12. MACHINES

A machine is a device by means of which a force is applied at one point to overcome a force at some other point more easily. - it makes work easier.

Terms:

Effort :- This is the force applied to overcome a load
Load :- force to be overcome
Mechanical advantage (.M.A) :- This is the ratio of the load to effort. i.e

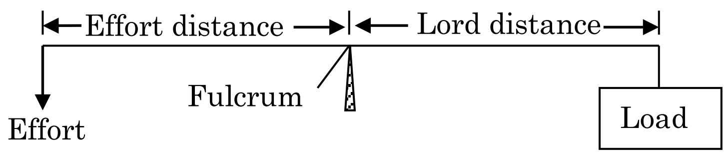
$$M.A = \frac{\text{Load}}{\text{Effort}}$$

Mechanical advantage has no units.

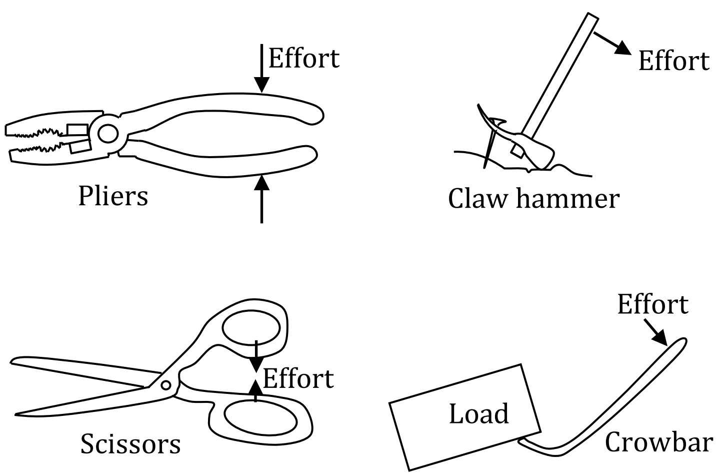
12.1: Levers

A lever is a rigid bar arranged to turn about a fixed point (***fulcrum***) when an effort is applied to overcome a load.

Fisrt Class Lever:



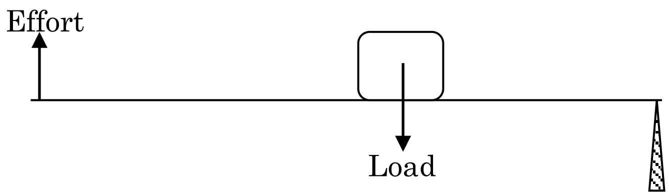
Examples: see saw, pliers, claw hammer, scissors, crowbar.



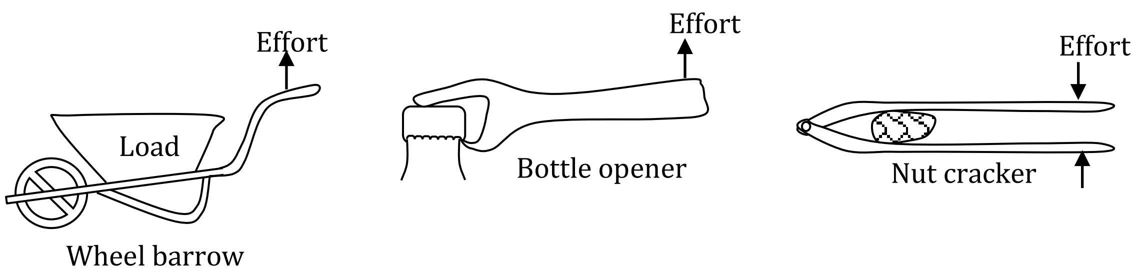
By application of moments, the effort will overcome the load if the moment of the effort about the fulcrum just begins to exceed that of the load about the fulcrum. Thus, before the load is overcome, the condition that
Effort x *effort distance = load* x *load distance*
must be fulfilled.
Thus a smaller effort than the load can be used if the effort distance is greater than the load distance

Second Class Lever

In this arrangement the load is between the fulcrum and the effort



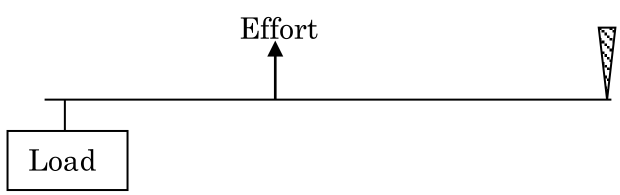
Examples of second class lever include: wheel barrow, bottle opener, nut cracker.



