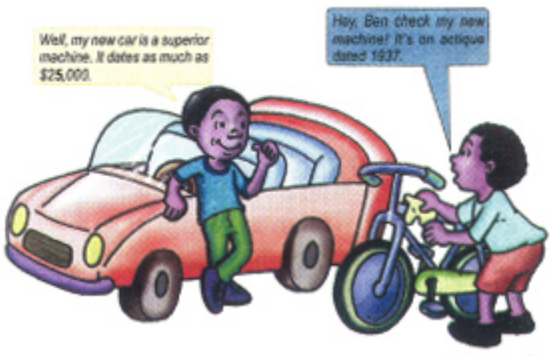
7 MACHINES



MACHINES

The world without machines will be difficult to live in. Machines have come to be a part of human life, we save a lot of energy by using machines.

OBJECTIVES

At the end of this topic, students should be able to:

- define a machine and list at least five simple machines;
- define force ratio, velocity ratio and efficiency as applied to machines and write down the mathematical relationship between them;
- state the effect of friction on force ratio and efficiency of a machine.

Definition and general description of a machine

A machine is a device that assists man to do his work easily and comfortably. A machine is a force multiplier. It magnifies our effort many times to assist us to do work which normally we are not able to do by exerting muscular forces. For example, we cannot exert enough force through our muscles alone to lift a car. The car can be lifted with easy using a screw jack. The little effort of our muscle is magnified many times by the jack to lift the car.

Complex machines

Complicated machines like sewing machines, generators, lathe machines, bicycles and most engines are complex machines. *They are called complex machines because they are made* up of simple machines as their basic parts.

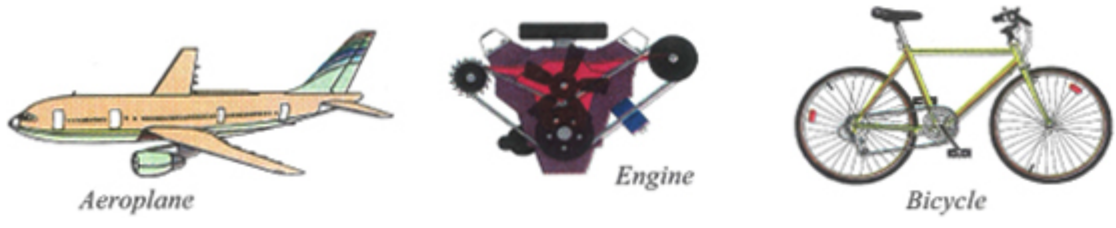


Figure 7.1: Examples of complex machines

Simple machines

All complex machines consist of many simple parts. Each part of a complex machine is also a machine. The basic parts which a complex machine consists of, are called a simple machines.

Figure 7.2: Examples of simple machines

The two major types of a simple machine are the **lever** and the **inclined plane.** Simple machines like pulleys, wheel and axles and gears are variations of the lever while screws, screw jacks and wedges are different forms of inclined plane.

Terms and definitions

1. Effort (E)

The force applied on a machine to overcome a load or resistance is called an **effort.** A small effort is needed to lift a heavy load in a good machine. The unit of effort is Newton (N).

2. Load(L)

The weight or resistance lifted by a machine is called load. The unit of load is Newton (N).

3. Force ratio (F.R.)

Force ratio is the ratio of load lifted by the machine to the effort applied to lift the load. Force ratio becomes a mechanical advantage (M. A.) if it is greater than one. In most practical machines, the load lifted is always more than the effort applied; therefore, we define mechanical advantage as:

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

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

Mechanical advantage (M.A.) has no unit because it is the ratio of two forces.

Effect of friction on mechanical advantage

The size of mechanical advantage (M.A.) of practical machines depends on the friction between its moving parts. Mechanical advantage is high if the friction between the moving parts of the machine is reduced. A good machine magnifies the effort many times; therefore, mechanical advantage is greater than one. A machine with M.A. = 5 magnifies the effort 5 times; meaning that the ratio of load to effort is 5:1.

4. Velocity ratio (V.R.)

Velocity ratio is the ratio of distance travelled by the effort to the distance travelled by the load. It has no unit because it is the ratio of two distances.

