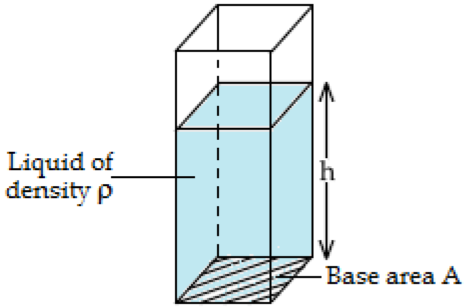
FINAL PART OF S2 PRESURE NOTES JUNE 2021

PRESSURE IN LIQUIDS

The weight of a liquid exerts pressure on the base of the container or on any object below the liquid surface.

Calculating pressure in liquids

Consider a liquid of mass m poured in a vessel to a height h, if the acceleration due to gravity is g and density of the liquid is ρ



The weight of the liquid on the base of the vessel will be given by:

w=mg

But m=V X ρ

W = V X ρ X g

Also V= (L X W) X h = A X h

$\therefore w = A \times h \times \rho \times g$

The pressure acting on the base will be given by

$\text{Pressure} = \frac{\text{Force}}{\text{Area}}$

Force = $w = A \times h \times \rho \times g$

$\text{Pressure} = \frac{A \times h \times \rho \times g}{A}$

Pressure = $h\rho g$

Pressure = height X density X gravity

Height must be in metres and density in kgm^{-3}

From the above expression, we can conclude that the pressure at any point in a liquid depends on the;

(i) Density of liquid

(ii) Height of a liquid column or depth below the liquid surface.

Examples

1. Water is poured in a vessel to a height of 0.4m. What pressure is exerted by the water at the base of vessel? If density of water =1000kgm^{-3}. g=10 ms^{-2}.

Pressure=$h\rho g$

P = 0.4 x 1000 x 10

P = 4000 Pa

2. What pressure is exerted by a column of mercury height 76cm density for mercury = 13600kgm^{-3}. Use g=10 ms^{-2}

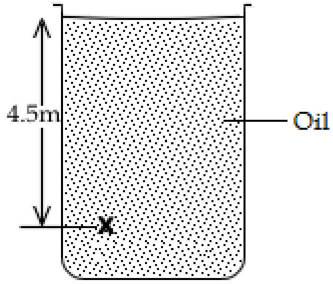
$h = \frac{76}{100} = 0.76\text{m}$

p=hpg

= 0.76 x 13600 x 10

P= **103360P**

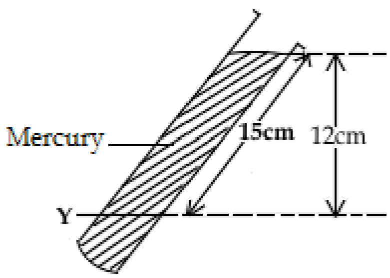
3. In the diagram calculate the pressure exerted by oil at point **x** if the density of oil is 800 kgm^{-3} use g = 10 ms^{-2}



p=hpg
h=4.5m
P=800kg/m^3
g=10 ms^{-2}
p=hpg
= 4.5 x 800 x 10
= 36000 Pa
= 3.6 x 10^4 Pa

Practice questions (skip five lines after each question)

1. In the diagram, the test tube contains mercury. What pressure is exerted by mercury at Y, use g=10 ms^{-2}



2. What will be the pressure at a point 50cm below the surface of;
(a) Mercury of density 13600kgm^{-3}?
(b) Oil of density 800kgm^{-3} ?
(c) seawater of density 1026kgm^{-3}
3. What pressure is acting on a diver at a depth of 10m below the surface of water?
4. Workout the pressure exerted by a column of 77cm of mercury of density 13600kgm^{-3}.

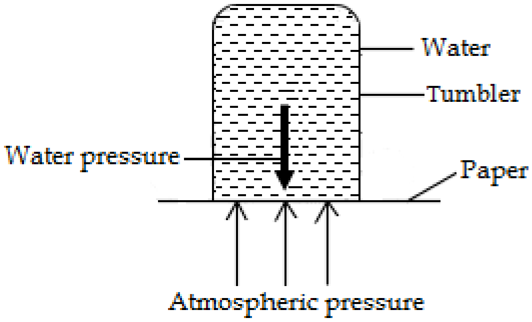
ATMOSPHERIC PRESSURE

This is the pressure exerted on the surface of the earth by the weight of air above it.

Experiments to show the existence of atmospheric pressure

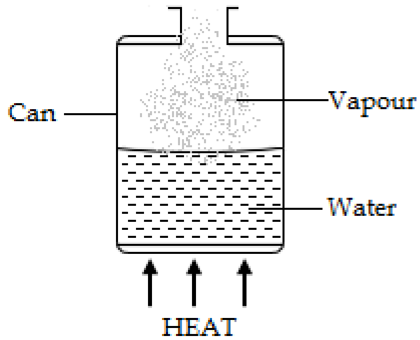
1. The tumbler experiment

A clean tumbler is filled with water to the brim. A plain clean piece of paper is then carefully placed on top of the tumbler to cover the water. With one hand placed on the paper and the other hand holding the tumbler, the tumbler is inverted and the hand holding the paper is removed.

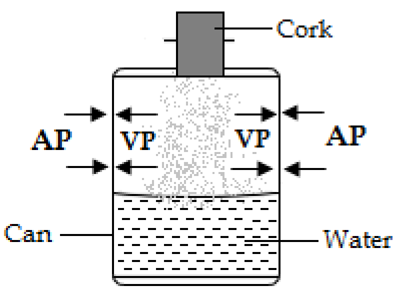


Observation: The water though supported by a thin paper does not pour.
Explanation: The atmospheric pressure acts on the paper and since it is greater than the water pressure, the water is supported and does not pour.

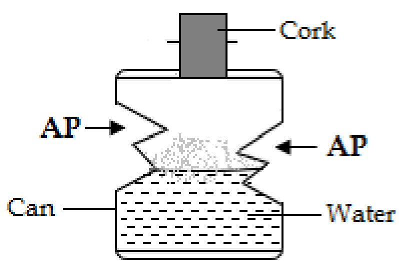
2. The crushing can experiment
Procedure
A little amount of Water is poured into a metallic can. The can is heated until the water boils.



The mouth of the can is fitted with a cork and the heating is immediately stopped. The steam in the can exerts pressure on the walls of the can which cancels out the atmospheric pressure exerted on the outside of the can.



Cold water is poured onto the can to condense the steam.
Observation
The can crushes inwards with a bang

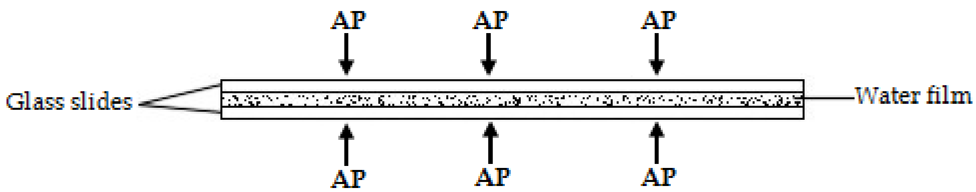


Explanation

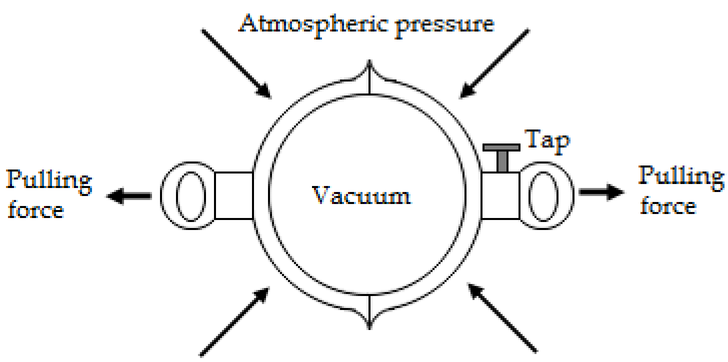
The cold water condenses steam creating a partial vacuum and a drop in pressure inside the can. The great atmospheric pressure pushes the walls of the container inwards with a great force making it crush with a bang.

3. Slide experiment

When two glass slides are pressed together with a water film between them, it is very difficult to separate the slides. The water drives out the air between the slides reducing the pressure, the greater atmospheric pressure then presses the two slides tightly together.



4. Magdeburg hemispheres



This is a pair of copper or brass hemispheres joined to form a hollow globe. When the air is extracted from the hemispheres leaving a vacuum inside the great pressure of the atmosphere prevents them from being pulled apart. When the air was readmitted the hemispheres fell apart.

Note: The hemispheres were named after the German city of *Magdeburg*, where they were invented.

MEASURING ATMOSPEHRIC PRESURE

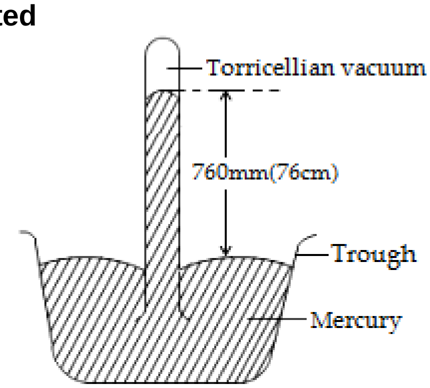
A barometer is an instrument used for measuring atmospheric pressure. There are various types of barometers they include;

(i) Simple mercury barometer
(ii) Aneroid barometer
(iii) Bourdon gauge.

