AN INITIATIVE
OF ONLINE EDUCATION
BY
LITTLE STAR HIGH SCHOOL BALLY

SUBJECT :PHYSICS
CLASS 10

FACULTY
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Physics

MACHINES

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DEFINATION OF MACHINES

1(d).1 MACHINE

It is our effort, always, to derive maximum advantage of the force available to us and to use it in a convenient way. The device which helps us to achieve it is called a *machine*. It is capable of doing the following jobs.

(i) *To change the direction of force applied*. To lift a weight upward, against gravity, we have to apply a force in vertically upward direction which is not convenient to us. By using a string and pulley we can lift the weight upward by pulling the string downward.

(ii) *To multiply force*. A crow bar can help us in lifting a greater weight than the force available to us.

(iii) *To apply the force at a more convenient place*. To raise coal in a grate we use a poker.

(iv) *To multiply speed*. By using a proper combination of gear system we can have the speed increased.

A machine is a device which enables us to change direction of force, to multiply force, to get the force applied at a convenient place and to multiply the speed of a given body.

Machine

A simple machine can

(i) change the direction of force applied

(ii) multiply force

(iii) make the force to act at a more convenient place

(iv) multiply speed.

An ideal machine is one which does not require any energy for its own working. This is possible only where there is no friction between different parts of the machine.

An ideal machine is only a theoretical concept.

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Machines made up of very few parts are simple machines.

Important terms related to simple machines

Effort : An effort is the force applied to a machine to do work.

Load : Load is the force that a machine exerts on a given body to be moved.

Fulcrum : A fixed point about which the machine can turn.

Mechanical advantage : The ratio of the load to the effort is called the mechanical advantage of the machine.

$$M.A. = \frac{\text{Load (L)}}{\text{Effort (E)}} \quad \text{or} \quad M.A. = \frac{\text{effort arm}}{\text{load arm}}$$

MA > 1 : If the effort needed by machines is less than the load. Machine works as force multiplier.

MA < 1 : If a machine needs an effort greater than the load. Machine gives gain in speed.

MA = 1 : If the effort needed is equal to the load. Machine is used to change the direction of effort as there is no gain in force or speed.

EFICIENCY OF A MACHINES

Efficiency of a machine is the **ratio of work output to the work input**. It is denoted by **η (eta).**

$$\eta = \frac{W_{output}}{W_{input}}$$

Efficiency is usually expressed as a percentage, $\eta = \frac{W_{output}}{W_{input}} \times 100\ \%$

Principle of a Machine

When energy is supplied to a machine by applying an effort, it does some useful work.
The point at which energy is supplied to a machine by applying effort, is called the **effort point**
The point where energy is obtained by overcoming the load, is called the **load point**.

Input energy : Work done at the effort point
= Effort × Displacement of the point of application of effort.

Output energy : Work done at the load point
= Load × Displacement of the point of application of the load.

Ideal Machine : An ideal machine is that in which there is no loss of energy in any manner.
The work output is equal to the work input.
i.e. the efficiency of an ideal machine = 100%

1(d).5 LEVER

A lever is a rigid bar straight or bent, which is capable of turning about a fixed point called fulcrum.

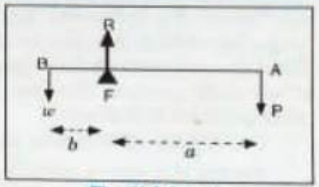

Fig. 1(d).2 Lever.

The points of application of effort (P) and load (W) may be situated on same side or on opposite sides of the fulcrum (F). A reaction R acts in a direction perpendicular to the rod at F (Fig. 1(d).2). When the lever is in equilibrium following conditions should be met with.

(i) Three forces W, P and R must be co-planer.

(ii) W, P and R should meet at a point or be parallel to each other.

(iii) Their resultant is zero.

(iv) Clockwise moment and anti-clockwise moments, about any point, must be equal.

Following terms will often be used in connection with study of lever.