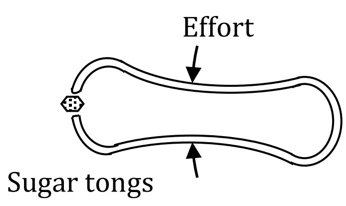
In second class levers, because effort distance is always greater than the load distance, it follows that the effort is always smaller than the load. See the diagrams of the examples given above.

Third Class Lever:

Here the effort is between the load and the fulcrum.



It is clear that in this arrangement the effort is always greater than the load. Examples of third class levers include: sugar tongs, the arm, table knife



Relationship between Distances moved by the Load and Effort

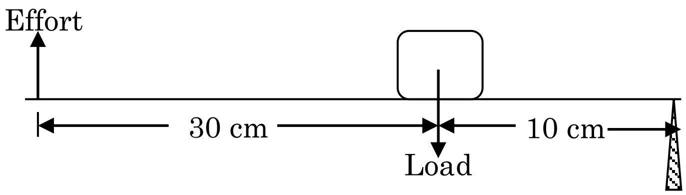
In order for an effort to move a load through a given distance, the effort must move a certain distance.

$$\text{Velocity ratio} = \frac{\text{Distance moved by effort}}{\text{Distance moved by load in the same time}}$$

Velocity ratio has no units.

Example:

What is the velocity ratio in the lever system below?



Solution

$$\text{Velocity ratio} = \frac{\text{Effort distance from fulcrum}}{\text{Load distance from fulcrum}} = \frac{40}{10} = 4$$

Efficiency: (η)

This is the ratio of the useful work got out of a machine to the work put in a machine.

i.e $\text{Efficiency} = \frac{\text{Useful work got out of a machine}}{\text{Work put in the machine}}$

$= \frac{\text{Load x distance moved by load}}{\text{Effort x distance moved by effort}}$

$= \frac{\text{Load}}{\text{Effort}} \text{x} \frac{\text{load distance}}{\text{effort distance}}$

$$= M.A \text{ x } \frac{1}{\text{V.R}} = \frac{\text{M.A}}{\text{V.R}}$$ Type equation here.

Example:

An effort of 100N moves through 12cm while moving a load of 400N through 2cm. Find

(i) the mechanical advantage
(ii) the velocity ratio
(iii) the efficiency of the machine

Solution

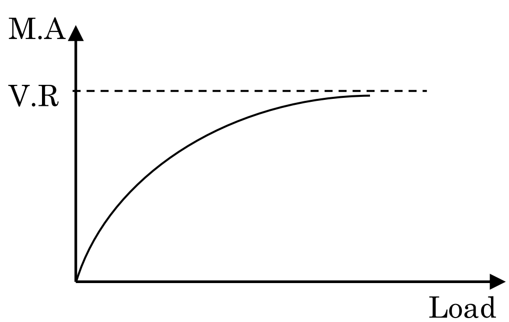
(i)Mechanical advantage $= \frac{\text{load}}{\text{effort}} = \frac{400}{100} = 4$

(ii)Velocity ratio $= \frac{\text{effort distance}}{\text{load distance}} = \frac{12}{2} = 6$

(iii)Efficiency $= \frac{\text{mechanical advantage}}{\text{velocity ratio}} \text{ x } 100\% = \frac{4}{6} \text{ x } 100 = 66.7\%$

Graph of Mechanical Advantage (M.A) against Load

The mechanical advantage of a machine does not remain the same as the load is varied. For any machine the maximum possible mechanical advantage is equal to its velocity ratio. The following graph shows the variation of mechanical advantage with load.



Graph of Efficiency against Load

Like the mechanical advantage, the efficiency varies as the load varies but can never reach 100%. This is so because

(i) The machine has to overcome the frictional force in the moving parts.
(ii) Some work is spent in lifting parts of the machine.