SIMPLE MERCURY BAROMETER

How a simple mercury barometer is constructed

A thick walled glass tube about 1m long is filled with mercury and then inverted into a trough of mercury. The mercury falls until its height in the glass tube is about 760mm above the level of mercury in the trough outside the glass tube. At this point the pressure exerted by the mercury column in the glass tube is balanced by the atmospheric pressure exerted on the mercury surface in the trough.



Reading the atmospheric pressure

The pressure exerted by the mercury column in the glass tube is equal to value of the prevailing atmospheric pressure in millimetres of mercury (mmHg). At sea level the simple mercury barometer reads the standard atmospheric pressure of 760 mmHg.

The space above mercury in the glass tube is a vacuum called **Torricellian vacuum.**

This value standard atmospheric pressure in Pa or Nm^{-2} is computed using the expression **A.P = hρg**

Where: **AP**- Atmospheric pressure

$\rho = 13600kgm^{-3}$

$g = 10ms^{-2}$

$h = 0.76m$

Substituting:

$P = 13600 \times 10 \times 0.76$

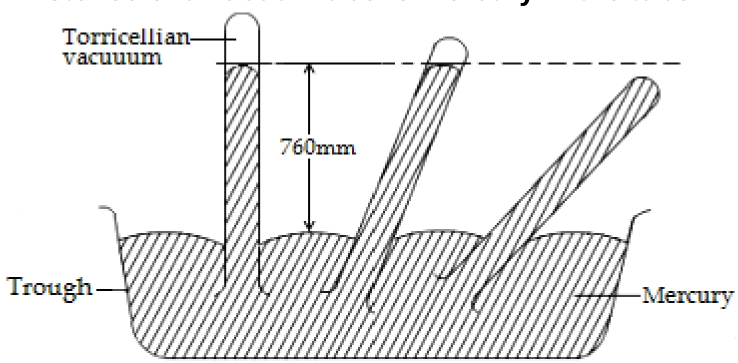
$P = 103360\ Nm^{-2}$

$\mathbf{P = 1.0336 \times 10^5\ Pa}$

Questions (Skip six lines after each question)

1. A barometer reads 76cmHg and 74.7cmHg at the bottom and top of a mountain respectively. If the density of air is $1.25kgm^{-3}$ and that of mercury is $13600kgm^{-3}$, find the height of the mountain.
2. A simple barometer is raised from sea level to a height of 1.32 km. given that the average density of air is 1.25 kgm^{-3}, density of mercury is 1.36×10^4 kgm^{-3} find the new length of the mercury column in the barometer.

Existence of a vacuum above mercury in the tube

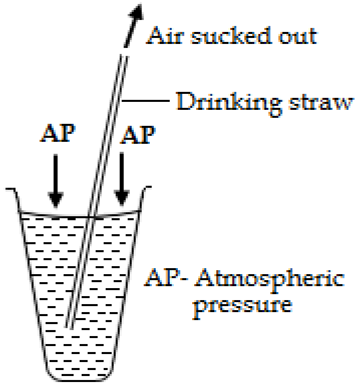


When the tube is tilted the mercury rises in the tube until the vertical height is 760mm. When the tube is tilted further until the top of the tube is less than 760 mm above the level in the dish, mercury completely fills the tube indicating that there is a vacuum above mercury. If there was air mercury would **NOT** completely fill the tube.

Applications of atmospheric pressure

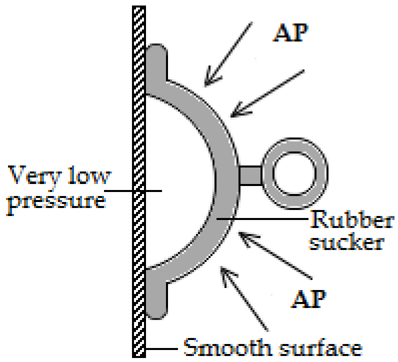
1. Drinking straw
2. Syringe
3. Rubber sucker
4. The siphon
5. Bicycle pump
6. Lift pump
7. Force pump

1. The drinking straw



Air is sucked out of the straw to reduce the pressure inside. Then atmospheric pressure acts on the liquid surface forcing it up the straw into the mouth.

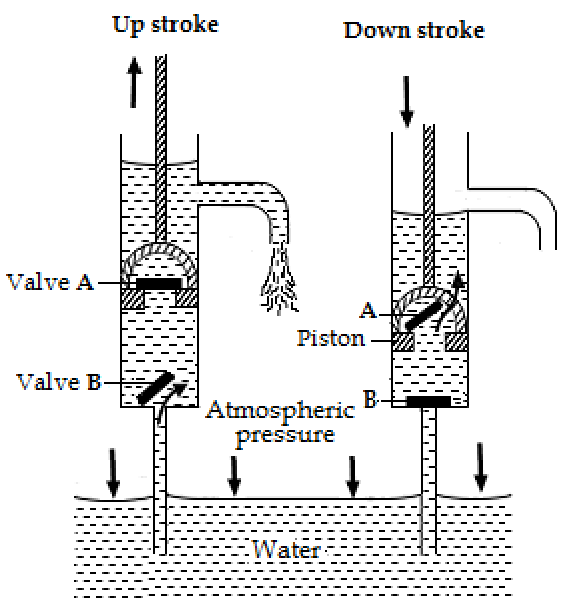
2. Rubber sucker



When the sucker is pushed against a flat surface air is forced out from underneath the sucker to reduce the pressure. The atmospheric pressure exerted on the outside holds the rubber sucker firmly in place. A rubber sucker is used for hanging objects onto surfaces e.g. cards, posters, decorations, balloons etc.

3. The lift pump

A lift pump is used to raise water from wells. It has two valves, a piston valve A and a barrel valve B. The valves open in turn during the upstroke and down stroke. The pump is started by first pouring water on top of the piston to prevent air leaking past it.



The up stroke

During the upstroke, valve A is closed and the pressure falls in the barrel below the piston. Atmospheric pressure acting on the surface of the water forces the water to rise through valve B into the barrel.

The down stroke

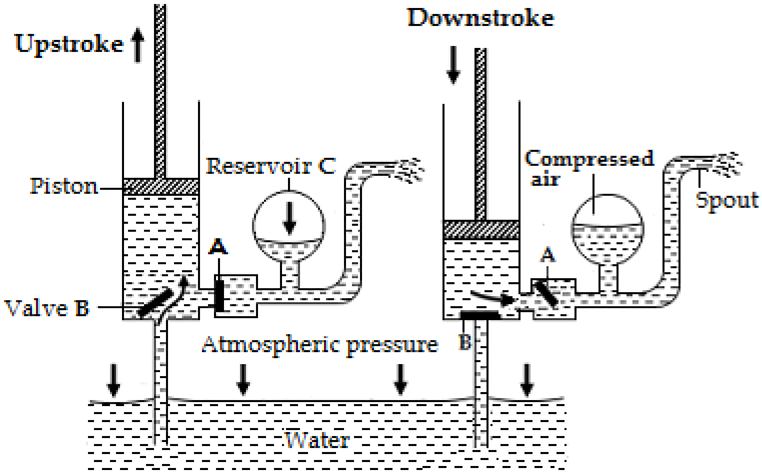
During the down stroke the valve B is closed by the weight water in the barrel. Due to the water pressure valve A opens and allows water to rise above the piston. On the next upstroke the water above the piston is lifted and pours out through the spout.

Limitations of the lift pump.

This pump can only be used to lift water to heights of up to 10 metres. This is the height of the column of water that can be supported by the atmospheric pressure.

4. The force pump

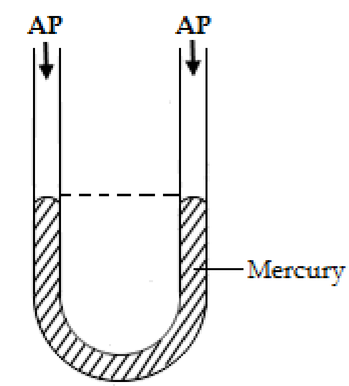
Force pumps can raise water to heights greater than 10 m if the pump itself is within 10 m of the water supply. The water is forced out through the spout by the pressure applied by the piston



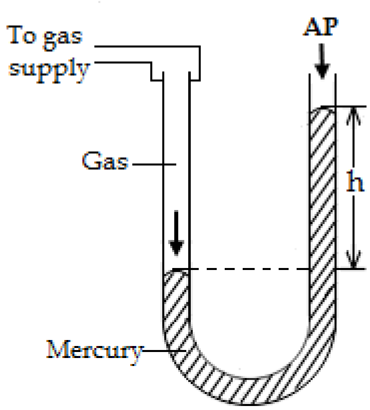
During the upstroke, valve A closes and atmospheric pressure forces water up into the barrel of the pump through valve B.

During the down stroke, valve B closes and water is forced through valve A into the reservoir C and also out of the spout. The air in C is compressed and on the next upstroke it expands and forces out water. This maintains a continuous supply of water.

MEASURING GAS PRESSURE USING A MANOMETER



A manometer is an instrument used to measure fluid pressure. It is made of a U-tube containing mercury for high pressure and water for low pressure. When both arms of the U-tube are open, the level of the liquid is the same due the atmospheric pressure exerted on the liquid surface.



When measuring gas pressure, one arm of the manometer is connected to a gas supply while the other arm is left open. The gas pressure forces the liquid to rise in the open arm. The pressure exerted by the liquid column in the open arm is pressure by which the gas pressure exceeds the atmospheric pressure.