(a) ***Effort arm (a)***. It is the perpendicular distance of the line of action of effort from the fulcrum. This is equal to AF in fig. (1(d).2).

(b) ***Load arm (b)***. It is the perpendicular distance of the line of action of resistance (or load) from the fulcrum. This is equal to BF in fig. (1(d).2).

Mechanical advantage of Lever

Take moments of W, P and R about F. Since line of action of passes through F, its moment about F is zero.

Moment of P about $F = P \times AF$ clockwise

Moment of W about $F = W \times BF$ anti-clockwise

While in equilibrium, $P \times AF = W \times BF$

$$\frac{W}{P} = \frac{AF}{BF} = \frac{a}{b} \quad ...(1)$$

Thus, mechanical advantage of a lever is equal to the ratio between effort arm to the load arm.

Case (i) *If* $a = b$ $\qquad \frac{W}{P} = 1 \quad$ *or* $\quad W = P$

In this case there is no multiplication of force. We can lift the load equal to the effort applied

Case (ii) *If* $a > b$, $W > P$

We can lift a greater load with a smaller effort.

Case (iii) *If* $a < b$, $W < P$

We shall be able to lift a smaller load with a greater effort applied.

1(d).6 CLASSIFICATION OF LEVER

Lever is classified into following three categories, depending upon the situation of the point of application of effort and load with respect to fulcrum.

(a) **Class I lever or Lever of first order**

In this type of lever, fulcrum F is situated inbetween the point of application of effort and load. Schematic diagram of class I lever is shown in fig. (1(d).2). In this case $a = b$ or $a > b$ or $a < b$. Therefore, the mechanical advantage can have any value.

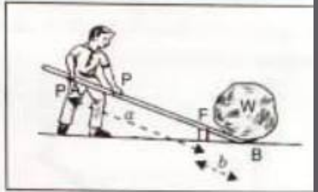

Fig. 1(d).3 A crow bar.

Examples. (i) ***A crow bar*** (fig. 1(d).3)

To move a heavy stone we, sometimes, place one end of a strong and long rod below the stone. Place a fulcrum F (a brick or a wedge) below the rod near this end. Apply an effort P at the free end. Greater the distance between F and the point of application of effort, lesser force will be required to move the stone.

LEVER

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(ii) ***A sea-saw*** (fig. 1(*d*).4).

It consists a flat wooden board supported on a fulcrum *F* at the centre. Two children sitting on the two sides of fulcrum can make it to move clockwise and anticlockwise alternatively. Weight of one child provides the load and that of the other provides the effort.

Fig. 1(*d*).4 Sea-saw

Fig. 1(*d*).5 A pair of scissors

(iii) ***A pair of scissors*** (fig. 1(*d*).5)

In case of a pair of scissors, the load *W* (paper to be cut) is placed inbetween the two blades. Effort *P* is applied with the help of a thumb and fingers at two points while the fulcrum *F* (placed where the two blades cross each other) is in the centre. As effort is applied, the two blades move in opposite directions, thus, cutting the paper into two parts.

(iv) ***Handle of a water pump*** (fig. 1(*d*).6)

In a water pump, piston is the load connected to one end of the handle, which is capable of turning about a point *F*. Effort *P* is applied to the second free end of the handle. Greater the distance (*a*) between the point of application of effort from *F*, smaller is the force required to work the system.

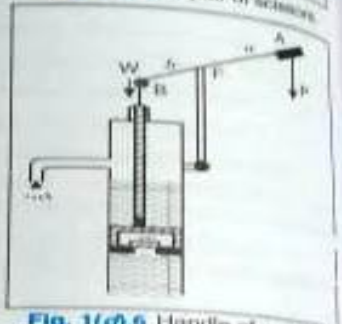

Fig. 1(*d*).6 Handle of a water pump.

(*b*) **Class II lever or Lever of second order**

In this type of lever, the point of application of load is situated inbetween fulcrum and point of application of effort. The schematic diagram of this type of lever is shown in fig. (1(*d*).7)

In such a case $a > b$. Therefore, mechanical advantage is always greater than 1.

