes through the centre of the wheel. The wheel is attached to the rod in such a way that when we turn the wheel, the axle also turns. Let us take the example of a screw driver, which is a wheel and axle. The handle of the screw driver is the wheel and the rod is the axle. When we turn the wheel, the rod also turns. Screw driver always uses lesser force because the long handle gives more space to apply it. Other examples of wheel and axle are door knob, steering wheel of a car, etc.



You can also use wheel–axle to take water out from a well. In that case, two separate ropes are passed over the wheel and the axle, but the ropes are whirled in opposite turns. The bucket is attached to the rope that passes over the axle. To take water out of the well, you have to pull the rope whirled around the wheel. This, in turn, rotates the axle and the rope attached to it whirls around it. In this way, the water-filled bucket comes up.



Inclined Plane and Wedge

In hospitals, you must have seen that a slope is made besides the normal stairs. Do you know why the slope is made there?

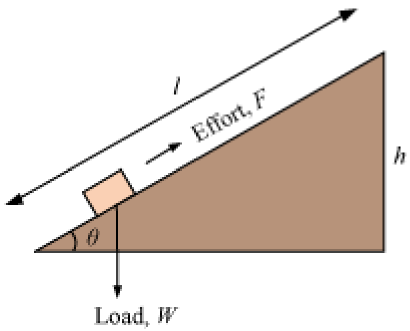
It is used for carrying patients in a wheel chair. The slope besides the stairs is an example of inclined plane. It is the simplest form of machine mainly used for lifting heavy load up to a small height. An inclined plane can be made up of a wooden plank or of concrete. One end of the plank is kept at a certain height and the other end is kept at the ground level so that the plank makes an angle with the ground. Now, some heavy load can be easily rolled over the plane of the plank.

Do you know?

You must have seen trucks full with heavy loads. Do you know how the trucks are loaded?

Mechanical Advantage of Inclined Plane

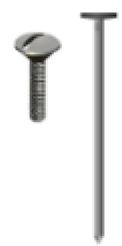
If you visit a hill station, then you will notice that the hill roads are winding. What is the reason behind that?



$$\text{Mechanical advantage} = \frac{\text{Length of the inclined plane}}{\text{Height of the inclined plane}} = \frac{l}{h}$$

You can easily make out from the equation that for a certain height, we can obtain a greater mechanical advantage by increasing the length of the inclined plane. Now, can you answer why the roads are made winding through hills?

Which one is easy, fitting a screw or hammering a nail in the wood?



A **screw** is a rotating (winding) inclined plane made up of iron strips. The threads on the screw are made in such a way that when fitted in an object, the screw goes in as if it is going down an inclined plane. Therefore, it is easy to fit a screw.

Do you know, how water is lifted from a low-lying area?

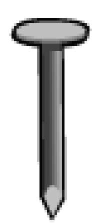
This task was achieved using the machine invented by the Greek scientist **Archimedes**. This machine was historically used to carry water from the low-lying surfaces. It was known as **Archimedes' Screw.** A circular rod enclosing a helix and inclined at an angle of 45o45o is fitted inside the pipe with one of its end in water. The water is pumped out by turning a screw-shaped surface inside the pipe.

Wedge

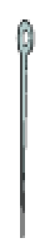
You must have seen that people use an axe to cut trees; or in a meat shop, the butcher uses a sharp-edged heavy knife to cut meat. These are all simple machines called wedges. Wedge is a device that has two inclined planes, which form a sharp or pointed edge. Wedges are mainly used for cutting or making a hole in an object. A force is applied on the other end, which is made blunt. As the area of the sharp edge is very small, it increases the pressure at the pointed edges and cut an object. Nail, needle are some other examples of wedge.

Knife

Axe



Nail



Needle

Maintenance of Machines

Machines have made our life simple and effortless, so we must take care of these machines to minimize its wear and tear. We can take care of machines by:

- keeping them away from dust and moisture
- lubricating them properly
- painting their iron parts