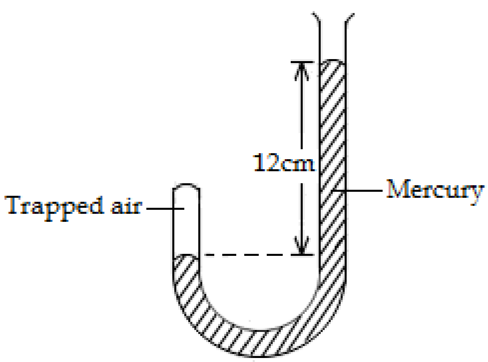
Excess pressure = h ρ g
Where h is the height of the liquid column above the level of the liquid in the arm connected to the gas supply. The height **h** is called the head of the mercury or water in case of a water manometer. The gas pressure is equal to the sum of excess pressure and the prevailing atmospheric pressure in similar units.
Gas Pressure = Excess Pressure + Atmospheric Pressure
The units of pressure can be expressed in terms of the height and type of the liquid column in the manometer, eg mmHg, cmHg, cmH_2O etc.

Examples

1. A mercury manometer reads 20 cm when connected to a gas supply. What is the excess pressure of the gas in mmHg, if the atmospheric pressure is 760 mmHg? What is the pressure of the gas?

G.P = E.P + A.P
$= (20 \times 10 + 760)\text{mmHg}$
G.P = 960 mmHg
GP = h ρ g
$= \frac{960}{1000} \times 13600 \times 10$
= 0.96 X 13600 X10
GP= 130560 Pa

2. Air is trapped by mercury in a J-tube as shown in the diagram below. The value of the prevailing atmospheric pressure is 760 mmHg. What is the pressure exerted by air in Pa?



Air pressure = EP + AP
$= (12 \times 10 + 760)\text{mmHg}$
P = 880 mmHg
P = h ρ g
$= \frac{880}{1000} \times 13600 \times 10$
= 0.88 X 13600 X10
P = 119680Pa

3. The reading of a mercury manometer is 85mm when the manometer is connected to the gas supply assuming the atmospheric pressure to be 755 mmHg what is the pressure of the gas in Nm^{-2}?

GP = EP + AP
$= (85 + 755)\text{mmHg}$
GP = 840mm Hg
GP = h ρ g
$= \frac{840}{1000} \times 13600 \times 10$
= 0.84 X 13600 X10
GP= 114240 Nm^{-2}

4. A water manometer connected to a gas mains reads 18 cm. calculate the;

(i) Pressure of the gas in excess of the atmospheric pressure in cmH_2O
EP = 18 cmH_2O
ii) Pressure of the gas in Pa (assume that atmospheric pressure is 760mmhg)

$$= \frac{18}{100} \times 1000 \times 10 + \frac{760}{1000} \times 13600 \times 10$$

= 1800 + 103360

=105160 Pa

5. A mercury manometer connected to a gas supply reads 15 cm. Calculate the pressure of the gas in excess of the atmospheric pressure and state clearly the units used. Find the pressure of the gas given that the atmospheric pressure is $1.01 X 10^5$ Pa

Excess pressure = h ρ g

$$= \frac{15}{100} \times 13600 \times 10$$

= 0.15 X 13600 X 10

=20400 Pa

GP = EP + AP

GP = $2.04 X 10^4 + 1.01 X 10^5$

= $(2.04 + 10.1) X 10^4$

= $1.214 X 10^5$ Pa

Exercise (Skip five lines after each question)

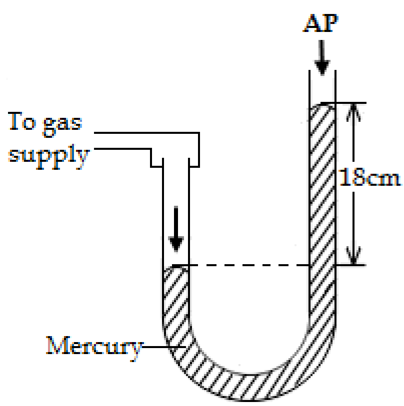
1. The reading of a certain liquid manometer connected to a gas supply is found to be 35 cm. The atmospheric pressure is 76 cmHg and the liquid in the manometer has a density of 1800 kgm-3

(a) What is the excess pressure in Pa?

(b) Work out the gas pressure in Nm^{-2}

2. A water manometer shows a difference in level of 12 cm when connected to a laboratory gas supply. Calculate the pressure exerted by the gas supply. (AP=760 mmHg).

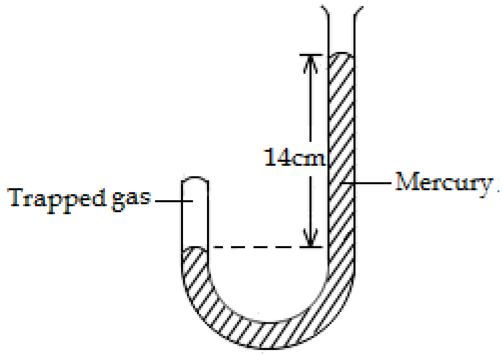
3. The diagram below shows a mercury manometer connected to a gas supply



(a)What is the excess pressure in terms of the head of mercury?

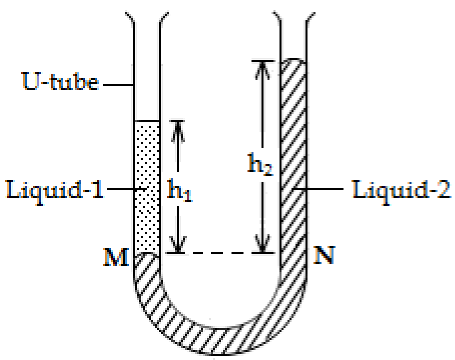
(b) If the atmospheric pressure is 754 mmHg calculate the pressure of the gas.

4. A gas is trapped by mercury in a J-tube as shown in the diagram below. The value of the prevailing atmospheric pressure is 750 mmHg. What is the pressure exerted by gas in Pa?



Comparing densities of two liquids using a u-tube

When two immiscible liquids are poured in a U-tube they form a layer separating them and each liquid rises to its own level in each arm of the U-tube. The pressure is the same along the same horizontal level in both liquid columns. By measuring the heights h_1 and h_2 of the liquid columns you can compare the densities ρ_1 and ρ_2 of the two liquids.



From liquid pressure = **h ρ g**

Pressure at a point M in liquid-1 = $h_1\rho_1 g$

Pressure at a point N in liquid-2 = $h_2\rho_2 g$

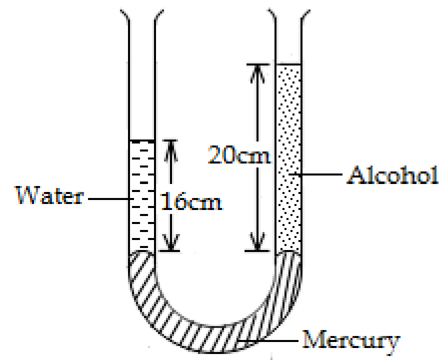
The pressure at M is equal to the pressure at N ie, $h_1\rho_1 g = h_2\rho_2 g$

$$\frac{\rho_1}{\rho_2} = \frac{h_2}{h_1}$$

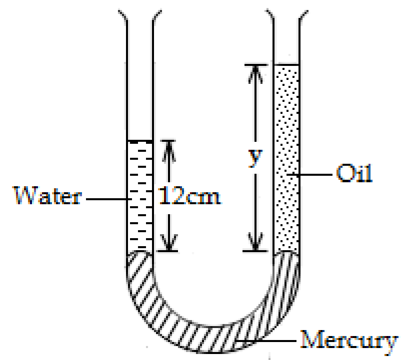
Examples (Skip five lines after each question)

1. In a U-tube, the bottom of a 12 cm liquid column in the left arm is at the same level with a point 16cm below the surface of water in the right arm of the U-tube. Calculate the density of the liquid given that the density of water is 1000 kgm^{-3}.

2. The U-tube shown in the diagram below contains water, mercury and alcohol. The level of mercury in the arms of the manometer is the same. Determine the density of alcohol. (Density of water is 1000 kgm^{-3})

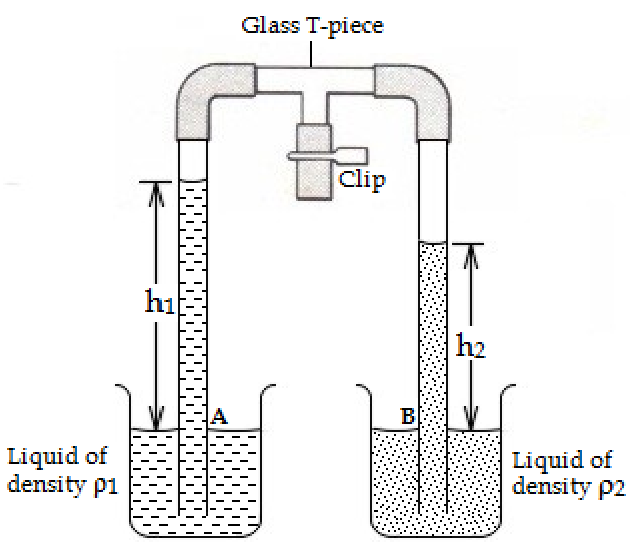


3. A U-tube contains water, mercury and oil of density 890 kgm^{-3} as shown in the diagram below. Using the indicated measurements calculate the height y of the oil column.



Comparing densities of two liquids using Hare's apparatus

The apparatus consists of two vertical wide-bore glass tubes connected at the top by a glass T-piece. These tubes dip into beakers containing the two liquids of densities ρ_1 and ρ_2



Air is sucked out of the tubes through the centre limb of the T-piece to reduce pressure inside and the clip is closed. The atmospheric pressure pushes the liquids up the tubes. The liquids rise until the pressures exerted at the base of each column are each equal to atmospheric pressure.