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

A machine with velocity ratio (V.R.) = 10 means that the effort travelled a distance 10 times longer than the distance travelled by the load or the ratio of effort distance to load distance is 10:1. **Velocity ratio is independent of friction.** For an ideal or a perfect machine, friction is zero; therefore, work done by the effort is equal to the work done by the load. The price paid by the operator in lifting a heavy load by a small effort is that his effort must travel longer distance than the load in order to conserve energy.

5. Efficiency of a machine (Îµ)

Efficiency is the ratio of work done by the machine to the work input to the machine.

$$\text{Efficiency}(\varepsilon) = \frac{\text{work done}}{\text{work input}} \times 100\%$$

Efficiency and friction

The efficiency of an ideal or perfect machine is 100%. This is because friction is zero. The work done by the effort on a perfect machine is equal to the work done on the load (i.e. no energy is lost in a perfect machine). A perfect or an ideal machine is not possible due to friction between the moving parts of the machine. *Friction reduces the efficiency of a real or practical machine making work output of the machine (work done on the load) less than the work input to the machine (work done by the effort).* A machine with efficiency of 80% means that the 80% of the total energy supplied to the machine is used to lift the load. The remaining 20% of the supplied energy is wasted as heat as a result of friction.

Relationship between M.A., V.R. and efficiency of a machine

The efficiency of machine (Îµ) is related to the mechanical advantage (M.A.) and velocity ratio (V.R.) by the formula:

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

This formula can be proved as follows:

$$\text{Efficiency}(\varepsilon) = \frac{\text{Work done on the load}}{\text{Work done by the effort}} \times 100$$

$$\text{Efficiency}(\varepsilon) = \frac{\text{Load} \times \text{load distance}}{\text{Effort} \times \text{effort distance}} \times 100$$

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

$$\text{Efficiency}(\varepsilon) = M.A. \times \frac{1}{V.R.} \times 100\%$$

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

Worked examples

1. A simple machine has a velocity ratio of 6 and is used to lift a load of 500 N with an effort of 125 N. Calculate:
   (a) the mechanical advantage;
   (b) the distance moved by the effort if the load travelled 8 m;
   (c) energy lost as friction;
   (d) efficiency of the machine.

Solution

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

$$\text{Mechanical advantage} = \frac{500}{125} = 4$$

(b) $V.R. = \frac{\text{Distance moved by effort}}{\text{Distance movedby load}}$

$$6 = \frac{D_E}{8} \quad \Rightarrow D_E = 6 \times 8 = 48\, m$$

(c) Work done by effort $= E \times D_E$.
$= 125 \times 48 = 6000$ J
Work done by load $= L \times D_L$
$= 500 \times 8 = 4000$ J
Energy wasted by friction $= 6000$ J $- 4000$ J
$= 2000$ J

(d) $\text{Efficiency}(\varepsilon) = M.A. \times \frac{1}{V.R.} \times 100\%$

$$\text{Efficiency}(\varepsilon) = \frac{4}{6} \times 100\% = 66.7\%$$

2. In a certain machine an effort of 10N is used to lift a load of 30N. The effort travelled through a distance of 4 m to lift the load through a height of 1 m, calculate the:
   (a) mechanical advantage;
   (b) velocity ratio;
   (c) work done by the load
   (d) work done by the effort;
   (e) efficiency of the machine.

Solution

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

$\text{Mechanical advantage} = \frac{30}{10} = 3$

(b) $V.R. = \frac{\text{Distance moved by effort}}{\text{Distance movedby load}}$

$V.R. = \frac{4}{1} = 4$

(c) Work done by load = $L \times D_L = 30\times1=30$ J

(d) Work done by effort = $E \times D_E = 10\times4=40$ J

(e) $\text{Efficiency}(\varepsilon) = M.A. \times \frac{1}{V.R.} \times 100\%$

$\text{Efficiency}(\varepsilon) = \frac{3}{4} \times 100\% = 75\%$

3. A machine with efficiency 80% and velocity ratio 5 lifts a weight of 1500 N through a vertical height of 4.5 m calculate:
   (a) the mechanical advantage of the machine;
   (b) the effort needed to lift the weight;
   (c) the work done by the effort.