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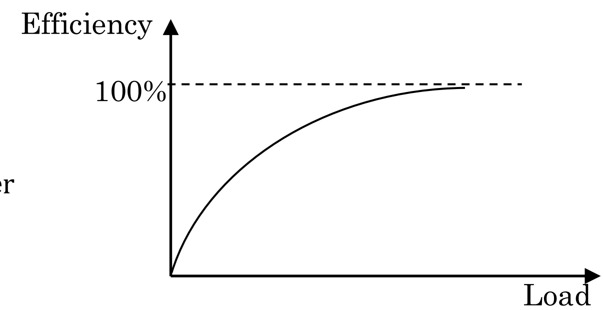


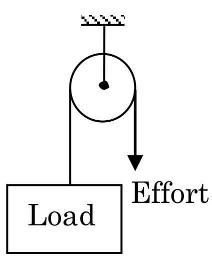
Why M.A or Efficiency increases with the Load

Since the weight of the moving parts remains the same, and the frictional force may NOT increase proportionally, the work wasted on these become a smaller portion compared to that done against the actual load as the load increases. Thus mechanical advantage and efficiency become greater.

12.2: Pulleys

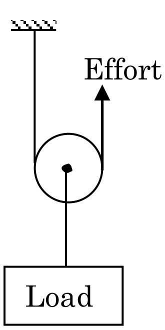
A pulley is a wheel, usually with a groove over which a string or rope can be passed.

SINGLE FIXED PULLEY



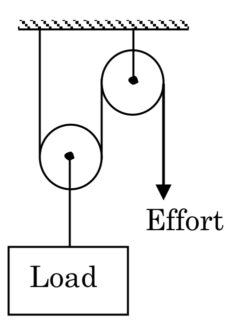
V.R = 1

SINGLE MOVABLE PULLEY



V.R = 2

(i)

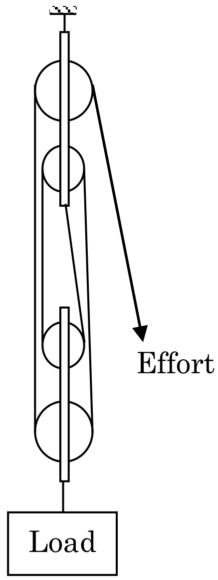


(ii)

The system in figure (ii) is the same as the single movable pulley in figure (i) except that the effort is applied downwards. This makes it more convenient since part of the operator's weight can form the effort E

V.R = 2

BLOCK AND TACKLE SYSTEM



V.R = number of strings supporting the movable block (or number of pulleys if the effort is applied downwards).
In this case the V.R = 4
The system consists of two blocks, with the upper fixed and the lower movable. Each block may contain any number of pulleys with a single string rope going round the pulleys.

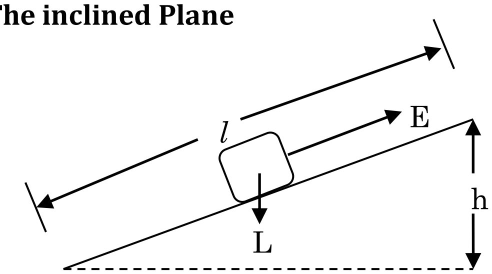
Experiment: To investigate the V.R of a Block and Tackle System.

a) Record the total number of pulleys provided
b) Arrange a block-and-tackle system with a mass hanging at the lower block
c) Make a mark x on the free part of the string
d) Note the position of the hanging mass and that of the mark x.
e) Pull gently the free end of the string through a distance e = 10cm and note the corresponding distance l moved by the hanging mass.
f) Repeat the procedure (e) when e = 15, 20, 25, 30,and 35cm and fill the table below:

e/cm	l/cm	e/l
10		
15		
20		
25		
30		
35		

What is the velocity ratio?

12.3: The inclined Plane



When the effort E, acting along the plane, moves the load L through a distance *l* along the plane, the load is effectively raised vertically a height h.
This arrangement enables an effort E to lift a bigger load L

$$\text{Velocity ratio} = \frac{\text{distance moved by effort}}{\text{height risen by the load}} = \frac{l}{h}$$

Example:

An effort of 50N is used to haul a 300N box along an incline which rises vertically 1 m for every 8 m distance along the plane. Find

(i) the velocity ratio

(ii) the mechanical advantage

(iii) the efficiency

State the factors in this arrangement that make the efficiency become less than 100%