The Pressure at A is equal to the Pressure at B

$h_1\rho_1 g = h_2\rho_2 g$

$$\frac{\rho_1}{\rho_2} = \frac{h_2}{h_1}$$

Note: The advantage of using Hare's apparatus over a U-tube is that miscible liquids can also be used.

S2 PHYSICS NOTES JUNE 2021

MACHINES

A machine is device that simplifies work.

In a machine, an effort applied at one point is used to overcome a big load at another point.

Simple machines which are divided into seven categories;

- The lever.
- Pulleys
- Wheel and axle
- Inclined plane
- Screw
- Gear
- Wedge

Definitions

Mechanical Advantage (M.A)

Mechanical Advantage of a machine is the ratio of load to effort.

$$\text{Mechanical advantage} = \frac{\text{Load}}{\text{Effort}}$$

$$\text{M.A} = \frac{\text{L}}{\text{E}}$$

M.A has no units because it is ratio of similar qualities.

If M.A is greater than 1, we can use such a machine to move a load using a smaller effort.

If the M.A is less than 1, the effort needed will be greater than the load.

VELOCITY RATIO (V.R)

It is defined as the ratio of the distance moved by the effort to the distance moved by the load in the same time.

$$\text{V.R} = \frac{\text{Distance effort moves}}{\text{Distance load moves in the same time}}$$

Velocity ratio has no units

If a machine has a large velocity ratio, then a small effort moves a longer distance.

If two machines have velocity ratios VR_1 and VR_2 the resultant velocity ratio is

$VR = VR_1 \text{ X } VR_2$

EFFICIENCY OF A MACHINE

The efficiency of a machine is the ratio of work output to work input expressed as a percentage.

$$\text{Efficiency} = \frac{\text{Work out put}}{\text{Work input}} \times 100\%$$

Efficiency is represented by a Greek letter **η (eta)**

Note: (i) Work done by the effort is the work input.

(ii)Work done on the load is the work output. This is the useful work done by the machine.

Definitions

Work input is the product of the effort and the distance moved by the effort.

Work output is the product of the load and the distance moved by load.

$$\text{Efficiency}, \eta = \frac{\text{L} \times \text{d}_\text{l}}{\text{E} \times \text{d}_\text{e}} \text{X}100\%$$

Where L – Load

E – Effort

d_l - distance moved by load

d_e - distance moved by the effort

Note: A machine cannot be 100% efficient because;
(i) Part of the effort is used to overcome friction in the movable parts of the machine
(ii) Part of the effort is used to lift the movable parts of the machine which also have weight.
Note: The efficiency of a machine is the ratio of the useful work done by the machine to the total work put into the machine expressed as a percentage.

Examples

1. A load of 600N is lifted through a distance of 1m by an effort of 200N moving through a distance of 4m. Calculate the,
   (i) Mechanical advantage.
   (ii)Velocity ratio
   (iii) Efficiency

(i)

$$\mathrm{M.A} = \frac{\mathrm{L}}{\mathrm{E}} = \frac{600}{200} = 3$$

M.A = 3

(ii)

$$\mathrm{V.R} = \frac{\text{Distance moved by effort}}{\text{Distance moved by load in the same time.}}$$

$$= \frac{4}{1}$$

V.R = 4

(iii) $\eta = \frac{\text{Work output}}{\text{Work input}} \text{x } 100\%$

Work output = Load x distance moved by load

Work input = Effort x distance moved by effort

$$\eta = \frac{600 \text{ x}1}{200 \text{ x } 4} \text{ x } 100\%$$

$$= \frac{600}{800} \times 100\%$$

η = 75%

2. A simple machine with a mechanical advantage of 4 is used to raise a load of 500N through a distance of 5m if the effort moves a distance of 25m. Calculate the,

(i) Effort.

$$\mathrm{M.A} = \frac{\mathrm{L}}{\mathrm{E}}$$

$$4 = \frac{500}{\mathrm{E}}$$

$$\mathrm{E} = \frac{500}{4} = \mathbf{125N}$$

(ii) Velocity ratio

$$\mathrm{V.R} = \frac{\mathrm{de}}{\mathrm{dl}}$$

$$\mathrm{V.R} = \frac{25}{5} = \mathbf{5}$$

(iii) Efficiency of the machine.

$$\eta = \frac{\text{Work Output}}{\text{Work Input}} X100$$

$$= \frac{500 \text{ X } 5}{125 \text{ X } 25} \times 100\%$$

$$= \frac{2500}{3125} \times 100$$

η = 80%

Expression for Efficiency (η), mechanical advantage (M.A) and Velocity Ratio (V.R)

$$\text{Efficiency} = \frac{\text{Mechanical Advantage}}{\text{Velocity Ratio}} \times 100$$

$$\boldsymbol{\eta} = \frac{\mathbf{M.A}}{\mathbf{V.R}} \times \mathbf{100\%}$$

Note: This is an expression used to calculate efficiency only. It MUST not be used as a definition.

EXAMPLES

1. In a certain machine of velocity ratio 5 a load of weight 200N is raised by an effort of 50N. What is the efficiency of the machine?

V.R = 5

$$\text{M.A} = \frac{L}{E} = \frac{200}{50} = 4$$

$$\eta = \frac{\text{M.A}}{\text{V.R}} \times 100\%$$

$$\eta = \frac{4}{5} \times 100\%$$

η = 80%

2. A machine of velocity ratio 3 has an efficiency of 80%. If the machine is used to lift a load of 240N, calculate the,

(i) M.A

$$\eta = \frac{\text{M.A}}{\text{V.R}} \times 100\%$$

$$80 = \frac{\text{M.A}}{3} \times 100\%$$

$$\text{M.A} = \frac{80 \text{ X } 3}{100}$$

$$= \frac{240}{100}$$

M.A = 2.4

(ii) Effort required

(i) V.R = 3, E =80%

(ii) M.A = 2.4, Load = 240N

$$\text{M.A} = \frac{L}{E}$$

$$2.4 = \frac{240}{E}$$

$$E = \frac{240}{2.4} = \mathbf{100N}$$

3. In a certain machine an effort of 10N is used to lift a load through 1m if the efficiency is 75%. Given that the V.R is 4 calculate the load

E = 10N, η=75%, V.R = 4, dl = 1m

$$\eta = \frac{\text{M.A}}{\text{V.R}} \times 100\%$$

$$75 = \frac{\text{M.A}}{4} \times 100\%$$

$$\text{M.A} = \frac{75 \text{ X } 4}{100} = \frac{300}{100}$$

M.A = 3

$$M.A = \frac{L}{E}$$

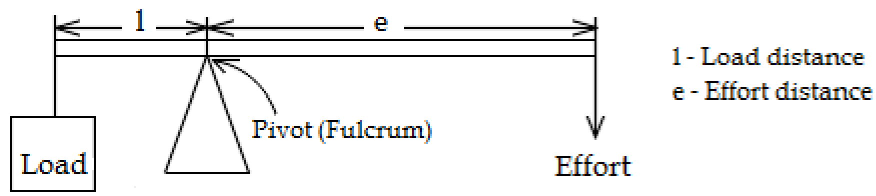
$$3 = \frac{L}{10}$$

L = 3 x 10

L = 30N

THE LEVER

The lever is the most common simple machine. It is any device which can turn about a point called the pivot or fulcrum. The distance of the effort from the pivot is called the effort distance while the distance of the load from the pivot is the load distance.



The principle of the lever

A small effort can be used to overcome a big load if the small effort is further away from the pivot than a big load is from the pivot.

This illustrates the principle of the lever which states that;

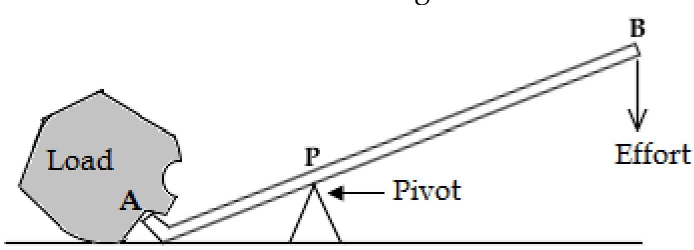
Effort x Effort distance = load x load distance.