Solution

(a) $\text{Efficiency}(\varepsilon) = M.A. \times \frac{1}{V.R.} \times 100\%$

$80 = \frac{M.A.}{5} \times 100\%$

$M.A. = \frac{80\times5}{100} = 4$

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

(b) $\Rightarrow \text{Effort} = \frac{\text{Load}}{\text{M.A.}} = \frac{1500}{4} = 375\ N$

(c) Effort distance $D_E = V.R. \times D_L$

$= 5 \times 4.5 = 22.5$ m

Work done by effort $= E \times D_E$

$= 375\times22.5$

$= 8437.5$ J

Summary

â€¢ A machine is a device which uses the force applied at one end to lift a load at the other end.

â€¢ Two major types of a simple machines are: the lever and the inclined plane.

â€¢ Simple mahines like pulleys, wheel and axle and gears are variations of the lever.

- $\text{Mechanical advantage} = \dfrac{\text{Load}}{\text{Effort}}$

â€¢ Velocity ratio is the ratio of distance travelled by the effort to the distance travelled by the load. $V.R. = \dfrac{\text{Distance travelled by effort}}{\text{Distance travelled by load}}$

â€¢ Efficiency is the ratio of work done by the machine to the work input to the machine.

$$\text{Efficiency}\,(\varepsilon) = \frac{\text{work done}}{\text{work input}} \times 100\%$$

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

â€¢ Friction reduces the efficiency of a real or practical machine masking work output of the machine (work done on the load) less than the work input to the machine (work done by the effort).

Practice questions 7a

1. (a) What is a machine? State **two** classes of machine and give **two** examples of each.
   (b) Define these terms as applied to machines:
      (i) load
      (ii) effort and
      (iii) force ratio
   (c) A machine lifts a load of 700 N with an effort of 175 N. Calculate the mechanical advantage of the machine.
2. (a) Define *velocity ratio, mechanical advantage* and *efficiency* of machine.
   (b) Show that the efficiency of a machine is given by;
   $$\text{Efficiency}\,(\varepsilon) = \frac{M.A.}{V.R.} \times 100\%$$
   (c) A machine was used to raise a load of 650 N through a vertical height of 10 m. If the efficiency of the machine is 80% calculate the:
      (i) work done in lifting the load;
      (ii) work input to the machine;
      (iii) mechanical advantage if the velocity ratio is 5;
      (iv) effort used in lifting the load.
3. (a) Explain what is meant by the *mchanical advantage of a machine is 4.*
   (b) An effort of 40 N moving through a distance of 5 m lifts a load of 120 N through a vertical height of 1.25 m. Calculate;
      (i) the mechanical advantage;
      (ii) the velocity ratio;

(iii) work done by the load and the effort;
(iv) the efficiency of the machine.

4. (a) Define *mechanical advantage* and *efficiency* of a machine;
   (b) What is the effect of *friction* on *mechanical advantage* and *efficiency* of a machine?
   (c) When 15,000 J is supplied to a machine with velocity ratio 5, a load of 4000 N is lifted through a height of 3 m calculate the:
      (i) work done by the machine on the load;
      (ii) work done to overcome friction;
      (iii) efficiency of the machine;
      (iv) mechanical advantage of the machine.

SIMPLE MACHINES

OBJECTIVES

At the end of this section, students should be able to:

- calculate force ratio, velocity ratio and efficiency for simple machines;
- draw a lever, a pulley, wheel and axle, gears, an inclined plane, a screw and a wedge, and possibly do this to achieve a specified velocity ratio;
- apply simple machines to do work;
- identify simple machines that make up complex machines;
- solve simple problems on machines.

The lever

A lever is a simple machine which magnifies the effort applied at one end to lift a load at the other end. **A lever is a force multiplier.** This means that it increases the resultant effect of the applied force. Levers help to make our work easier.