Solution

(i) The velocity ratio = 8/1 = 8

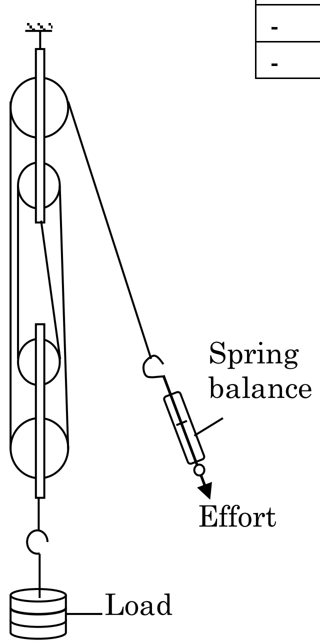
$$\text{(ii) Mechanicaladvantage} = \frac{\text{Load}}{\text{Effort}} = \frac{300}{50} = 6$$

$$\text{(iii) Efficiency} = \frac{\text{Mechanicaladvantage}}{\text{velocityratio}} \text{ x } 100 = \frac{6}{8} \text{ x } 100 = 75\%$$

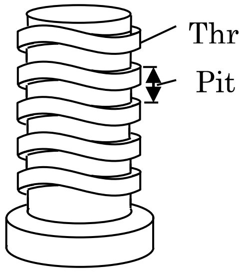
Experiment: To investigate the variation of M.A of a Pulley System with the load.

- The pulley system is arranged with the string appropriately assembled.
- A load is fixed to the lower block.
- A spring balance is fixed at the free end of the string.
- By pulling on the spring balance, the minimum effort E, required to lift the load, is found and noted.
- The procedure is repeated for several other values of the load and a table as shown below is filled.

Load/N	Effort, E/N	Load Effort
-	-	-
-	-	-
-	-	-



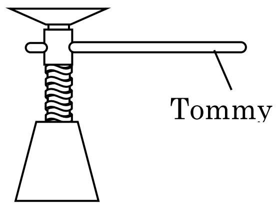
12.5: The Screw

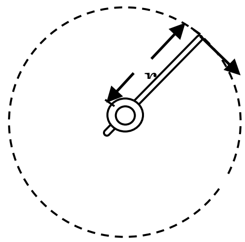


This is an application of an inclined plane. It is an inclined plane which, instead of stretching it in a straight line, has been taken round a cylinder. It can be likened to stairs climbing up to, say the fifth floor. The stair cases are arranged to turn several times in a narrow vertical space instead of following a single straight line.

Pitch:- This is the distance between adjacent threads

The screw Jack





When the screw is turned through one complete revolution, it advances a distances equal to one pitch

$$\therefore \qquad \text{V. R} = \frac{\text{Circumference of circle made by E}}{\text{Pitch}}$$

Usually, the effort is applied on a tommy bar some distance r from the axis of the screw. So

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

Example:

A screw jack is found to be 70% efficient. If an effort of 20N is used to lift a vehicle of 5000N and the pitch of the screw is 2 mm, what is the length of the tommy bar?

Solution:

Let r = length of the tommy bar

Then velocity ratio, $\text{V. R} = \frac{2\pi r}{\text{pitch}} = \frac{2\pi r}{2} = \pi r$

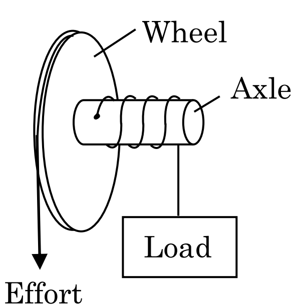
Mechanical advantage, M.A = 5000/20 = 250

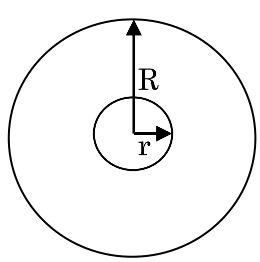
Now, efficiency = M.A/V.R

$\therefore \qquad 70/100 = 250/\pi r$

$$\therefore \qquad r = \frac{250 \text{ x } 100}{\pi \text{ x } 70} = 113.6 \text{ mm}$$