The mechanical advantage of the lever is calculated from;

$$M.A = \frac{\text{Load}}{\text{Effort}} = \frac{\text{Effort distance}}{\text{Load distance}}$$

Examples

1. A crow bar is used to lift a load as shown in the diagram below. Given AP = 15 cm and PB = 93 cm that find the mechanical advantage.



$$M.A = \frac{\text{Effort distance}}{\text{load distance}}$$

$$= \frac{93\text{cm}}{15\text{cm}} = 6.2$$

2. A man uses a crow bar 1.5m long to lift a rock of weight 600N if the pivot (fulcrum) is 0.5m from the end of the bar touching the load. How much effort must the man apply?

$$M.A = \frac{1M}{0.5M}$$

$$\frac{L}{E} = \frac{1m}{0.5m}$$

$$\frac{600N}{E} = \frac{1m}{0.5m}$$

$$E = \frac{600N \times 0.5}{1}$$

E = 300N

VELOCITY RATIO OF A LEVER

$$V.R = \frac{\text{Distance moved by effort}}{\text{Distance moved by the load}}$$

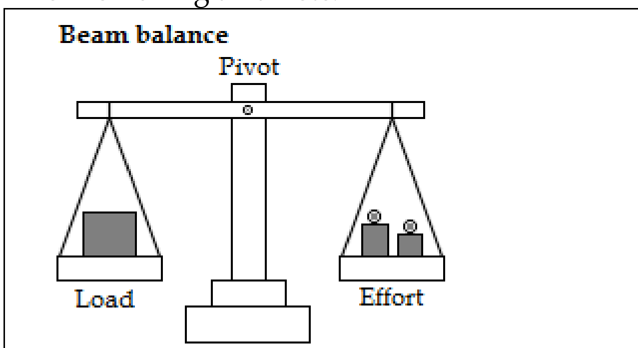
$$V.R = \frac{d_e}{d_l}$$

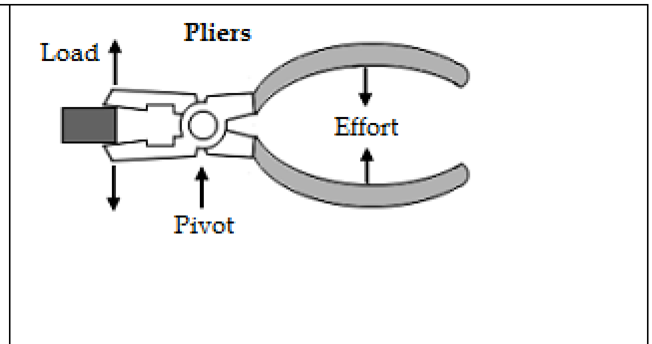
Note: The mechanical advantage of a lever is the same as its velocity ratio provided that the friction at the pivot is negligible.

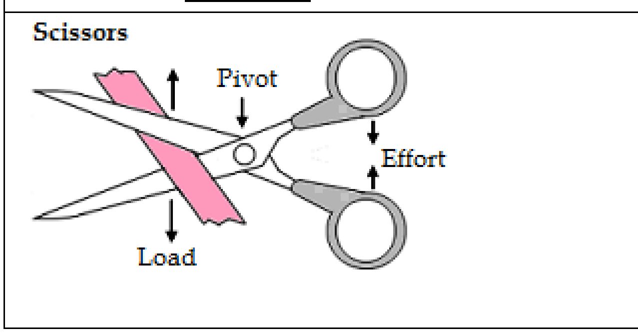
THE THREE CLASSES OF LEVERS

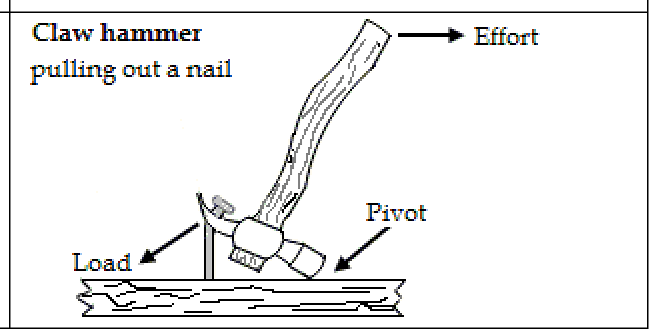
First class levers

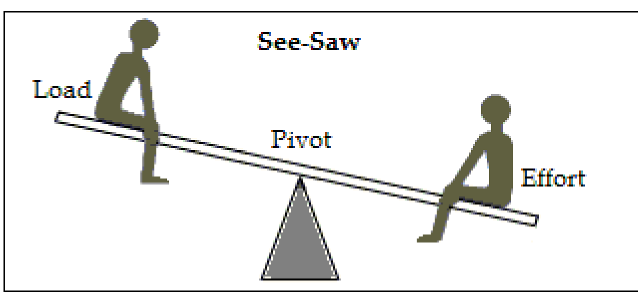
First (1st) class levers have the pivot between the effort and load.
For a greater M.A. the effort distance should be greater than the load distance. Examples of the first class levers include; beam balance, pair of pliers, pair of scissors, see-saw, crowbar, claw hammer when removing a nail etc.

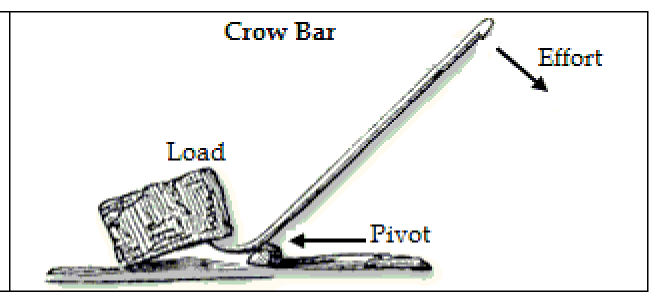






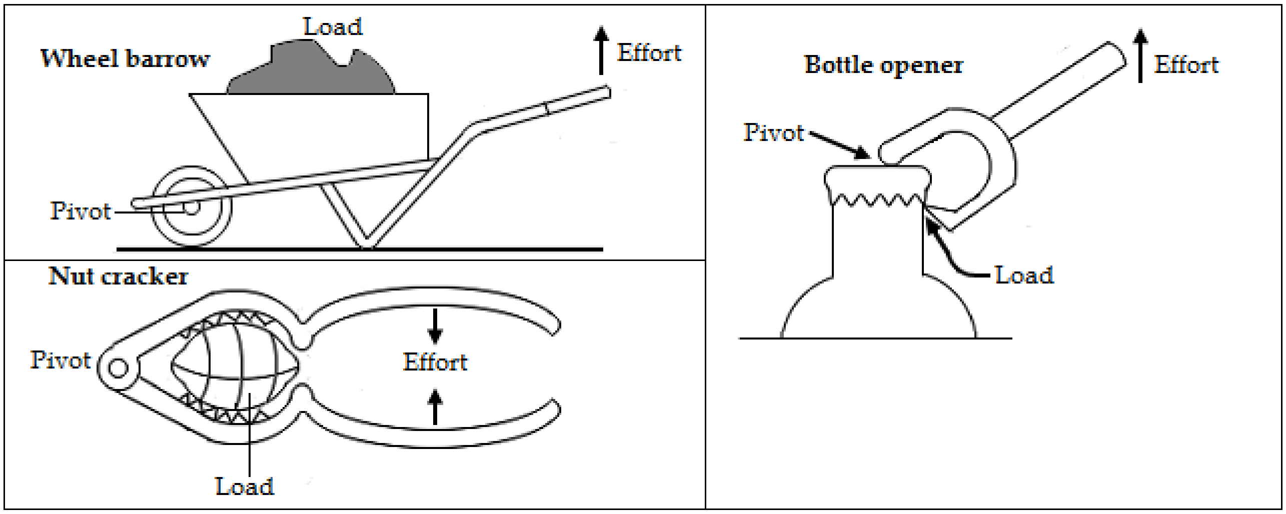






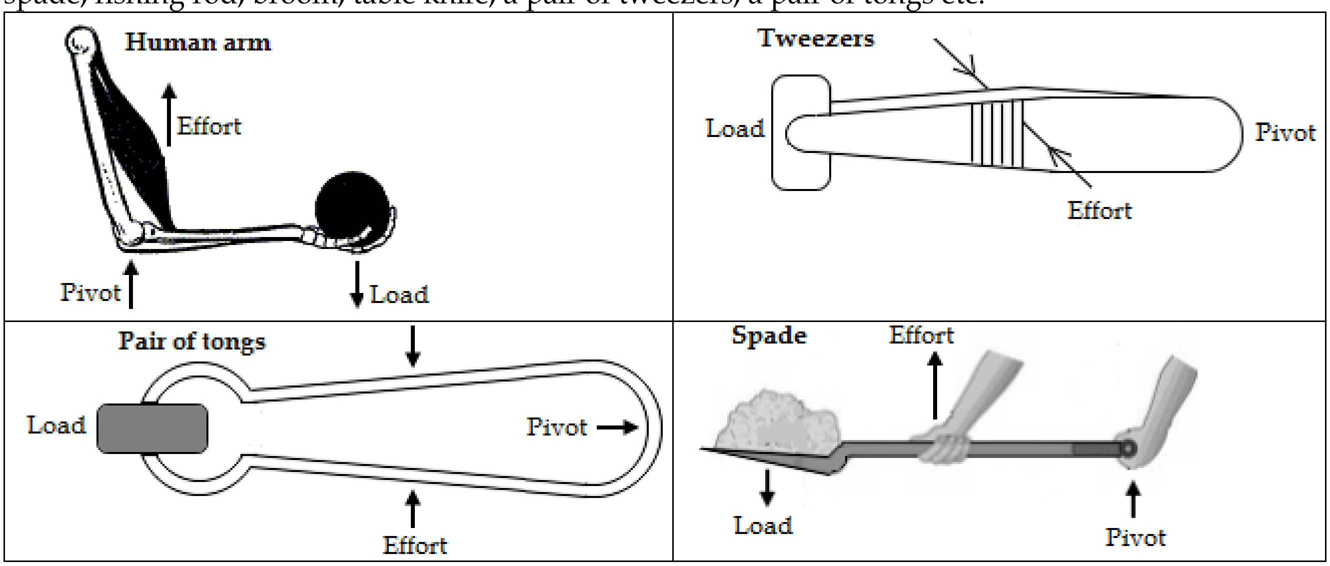
Second class levers

Second (2nd) class levers have the load between the effort and the pivot. Second class levers always give mechanical advantage greater than 1 because the effort distance is always longer than the load distance. Examples of second class levers include wheel barrow, bottle opener, nut cracker paper cutter etc.