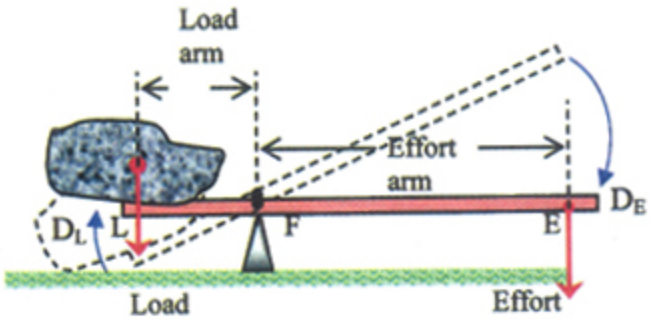


Figure 7.3: Lever and its parts

A simple lever consists of a bar which rotates about a **fulcrum** or **pivot.** The distance LF perpendicular to the line of action of the load and the fulcrum is called the **load arm.** The effort arm is the perpendicular distance FE between the fulcrum and the line of action of the effort. When an effort is applied at the point E, the lever turns about the fulcrum F to lift the load at L. The **velocity ratio** of a lever is the ratio of effort arm to load arm.

$$V.R. = \frac{\text{Effort arm}}{\text{Load arm}}$$

The longer the effort arm, the greater the velocity ratio for a lever.

Classes of levers

There are three classes of levers: the first class lever, the second-class lever and the third class lever.

1. **First class (order) levers.** The fulcrum or the turning point is between the load and the effort. Examples of first class levers are crowbar, scissors, claw hammer and pliers.

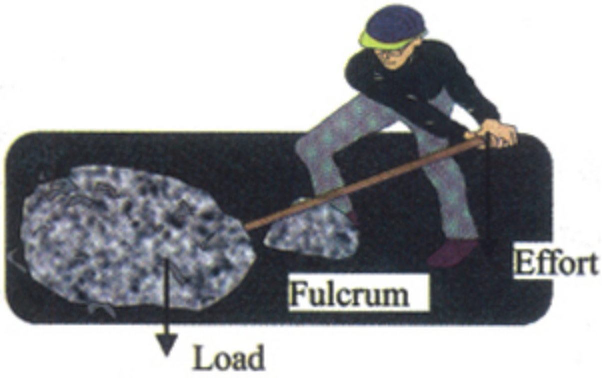


Figure 7.4a: First class order arrangement (LFE)

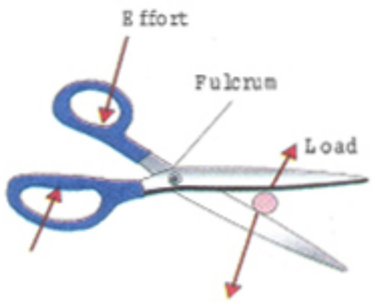


Figure 7.4b: Scissors

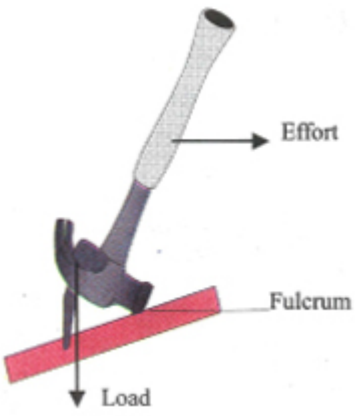


Figure 7.4c: Claw hammer

The mechanical advantage of these levers varies depending on the position of the fulcrum. We gain mechanical advantage if the effort arm is greater than the load arm.

2. **Second class (order) levers.** The load is between the effort and fulcrum in a second-class lever. Mechanical advantage is gained because the effort arm is longer than the load arm.

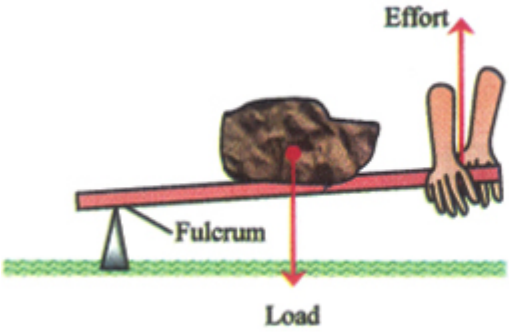


Figure 7.5a: Second class order arrangement (FLE)

The wheelbarrow, bottle top opener, nutcrackers, doors and car bonnets are examples of second-class lever.