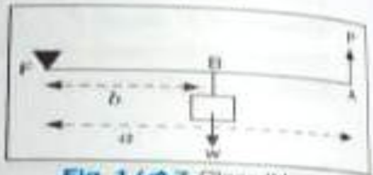

Fig. 1.(*d*).7 Class II lever.

Examples.

(i) ***Bottle opener*** (fig. 1(*d*).8)

One jaw which is in contact with the upper surface of the cap acts as fulcrum *F* while the second jaw placed below the lower edge of the cap experience the resistance (*W*). Effort *P* is applied upward at the free end. Thus, the load comes in between the fulcrum and the point of application of effort.

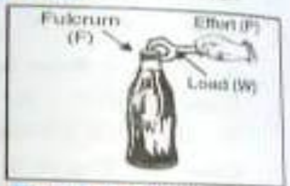

Fig. 1(*d*).8 Bottle opener

(ii) ***Using a bar to lift a load*** (fig. 1(*d*).9)

One end of the bar, which rests on a horizontal surface, acts as the fulcrum. As the free end is pulled upward, a body placed above the bar gets raised up. Here *W* acts vertically downward somewhere in between *F* and *P*.

(iii) ***A wheel barrow*** (fig. 1(*d*).10)

The moveable wheel acts as a fulcrum. The load is placed in the trolley, placed on two parallel beams while effort is applied at the two free ends. Thus, load *W* comes in between the point of application of effort and fulcrum.

(iv) ***A nut cracker*** (fig. 1(*d*).11)

The nut to be cracked is placed between the two jaws, while effort is applied at the two free ends of the two handles which are rivolted at the point *F*. It can be observed that handles are quite long so as to derive greater mechanical advantage.

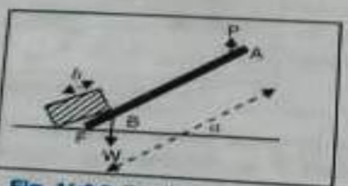

Fig. 1(*d*).9 Bar lifting a weight.

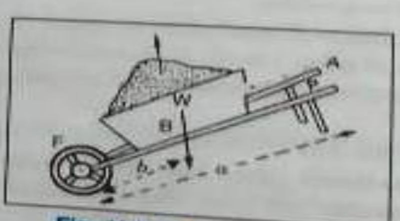

Fig. 1(*d*).10 A wheel barrow.

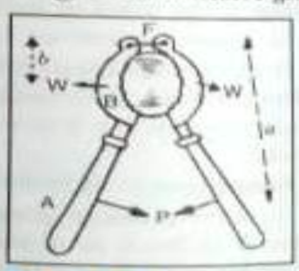

Fig. 1(*d*).11 Nut cracker.

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(c) Class III lever or Lever of third order

In this case, the point of application of effort is situated in between fulcrum and the point of application of load. The schematic diagram of this type of lever is shown in fig. 1(d).12.

Fig. 1(d).12 Class III lever.

Here $a < b$. Therefore, the mechanical advantage of class III lever is, always, less than one.

Examples (i) ***A pair of fire tongs*** (fig. 1(d).13)

A pair of tongs is held from within the middle while the burning coal (W) is held inbetween the two free ends of the tongs. The rear end where two limbs of the tongs join each other acts as a fulcrum F. Thus, point of application lies inbetween the load and fulcrum.

Fig. 1(d).13 Fire tongs

Fig. 1(d).14 The human forearm.

(ii) ***A human forearm*** (fig. 1(d).14)

Human arm is capable of turning about the elbow joint which acts a fulcrum. Load W is placed on hand while the effort P is applied by the muscles inbetween W and F.

(iii) ***A pair of forceps in a weight box*** (fig. 1(d).15).

This is similar to pair of fire tongs. The weight to be lifted is held inbetween the two free jaws while effort P is applied in the middle. The rear joint acts as a fulcrum.