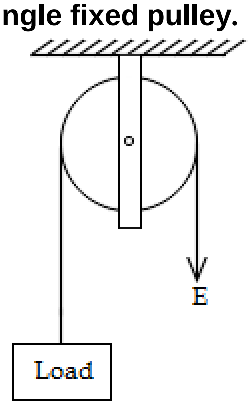
Third class levers

With third (3rd) class levers the effort is between the load and the pivot the load distance is always longer than effort distance. The M.A is less than one. The effort applied is greater than the load. The lever operates at a mechanical disadvantage The common examples of 3rd class levers are human arm, spade, fishing rod, broom, table knife, a pair of tweezers, a pair of tongs etc.



PULLEY SYSTEMS

Single fixed pulley.

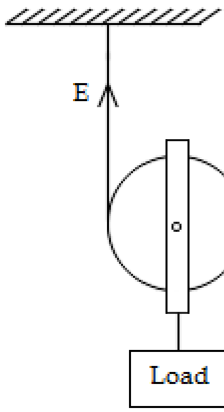


A single fixed pulley is used to lift a load by applying a down ward effort E.

If the friction in the pulley bearings is neglected, then the effort is equal to the load and the mechanical advantage is equal to 1. L=E, M.A =1

The velocity ratio in a single fixed pulley is one because the effort and load move equal distances it may be used raise small loads e.g. to top of buildings during construction.

Single movable pulley



A single movable pulley is used to raise a load by applying an upward effort E. The pulley moves along with the load

Total upward force is 2E because two parts of the rope support the pulley since load, L is supported by tension in two sections of string then L = 2E

$$\mathbf{M.A} = \frac{\mathbf{2E}}{\mathbf{E}} = \mathbf{2}$$

However the mechanical advantage is practically less than two because of the weight of the pulley block and friction in movable parts of the pulley.

To raise the load by one unit length, each side of the rope has to shorten by the same unit length. The free end therefore has to move twice the length so,

$$\mathrm{V.R} = \frac{\text{Distance moved by Effort}}{\text{Distance moved by Load}}$$

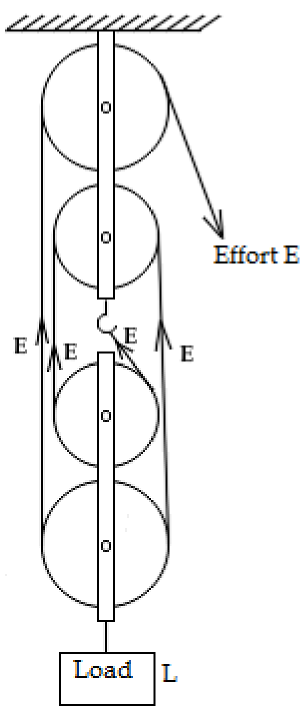
$$V.R = \frac{\text{2 unit length}}{\text{1 unit length}}$$

V.R = 2

Note: V.R = Number of parts of the rope supporting the load.

Block and tackle pulley system

This is a combination of fixed and movable pulleys. It consists of two blocks with one or more pulleys. The total upward force on the lower block is 4E



L = 4E

$$\mathrm{M.A} = \frac{\mathrm{L}}{\mathrm{E}}$$

$$\mathrm{M.A} = \frac{4\mathrm{E}}{\mathrm{E}}$$

M.A = 4

Four (4) of sections of the string cross between the two blocks, hence the velocity ratio is four (4).

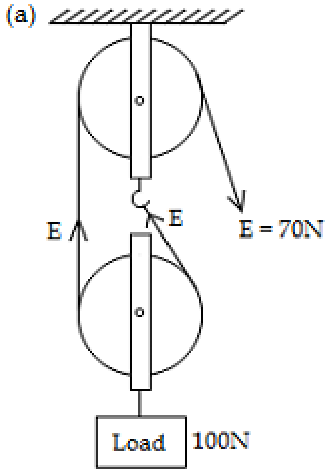
Practically M.A is less than 4, since extra effort is required to overcome friction and weight of the moving pulley block and rope.

Note: In practice pulleys in each block are mounted side by side and run independently on a common axle. The above arrangement is for simplicity. The rope passes each pulley in turn.

Examples

1. In each of the following pulley systems find the,

(i) M.A (ii) V.R (ii) Efficiency



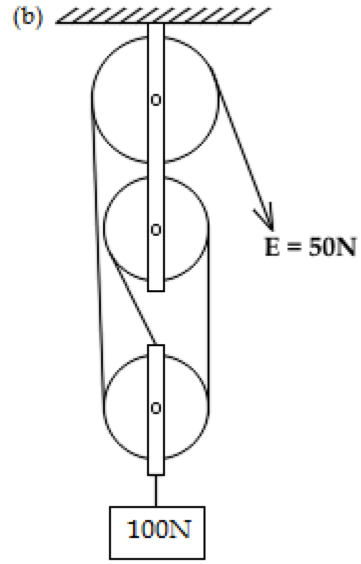
$$M.A = \frac{L}{E} = \frac{100}{70}$$

M.A = 1.4

V.R = 2

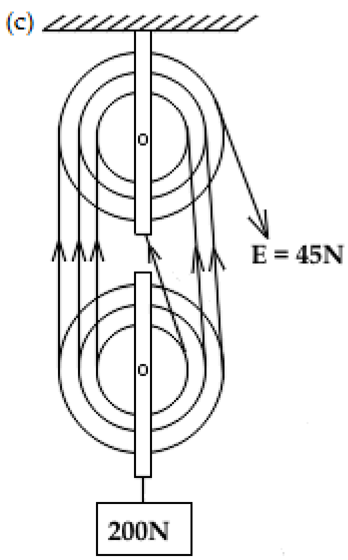
$$\eta = \frac{M.A}{V.R} \times 100\%$$

$$\eta = \frac{1.4}{2} \times 100\% = 70\%$$



$$M.A = \frac{L}{E} = \frac{100}{50} = 2 \quad V.R = 3$$

$$\eta = \frac{M.A}{V.R} \times 100\% = \frac{2}{3} \times 100\% = 66.7\%$$



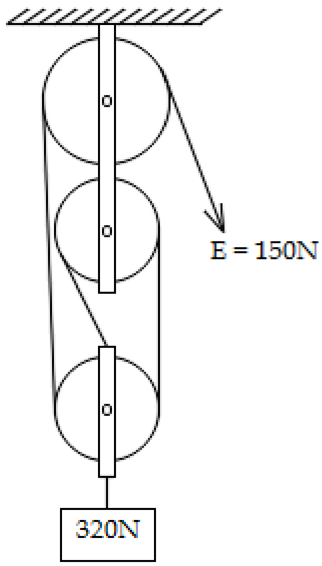
$$M.A = \frac{L}{E} = \frac{200}{45} = 4.44$$

V.R = 6

$$\eta = \frac{M.A}{V.R} \times 100\%$$

$$= \frac{4.44}{6} \times 100\% = 74\%$$

2. The diagram below shows 3 pulleys connected by a rope. If an effort of 150N is needed to lift a load of 320N with this pulley system. What is the efficiency?



$$M.A = \frac{L}{E}$$

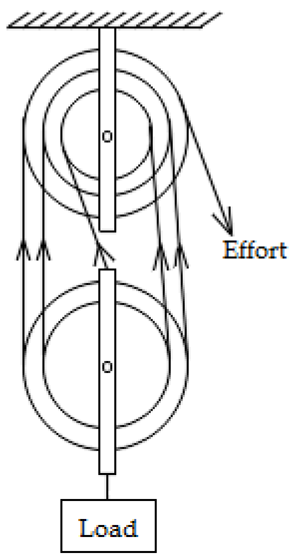
$$= \frac{320}{150} = 2.13$$

V.R = 3

$$\eta = \frac{M.A}{V.R} \times 100\%$$

$$= \frac{2.13}{3} \times 100\% = \mathbf{71}\%$$

3. The diagram below shows a pulley system used to lift a load of 800N. If each pulley has weight of 20N, calculate the efficiency of the system.



Total weight of the pulleys in the lower block = 20 x 2 = 40N
Load = 800 + 40 = 840N
Load = 5E since 5 sections of the rope support the lower block
5E = 840

$$E = \frac{840}{5}$$

E = 168N

$$M.A = \frac{L}{E} = \frac{800}{168} = 4.762$$

$$\eta = \frac{M.A}{V.R} \times 100\%$$

$$= \frac{4.762}{5} \times 100\% = 95.2\%$$

Practice (leave space of five lines for solutions to each question)

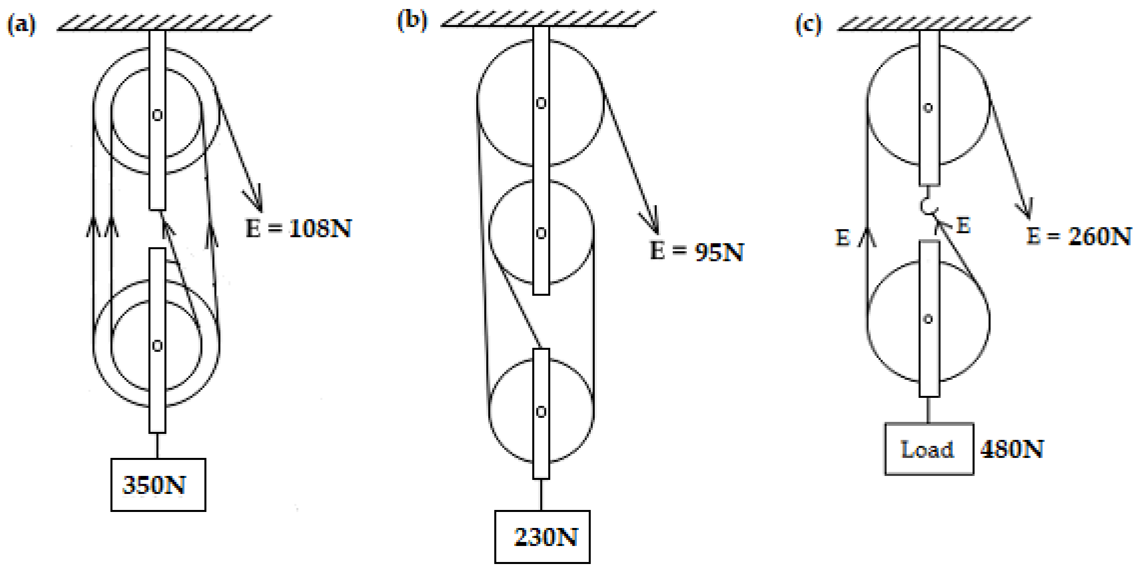
1. A pulley system of velocity ratio 3 is used to lift a load of 100 N. The effort needed is found to be 60 N.