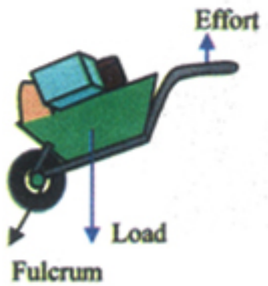


Figure 7.5b: Wheelbarrow

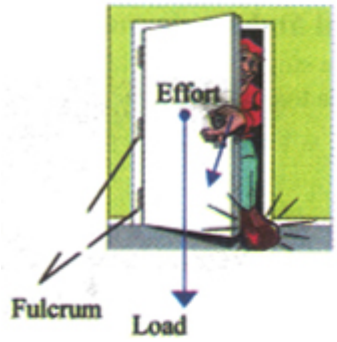


Figure 7.5c: Door

3. **Third class (order) levers.** These sets of lever have their effort applied between the load and the fulcrum. More effort is needed to overcome the load or resistance because effort distance is less than the load distance. Sugar tongs and the human arm are examples of third class machines.

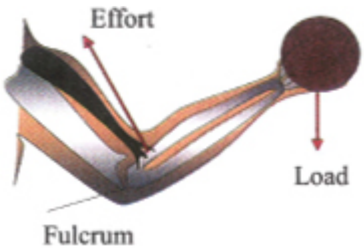


Figure 7.6a: The human arm

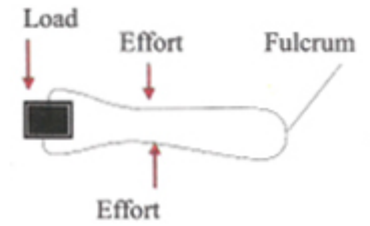


Figure 7.6b: The sugar tong

Pulleys

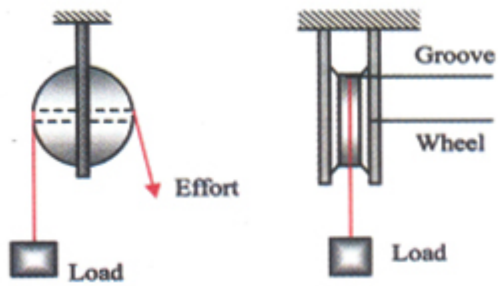


Figure 7.7: Side and front views of a single movable pulley

Pulley are machined used to raise loads on building sites.

Pulleys as simple machines are used to lift loads. It consists of a wheel with a groove in its rim. Rope passed through the grooves help in lifting the load vertically.

A pulley is Î± first class lever where an effort is applied continuously through the rope at one end to lift a load.

Single fixed and single movable pulleys

Figure 7.7 is a single fixed pulley. The effort applied at one end of the rope is transmitted by the rope to the load.

â€¢ The V.R. = 1 for a single fixed pulley, therefore the load and the effort travel the same distance.

â€¢ The M.A. = 1 for a single fixed pulley therefore, load lifted is equal to the effort applied to lift it if the pulley is without friction.

â€¢ The fixed pulleys enable us to pull downward (i.e. it changes the direction of the effort); it is easier pulling downward with an effort E than pulling upward.

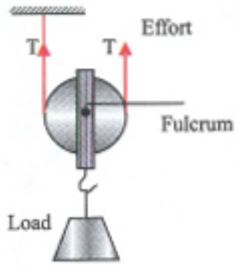


Figure 7.8: Side view of a single movable pulley

In a single movable pulley shown in figure 7.8, the load is attached to the pulley. The effort applied to the rope creates a tension T in the rope. The pulley will be in equilibrium if the total upward force (2T) is equal to the total downward force (L). Load L = 2T and the effort E = T. If the pulley is without friction, the mechanical advantage (M.A.) = 2.

$$M.A. = \frac{\text{Load}}{\text{Effort}} = \frac{2T}{T} = 2$$

â€¢ The single movable pulley is used to gain mechanical advantage. When the number of pulleys is increased the mechanical advantage increases.