12.6: Wheel and axle

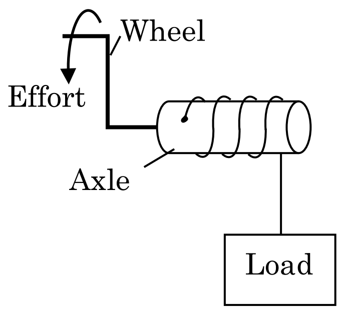




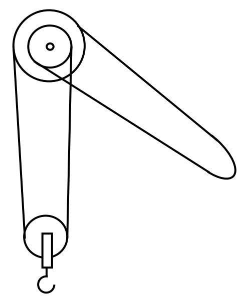
The effort is normally applied on the rope that goes round the wheel, while the load is lifted by the rope fixed on the axle. When the wheel makes one revolution, the axle also turns one revolution.

$$\text{So,} \quad V.R = \frac{\text{Circumference of wheel}}{\text{Circumference of axle}} = \frac{R}{r}$$

Windlass

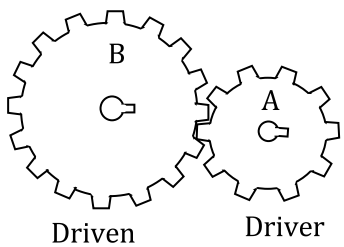


Weston differential pulley



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

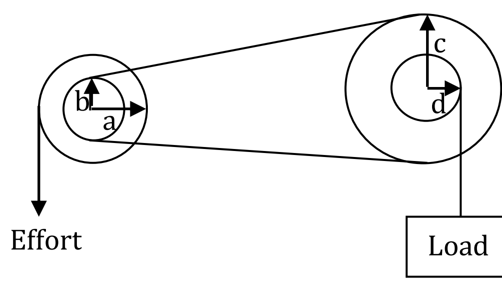
12.7: Gear systems



If two gears engage such that gear A drives gear B, A is referred to as the driver and B as the driven.

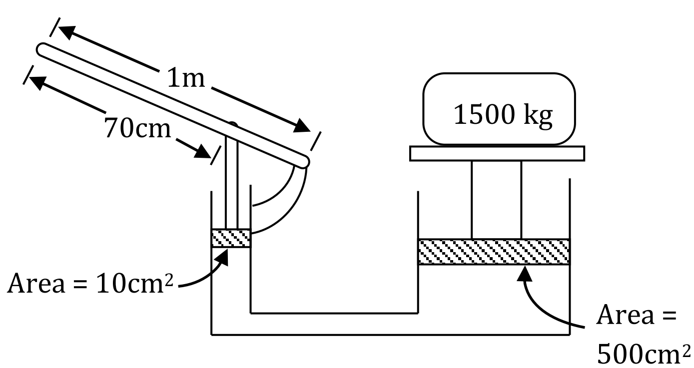
$$V.R = \frac{\text{No. of teeth on the driven}}{\text{No. of teeth on the driver}}$$

Combination of simple machines



V.R = Product of the individual velocity ratios
= a/b x c/d

Example:



For the hydraulic press shown , find the

(i) Velocity ratio
(ii) Efficiency

Solution

(i) V.R = V.R of lever x V.R of hydraulic pressure

$$= \frac{\text{effort distance}}{\text{Load distances}} \times \frac{\text{load piston area}}{\text{effort piston area}}$$

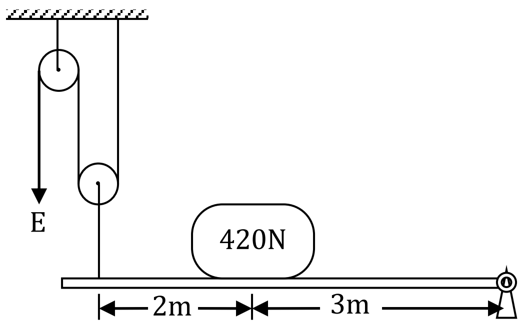
= 100/30 x 500/10 = 500/3
= 166.7

(ii) Efficiency $= \frac{\text{M.A}}{\text{V.R}} \times 100\%$

$$= \frac{1500 \times 10}{100 \times 500/3} = 90\%$$

Example:

An effort E is used to just lift a load of weight 420 N using the arrangement shown below



If the efficiency of the arrangement is 70%, find
(i) the velocity ratio of the system
(ii) the effort E.