(i) Draw the arrangement of the pulley system.

(ii) Calculate the efficiency of the system.

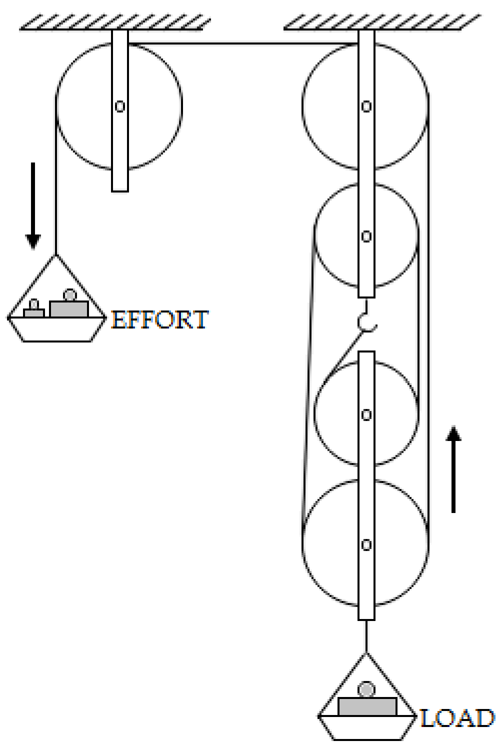
2. In each of the following pulley systems find the,

(i) M.A (ii) V.R (ii) Efficiency



Experiment to study the variation of M.A of a pulley system with the load

A pulley system with four pulleys is set up and scale pans hang up as shown in the diagram. The pans are treated as part of the machine itself.



Starting with a small weight in the load pan, weights are added to the effort pan until the load just rises with steady velocity.

The load and effort in Newtons are noted. The experiment is repeated for increasing loads and the results are entered in the table below

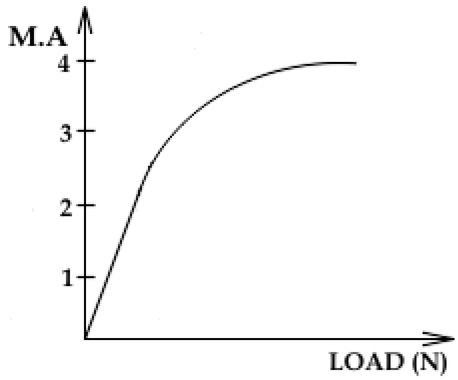
The velocity ratio of this pulley system may be obtained by measuring corresponding distances moved by the effort and load.

Load (N)	Effort (N)	M.A	$\eta = \frac{M.A}{V.R} x\ 100\%$

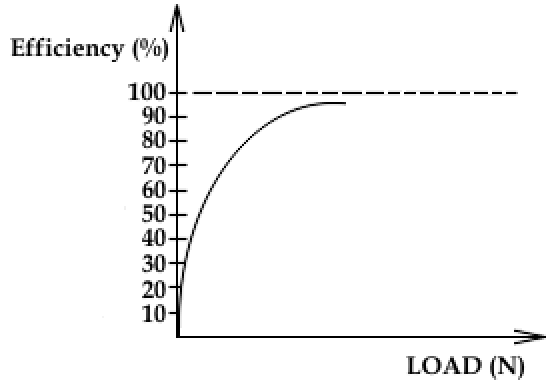
From the results obtained it is observed that the mechanical advantage increases with load but since there are only four pulleys the M.A cannot exceed 4.

The efficiency also increases with the load, but is less than 100% due to work wasted in overcoming friction and raising moving parts of the pulley system.

A graph of M.A against Load

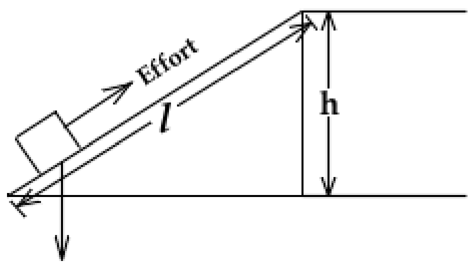


A graph of efficiency against Load



THE INCLINED PLANE

A heavy load can be easily raised by pulling it along a sloping surface than by lifting it vertically. Heavy packages are often loaded onto trucks using an inclined plane. Building materials are pushed to the top of relatively tall buildings using inclined planes. Examples of inclined planes are staircases, ramps and slides.



To raise a load through a vertical height h the smaller effort E moves a greater distance l equal to the length of the incline.

$$\text{V.R} = \frac{\text{distance moved by effort}}{\text{distance moved by load}}$$

$$\text{V.R} = \frac{\text{length of the incline}}{\text{height of the incline}}$$

$$\text{V.R} = \frac{l}{h}$$

Examples (leave space of five lines for solutions to each question)

1. A load of 750N is raised onto a truck 3m high using an inclined plane of length 12m using an effort of 200N. What is the efficiency of this system?

M.A = $\frac{L}{E}$ = $\frac{750}{200}$ = 3.75

$$\text{V.R} = \frac{l}{h} = \frac{12}{3} = 4$$

$$\eta = \frac{\text{M.A}}{\text{V.R}} \text{ x } 100\%$$

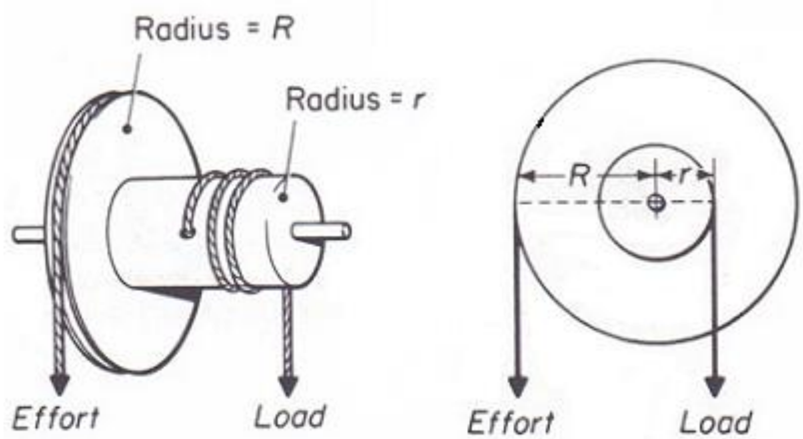
$$= \frac{3.75}{4} \text{ x } 100\% = \mathbf{93.75\%}$$

2. An inclined plane of length 20m is used to raise a load of 1600N through a height of 4m using an effort of 400N. Calculate the efficiency of the system.

3. A wooden plank 3 m long is used to raise a load of 1200 N through a vertical height of 60 cm. If the frictional force between the load and the plane is 40 N calculate the;
(i) Effort required
Work input = work output + work done against friction
(ii) Mechanical advantage
(iv) Efficiency

THE WHEEL AND AXLE

In the wheel and axle the effort is applied to the rope wound round a wheel and the load is raised by another rope wound oppositely on the axle.



For one complete turn of the wheel the effort moves a distance equal to the circumference of the wheel $2\pi R$ and the load moves a distance equal to the circumference of the axle $2\pi r$.
Since the circumference of the wheel is greater than that of the axle the effort moves through a greater distance than the load in this way a small effort can be used to overcome a large load.

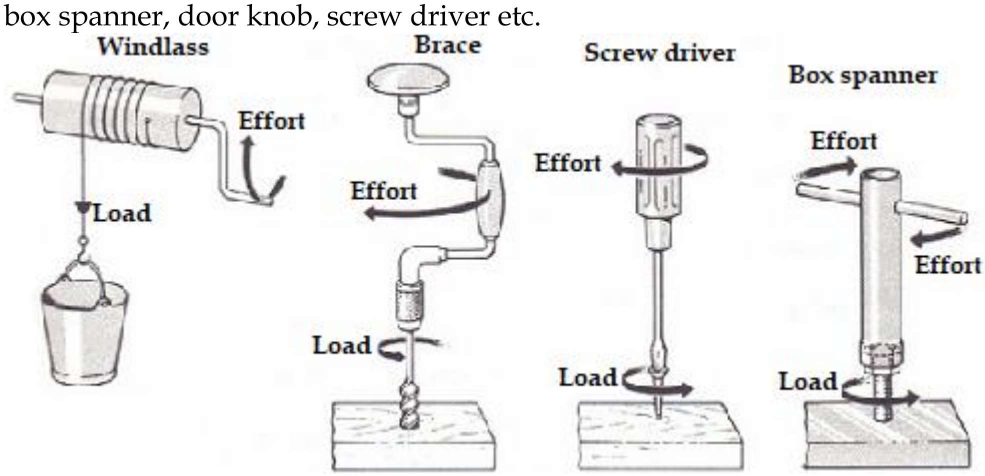
$$\mathrm{V.R} = \frac{\text{Diatance moved by effort}}{\text{Distance moved by the load}}$$

$$\mathrm{V.R} = \frac{\text{Circuference of the wheel}}{\text{Circumference of the axle}}$$

$$\mathrm{V.R} = \frac{2\pi R}{2\pi r}$$

$$\mathbf{V.R} = \frac{\mathbf{R}}{\mathbf{r}}$$

Examples simple machines that belong to the wheel and axle include; windlass, steering wheel, brace, box spanner, door knob, screw driver etc.