â€¢ In practical pulleys, the mechanical advantage is less than 2 due to friction which exists between the rope and the pulley, mass per unit length (thickness) of the rope and the weight of the pulley.

â€¢ The velocity ratio of a single movable pulley is 2; therefore, the effort travels twice the distance of the load.

â€¢ V.R. = The number of ropes supporting the load or weight.

Block and tackle system

A block of pulleys is made of two or more pulleys fixed to a common frame. When the pulleys are connected with a single rope, it becomes a **block and tackle.**

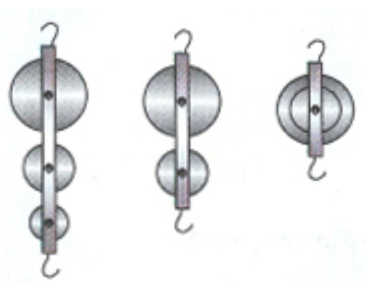


Figure 7.9: Blocks of pulleys

Two pulley systems

Two pulley systems consist of a movable pulley which aids in gaining mechanical advantage and a fixed pulley. The fixed pulley is used to change the direction of the effort so that we can pull downwards. For a two pulley systems:

â€¢ The V.R. is equal to the number of ropes attached to the movable pulley (load). In Figure 7.10(a) the V.R. = 2, two ropes attached to the movable pulley. This is equal to the number of pulleys in the system if the effort is pulling downwards.

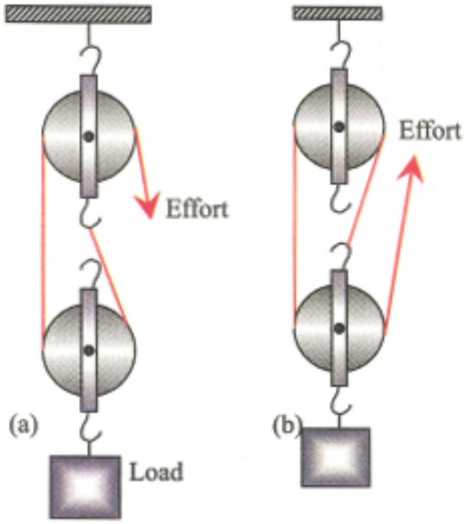


Figure 7.10: Two pulley systems

â€¢ In Figure 7.10(b), the V.R. = 3 because three ropes are attached to the movable pulley. The gain in mechanical advantage in Figure 7.10(b) is higher but we have to pull upwards.

â€¢ M.A. is not equal to the V.R. because friction and the weight of the pulley reduce the M.A.

Three pulley systems

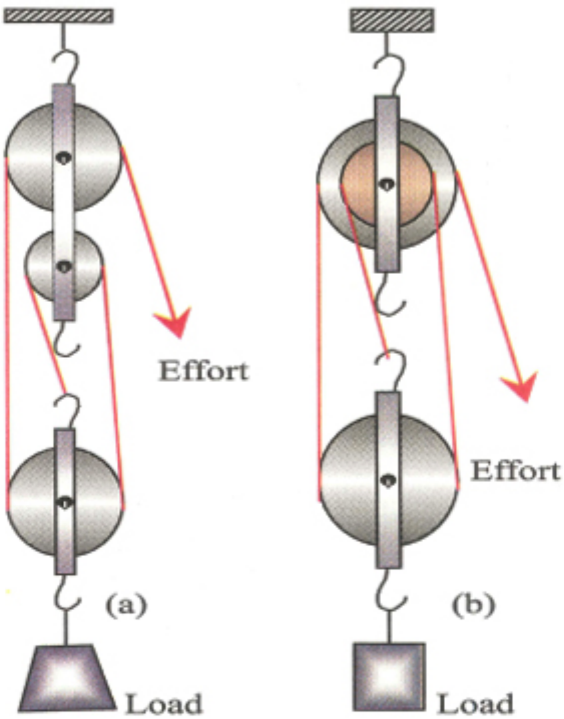


Figure 7.11: Three-pulley systems

Figure 7.11 shows two ways of arranging three pulley systems to give a V.R. of 3. Both arrangements give a higher mechanical advantage than the two pulley systems. Closer observations show that the V.R. is equal to the number of ropes attached to the movable pulley or **the number of pulleys in the system if the direction of the effort is downward.**

Four or more pulley systems

Higher velocity ratio can be obtained if the number of pulleys is increased (i.e. the number of ropes attached to the movable pulley is increased). Number of pulley is equal to the velocity ratio of the system.