Solution:

Overall velocity ratio = velocity ratio of the pulley system x velocity ratio of the lever

$$= 2 \times \frac{5}{3} = \frac{10}{3} = 3.33$$

$$\text{Efficiency} = \frac{\text{M.A}}{\text{V.R}} \times 100 = \frac{420 \times 3}{\text{E} \times 10} \times 100\%$$

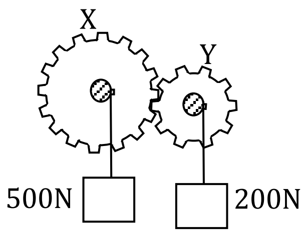
$$\therefore 70 = \frac{420 \times 3}{\text{E} \times 10} \times 100$$

$$\therefore \text{E} = \frac{420 \times 3}{70 \times 10} \times 100 = 180 \text{ N}$$

Exercise 12

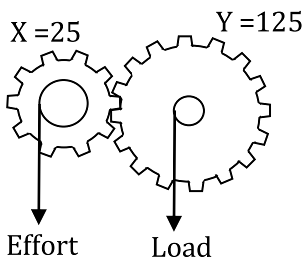
1. A load of 600 N is placed at 1.5 m from the pivot of a sea saw. Find the distance from the pivot at which a weight of 300 N should be placed to balance the sea saw.

2. Two gear wheels X and Y having 100 and 25 teeth respectively, mesh with each other. They are fastened on axles of equal diameters such that a weight of 200 N attached to a string wound round one axle raises a load of 500 N attached to a string wound round the other axle as shown. Find
 (i) the velocity ratio
 (ii) the efficiency of the system



3. A screw jack with a tommy bar of length 50 cm and a pitch of 2.5 mm is used to raise a load of 1200 N. If the efficiency is 40%, find
 (i) the velocity ratio
 (ii) the mechanical advantage

4. In the gear system shown below the wheels X and Y have the number of teeth shown. If the shaft diameters are 20 cm and 10 cm respectively, and the efficiency is 30%, find
 (i) the velocity ratio
 (ii) the effort required to lift a load of 900 N.



13. WORK, ENERGY AND POWER.

13.1: WORK

Work is said to be done if the point of application of a force moves in the direction of the force.It is measured as the product of the force and the distance moved in the direction of the force.

i.e.***Work = force x distance***

The SI unit of work is the joule (J)
A joule is the work done by a force of 1N in moving a distance of 1m
$\therefore$ 1J = 1Nm

Examples:

1. A force of 10N moves a body along a straight path and stops after 200J of work has been done. What distance was moved?
Solution:

$$\text{Distance} = \frac{\text{work}}{\text{force}} = \frac{200}{10} = 20 \text{ m}$$

2. A tangential force of 15N is applied to turn a wheel of radius of 70cm about the centre. How much work is done in 2 revolutions?
Solution:
In the 2 revolutions the force moves a distance equal to two circumferences of the circle described, i.e $2 \times 2\pi r = 4\pi \times 0.70$
$\therefore$ Work done = Force x distance = $15 \times 4\pi \times 0.70$ = $\underline{\underline{131.9\ J}}$

3. A body of mass 5kg is raised vertically a height of 8m. How much work is done?
Solution:
Work done = weight of body x height raised = $5 \times 10 \times 8$ = $\underline{\underline{400\ J}}$

13.2: POWER:

Power is the rate of doing work.

The SI unit of power is the watt (W)

$$1W=1Js^{-1}$$

A watt is the rate of doing work at 1 joule per second.

Examples
A pump delivers water at a rate of 1 litre per hour to a tank 20m above a well. Find the power of the pump.
Solution:

1 litre of water has a mass of 1 kg, and 1 hour = 3600 seconds
Work done every hour = weight raised per hour x height

$$\text{Power} = \frac{\text{Workdone}}{\text{Time}} = \frac{1 \text{ x } 10 \text{ x } 20}{3600} = 0.556 \text{ W}$$

13.3: ENERGY:

This is the capacity to do work. It is also measured in joules.

Source of energy

There are two sources of energy from which all the mentioned forms of energy are obtained and include Natural sources of energy and artificial source of energy .Natural sources of energy is also known as primary source and refers to those sources which occurs naturally and include water, sun, wind, fossil fuel, geothermal and biomass. Artificial source or secondary sources are those which are obtained from primary sources and include petroleum products obtained from natural fuels, electricity obtained from solar energy, wind energy and water energy.