Examples (leave space of five lines for solutions to each question)

1. A common windlass is used to raise 480N of gravel from an excavation by the application of an effort of 200N at right angles to the handle and crank. If the handle is 33cm from the axis and the radius of the axis is 11cm find the;

(i) Velocity ratio

(ii) Mechanical advantage

(iii) Efficiency

$$V.R = \frac{R}{r}$$

$$V.R = \frac{33}{11} = 3$$

$$M.A = \frac{L}{E} = \frac{480}{200} = 2.4$$

$$\eta = \frac{M.A}{V.R} x100$$

$$= \frac{2.4}{3} x\ 100 = 80\%$$

2. A machine consisting of a wheel of radius 60cm and an axle of radius 10cm is used to lift a load of 500N with an effort of 120N for this system calculate the M.A, V.R and efficiency.

3. A wheel and axle is used to raise a load of 28kg by a force of 40N applied to the rim of the wheel. If the radius of the wheel is 0.7m and that of the axle is 6cm calculate the M.A, V.R and efficiency.

4. A common windlass is used to raise a load of 480N by application of an effort 200 N at right angles to the handle. If the crank is 33 cm from the axis and the radius of the axle is 11 cm, calculate the;

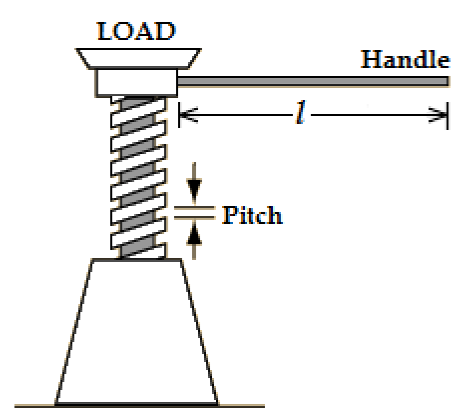
(i) Velocity ratio.

(ii) Efficiency of the windlass.

SCREWS

Screws and bolts are used daily for the purpose of fastening objects together. The screw is an essential feature of machines like vices, clamps, screw car jacks, cork screw, hand drill, jar lids, spanners, G-clamp etc.

The diagram below shows a screw jack



The pitch of the screw

The pitch of the screw is the distance between successive threads

When the effort applied to the lever at the top of the screw makes one complete turn the screw and load rises through a distance equal to the pitch.

$$V.R = \frac{\text{Circumference of circle made by the effort}}{\text{Pitch of the screw}}$$

$$V.R = \frac{2\pi r}{\text{pitch}}$$

r is the radius of the circular path made by the effort.

From the diagram

$$V.R = \frac{2\pi \boldsymbol{l}}{\text{pitch}}$$

Examples (leave space of five lines for solutions to each question)

1. A screw driver with a handle of radius 2.5cm is used to drive a screw with a pitch 1.5mm. If the efficiency of the system is 60% and the effort required is 5N calculate the;

(i) V.R

(ii) Load that opposes the motion of the screw

(iii) If part of the work done by effort is used to overcome friction calculate the work done in overcoming friction.

$\text{Pitch} = \frac{1.5}{10} = 0.15\text{cm}$

$$V.R = \frac{2\pi r}{\text{pitch}} = \frac{2 \text{ x } 3.14 \text{ x } 2.5}{0.15} = 105$$

$\eta = \frac{M.A}{V.R} \times 100 \qquad 60 = \frac{M.A}{105} \text{ x } 100$

$$M.A = \frac{60 \text{ x } 105}{100} = 63$$

$M.A = \frac{L}{E}$

$63 = \frac{L}{5} \qquad$ L = 63 X 5 = 315N

Work done by effort = effort x distance moved by effort

$\text{Work done by effort} = 5 \text{ x } 2 \text{ x } 3.14 \text{ x } \frac{2.5}{100} = 0.785\text{J}$

Work done to overcome friction = 100 – 60 = 40% of work input

$\text{Work done to overcome friction} = \frac{40}{100} \times 0.785 = \mathbf{0.314J}$

2. (a) What is meant by

(i) Velocity ratio of a machine?

(ii) Pitch of a screw?

(b) A load of 750N is raised using a screw jack whose lever arm is 50 cm has a pitch of 3.0 cm. If it is 40% efficient, Find the

(i) V.R

(ii) M.A

(iii) Effort applied

3. A screw jack with a lever arm of 56cm and a pitch of 2.5mm is used to raise a load of 800N. If its efficiency is 25%, find the;

(i) Velocity ratio

(ii) Mechanical advantage

4. A car whose weight is 16000N is lifted with a screw-jack of 11mm pitch if the handle is 0.28m from the screw and the force applied by the jack is 110N Find the;

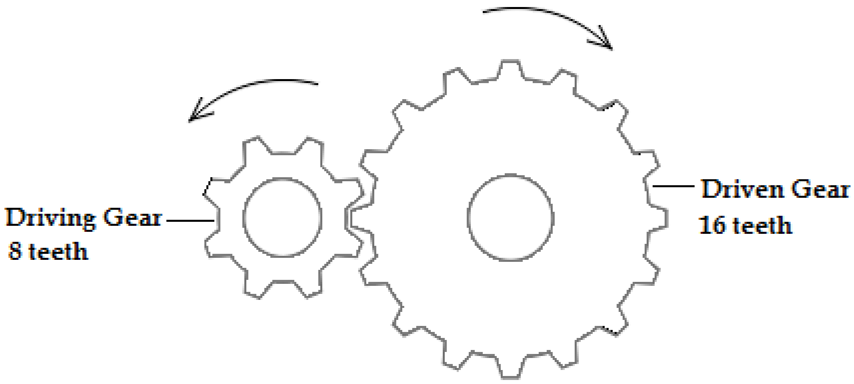
(i) Velocity ratio

(ii) Mechanical advantage

(iii) Efficiency

GEARS

A gear is a simple machine that consists of a wheel with teeth. Gears change speed and direction motion. When two gears engage each other, the turning of one gear will turn the other gear in the opposite direction. A smaller driving gear will always turn faster than the larger driven gear. Gears are found in clocks, drills, handheld egg beater, watches, vehicle gear box, gear bike etc.



The velocity ratio of a system of gears is given by;

$$V.R = \frac{\text{Number of teeth on driven wheel}}{\text{Number of teeth on driving wheel}}$$

$$V.R = \frac{16}{8}$$

V.R = 2

The gear with 8 teeth makes two revolutions for each complete revolution the driven gear of 16 teeth

Examples

1. A driving gear wheel having 25 teeth engages with a second wheel with 100 teeth, given the efficiency of the gear system is 85% calculate the velocity ratio and mechanical advantage.

$$V.R = \frac{\text{Number of teeth on driven wheel}}{\text{Number of teeth on driving wheel}}$$

$$V.R = \frac{100}{25} = 4$$

$$\eta = \frac{M.A}{V.R} \times 100\%$$

$$85 = \frac{M.A}{4} \times 100\%$$

$M.A = \frac{85 \times 4}{100}$ M.A = 3.4

2. A gear A has 40 teeth and drives another gear B with 120 teeth. How many times does A rotate for each revolution of B?

$$V.R = \frac{\text{Number of teeth on driven wheel}}{\text{Number of teeth on driving wheel}}$$

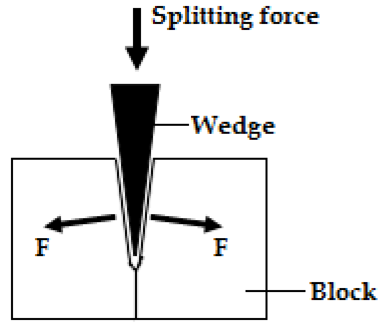
$$V.R = \frac{120}{40}$$

V.R = 3

Gear A rotates 3 times

THE WEDGE

A wedge is a simple machine consisting of two inclined planes forming a sharp edge. When the edge where the two planes meet is pushed into a material, the wedge produces two opposing forces perpendicular to its inclined surfaces. The two forces split the material. Wedges are used to cut or split things. Examples of wedges are axes, knifes, saws, chisels, scissors, needles etc.



HYDRAULIC MACHINES

When a force is exerted on the pump piston pressure is exerted on the fluid which is transmitted to large piston called a ram where a large force is created that overcomes a big load the velocity ratio of a hydraulic machine is calculated from the expression;

$$V.R = \frac{\text{Cross} - \text{sectional Area of the large piston (Ram)}}{\text{Cross} - \text{sectional Area of the small piston(Pump)}}$$

$$V.R = \frac{\pi R^2}{\pi r^2}$$

$$V.R = \frac{R^2}{r^2}$$