(iv) ***Bread cutter*** (fig. 1(d).16).

As a bread is sliced into pieces, effort P acts downward at a point on the handle while load W acts on the front end of the cutter. The rear end of the hand which is under the hand acts as a fulcrum F.

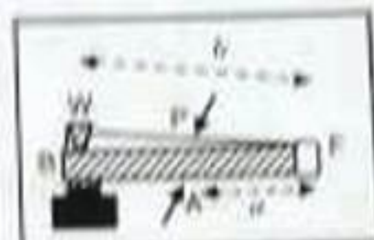


Fig. 1(d).15 Pair of forceps.

Fig. 1(d).16. A bread cutter.

PULLEY

1(d).7 PULLEY

It consists of a circular disc D of some thickness. It has a groove carved all along its circumference. The disc is mounted in a U-shaped frame F with the help of an axis passing through O. The frame is suspended from a rigid support S. A string passes through the groove. The two ends of the string hang on either side of the pulley.

A pulley or a combination of pulleys is employed to change the direction of effort or to multiply it. Accordingly, there is a variety of this type of machine.

1. A single fixed pulley. A single fixed pulley is shown in fig. (1(*d*).18). Let the string be pulled from A to B through a distance x in the down ward direction. As a result of this, the load W gets raised up from A' to B' through a distance x.

Input $= P \times x$; Output $= W \times x$

(i) For an ideal pulley

Output = input $\therefore$ $W \times x = P \times x$

$\therefore$ Mechanical advantage, $= \frac{W}{P} = 1$

Again, displacement of effort, $D = x$

displacement of load, $d = x$

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

Since efficiency, $E = \frac{M.A.}{V.R.} \times 100 = \frac{1}{1} \times 100$ or $E = 100\%$

(ii) Non-ideal pulley

If some of the energy is spent in overcoming friction, output will be less than the input

i.e. $W \times x < P \times x$ or $\frac{W}{P} < 1$

So, in case of a non-ideal single pulley

$M.A. < 1$; $V.R. = 1$

Since $M.A. = E \times V.R.$ $\therefore$ $E < 1$

or percentage efficiency $< 100\%$

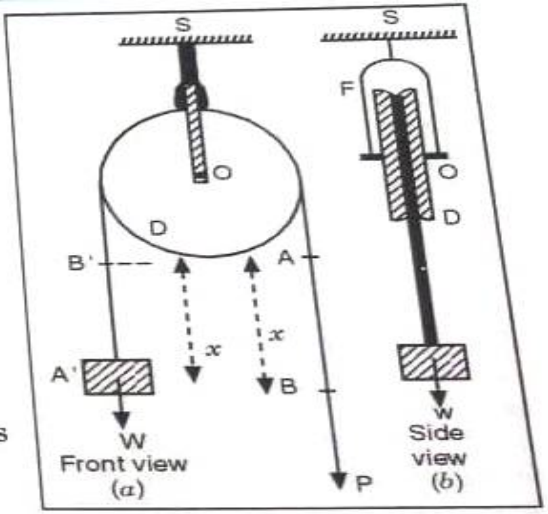


Fig. 1(*d*).18 Single fixed pulley.

2. A single movable pulley. **Case** (*i*) *If effort is applied in upward direction.* A single movable pulley P is supported by a string whose one end is fixed to a rigid support S while effort is applied at the other end (fig. 1(*d*).19). The load W is attached to the pulley P. Let the free end of the string be pulled from A to B through a distance x. This length is derived from two segments of the strings on either side of pulley. Thus, the pulley and hence the load W gets raised upward from A' to B' through a distance $x/2$.

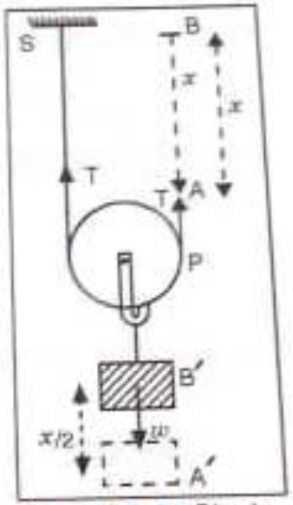


Fig. 1(*d*).19 Single movable pulley.