Renewable and Non-renewable Sources of energy

Energy sources are classified into renewable and non-renewable sources of energy**.**

Renewable source of energy is the source of energy which can be replaced or replenished with in short period of time after it has been used.

Examples of renewable sources include. solar, wind, geothermal, hydro(water, tides) biomass and nuclear energy.

Nonrenewable energy is the energy which is obtained from the sources which are in limited quantity. These sources of energy cannot be regenerated with in short period of time once they are used up. They take millions of years to be regenerated.

Examples of non-renewable sources of energy, include oils, gas, coal, charcoal, etc. . Nonrenewable sources are not environment friendly and can cause serious effects on our health.

Examples of forms of energy
(i) Mechanical energy
(ii) Electrical energy
(iii) Chemical energy
(iv) Heat energy
(v) Light energy
(vi) Nuclear energy

Mechanical Energy

This is energy possessed by a body due to movement and location. It is made up of two parts.

1. ***Potential Energy:***

This is energy possessed by a body because of its position. It is equal to the work done in raising a body to that position above the reference level.
The body is capable of doing work equal to the potential energy if it returns to the reference level.
Therefore a body of mass m at a height h above the reference level has potential energy equal to mgh.

2. ***Kinetic energy***

This is the energy possessed by a body by virtue of its motion.
A body of mass m is moving at a speed v has kinetic energy equal to $\frac{1}{2}mv^2$.
If a body is moved from rest to acquire a speed v, then the kinetic energy it has is equal to the work done by the external agent that makes it acquire this velocity.

Examples:

1. An object of mass 3kg is moving at a speed of $5ms^{-1}$. If it is to be stopped in 5s using a uniform force, find the power to do so.

Solution:

Work done to stop the object = Original kinetic energy
= $\frac{1}{2}mv^2$ = $\frac{1}{2} \times 3 \times 5^2$ = 37.5 J

$\therefore$ Power $= \frac{37.5}{5} = \underline{\underline{7.5\ W}}$

2. In the previous example suppose the stopping force acted over a distance of 4m, what was the force?

Solution:

$$\text{Force} = \frac{\text{Workdone}}{\text{Distance}} = \frac{37.5}{4} = 9.375\ \text{N}$$

3. A man of mass 75kg walks up 12 steps each 20cm high in 5s. Find the power he develops.

Solution:

Work done = weight of man x total height risen = 750 x 12 x 0.20 = 180 J
$\therefore$ Power = 180/5 = $\underline{\underline{36\ W}}$

13.4: Principle of conservation of energy

This principle states that:
Energy is neither created nor destroyed but can change form.
In other words, ***in a closed system the total energy is always constant***

Interchange of Energy in the Gravitational Field

A body moving under the influence of gravity possesses constant mechanical energy made up of two parts i.e.

Mechanical energy = kinetic energy + potential energy = constant

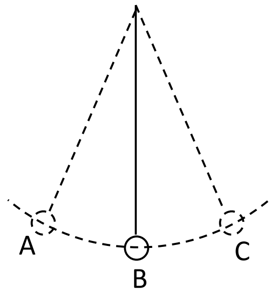
Thus a particle projected upwards keeps on losing kinetic energy and gaining potential energy such that

Kinetic energy lost = potential energy gained.

At the highest point, the particle has no kinetic energy but has maximum potential energy. On falling it keeps on gaining kinetic energy but losing potential energy

The Simple pendulum

A mass freely suspended on a string forms a simple pendulum.
When the mass is pulled to one side and then released, it swings between extreme points A and C. It has maximum potential energy at A and C but zero kinetic energy there. At point B, the kinetic energy is maximum while the potential energy is minimum there.



Since mechanical energy is conserved, it implies that a simple pendulum would swing for ever with a constant amplitude. However, in practice, the amplitude keeps on decreasing until it is completely zero i.e. it stops. This is because of

(i) Air resistance
(ii) Friction at the point of support.

Example:

1. A particle of mass 2 kg is at rest, freely suspended on a string. It is then struck horizontally and starts off with a velocity of $10 ms^{-1}$.
Find how high above the initial position is rises.
What kinetic energy does it have on retuning to the initial position?

Solution:
Let h = height risen
Potential energy gained = kinetic energy lost
$\therefore mgh = \frac{1}{2}mv^2$

$\therefore \quad h = \frac{v^2}{2g} = \frac{10^2}{2 \times 10} = \underline{\underline{5\text{ m}}}$

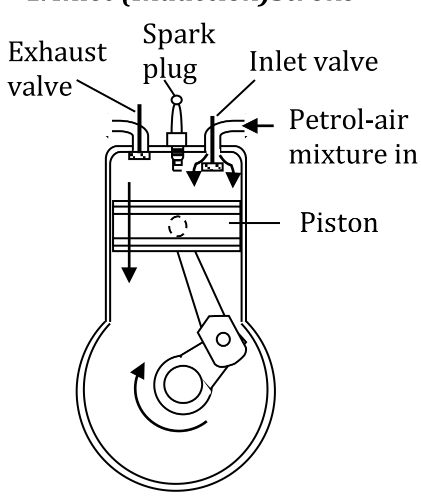
When the particle returns to the point of projection it will have the same kinetic energy as it had when it was leaving equal to $\frac{1}{2}mv^2$
$= \frac{1}{2} \times 2 \times 10^2 = \underline{\underline{100\text{ J}}}$

Engines

The main aim of making an engine is to transform chemical energy into mechanical energy. In an engine, fuel (a chemical) is burnt to produce mechanical power. However, not all the chemical energy is transformed into mechanical for running the engine. Some is wasted as heat and sound. Although sound is itself a form of mechanical energy, it is not used to run the engine.
We shall briefly look at a four-stroke petrol engine and a four-stroke diesel engine.

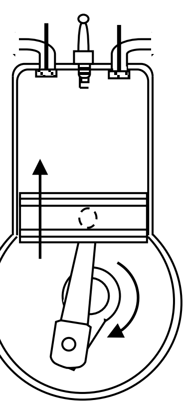
(a) *Four-Stroke Petrol Engine*

1. ***Inlet (Induction)Stroke***



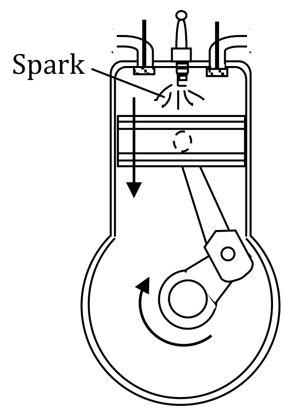
- Inlet valve is open
- Exhaust valve is closed
- Piston is moving down
- Petrol-air mixture is sucked into the cylinder

2. ***Compression Stroke***



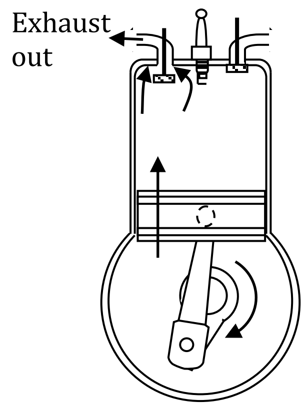
- Both valves are closed
- Piston is moving up

3. ***Power Stroke***



- Both valves are still closed
- When the piston is at the top the spark plug ignites the petrol-air mixture and the explosion pushes the piston down

4. ***Exhaust Stroke***



- Inlet valve is still closed
- Exhaust valve is open
- Piston is moving up
- Burnt gases are driven out

(b) Four Stroke Diesel Engine

A four-stroke diesel engine also performs the four stages of a cycle except:

1. During the inlet stroke ONLY AIR enters the cylinder.
2. During the compression stroke only air is compressed.
3. Instead of a spark plug a FUEL INJECTOR is used. At the end of the compression stroke diesel is injected into the cylinder and it burns automatically because the temperature of the compressed air is very high then.

Exercise 13

1. The work done to move a body through a distance of 6 m is 30 J. Find the force that acts on the body.

2. A bullet of mass 12g strikes a solid surface at a speed of 200 ms^{-1}. If the bullet penetrates to a depth of 3cm, calculate the average net force acting on the bullet while it is being brought to rest.

3. A machine lifts 4 boxes per minute through height 8 m. If each box weighs 100 N, find the power that is expended.

4. A pump rated at 500 W is used to raise water to a height of 60 m. What mass of water can it deliver in one hour?

5. A ball is dropped from rest at a height of 20 m above the ground. If the ball bounces on hitting the ground and lost 20% of its original energy, calculate the maximum height it reaches again.