Input $= P \times x$; Out put $= (W + w) \times \dfrac{x}{2}$

Where w = weight of the movable pulley.

For an ideal machine, output = input

$$\therefore \quad (W + w) \times \frac{x}{2} = P \times x \qquad \therefore \quad \frac{W}{P} + \frac{w}{P} = 2$$

or Mechanical advantage, $\dfrac{W}{P} = 2 - \dfrac{w}{P}$

Displacement of effort, $D = x$

Displacement of load, $d = x/2$

$$\therefore \quad V.R. = \frac{D}{d} = \frac{x}{x/2} = 2; \quad \text{Efficiency,} \quad E = \frac{M.R.}{V.R.} = \frac{2 - \frac{w}{P}}{2} \times 100$$

If the weight of the pulley is very small, $\dfrac{w}{P}$ can be ignored.

$$M.A. = \frac{W}{P} = 2$$

$$V.R. = 2 \quad \text{and} \quad E = \frac{2}{2} \times 100 = 100\%$$

For non-ideal machine

Due to loss of energy against fraction, output < input

$$\therefore \quad M.A. < 2$$

$$V.R. = 2$$

$$E < 100\%$$

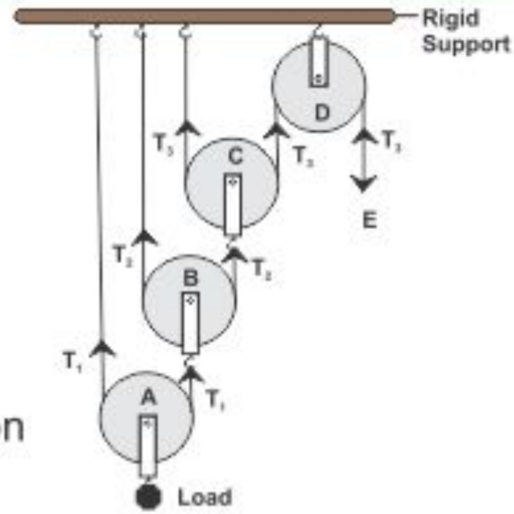
SURFING AID

For virtual experiment on simple machines-pulley reach webadress.
<http://webphysics.ph.msstate.edu/jc/library/4-7a/index.html>

COMBINATION OF PULLEY

Using one fixed pulley and other movable pulleys

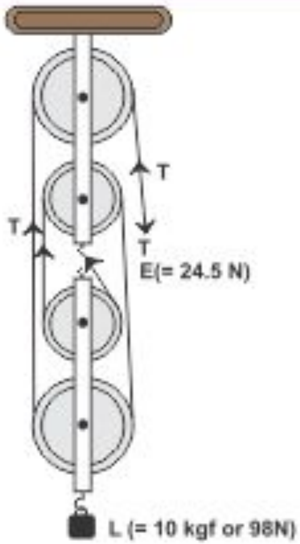
In this system there are n movable pulleys and one fixed pulley (e.g. in fig, 3 movable pulleys A, B, C and one fixed pulley D).



Formula for M.A. $= 2^n$ where n = number of movable
Velocity ratio V.R. $= 2^n$ pulleys with 1 fixed pulley

Efficiency = M.A. / V.R. = 1 or 100 % (for ideal situation)
In actual practice, the weight of the pulleys and string, and the friction between the bearings of the pulleys, both reduces the efficiency.

Using several fixed pulleys in two blocks - Block and tackle system



In this system of pulleys, two blocks of fixed pulleys are used.

One block (upper) having several fixed pulleys is fixed to a rigid support and the other block (lower) having several fixed pulleys is movable. This is called block and tackle arrangement.

The number of pulleys used in the movable lower block is either equal to or one less than the number of pulleys in the fixed upper block.

END