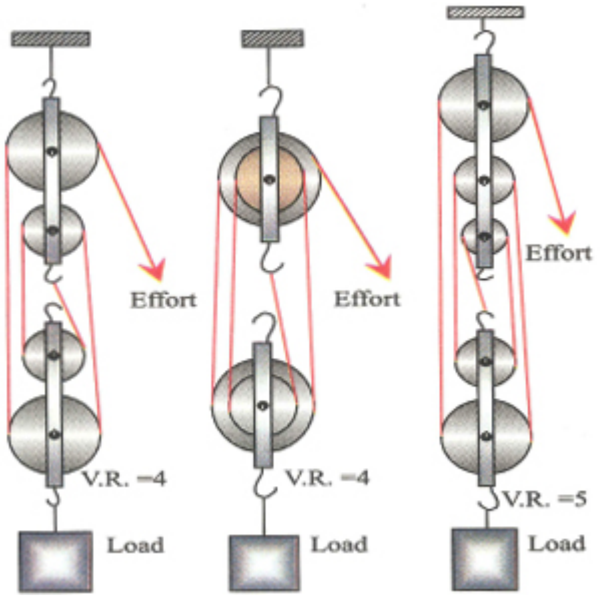
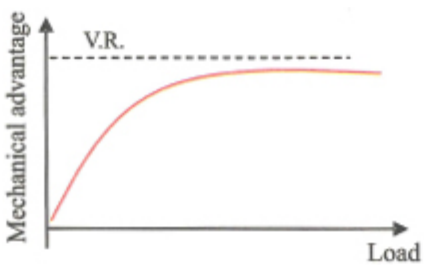
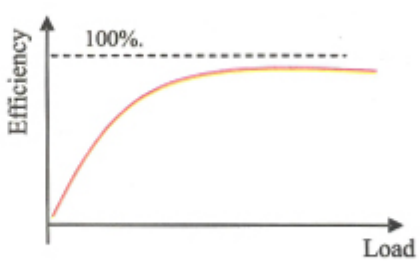


Figure 7.12: Four and five pulley systems

The velocity ratio of each of the pulley system shown in Figure 7.12 is equal to the number of pulleys in the system. The mechanical advantage of the block and tackle systems of pulleys is always less than the velocity ratio for all practical pulleys. This is because friction and the weight of the movable pulley or block of pulleys reduce the mechanical advantage of the pulley systems.

Mechanical advantage can be increased by increasing the load. This is because increasing the load makes the weight of the movable pulley insignificant. The efficiency of a pulley system can be increased but cannot reach 100%. The behaviour of mechanical advantage (M.A.) and efficiency (Îµ) of pulley systems as the load is increased are illustrated in the graph below.





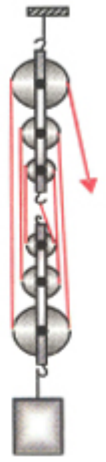
Worked examples

1. (a) Draw a block and tackle system of pulleys with a velocity ratio (V.R.) of 6

   (b) Calculate the efficiency of the pulley system in (a) if an effort of 120 N is needed to lift a load of 600 N.

Solution

(a)



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

$$M.A. = \frac{600\ N}{120\ N} = 5$$

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

$$\varepsilon = \frac{5}{6} \times 100\%$$

$$\varepsilon = 83.3\%$$

2. A pulley system has a velocity ratio of 4. If the efficiency of the pulley system is 75% calculate the:

   (a) distance travelled by the effort when the load is raised by 12 m.

   (b) effort needed to lift a load of 1200 N.

   (c) work done by the load and effort.

   (d) work done against friction.

Solution

(a) Velocity ratio $= \dfrac{\text{effort distance}}{\text{load distance}} = \dfrac{D_E}{D_L}$

$$4 = \frac{D_E}{12}$$

Effort distance = 4 × 12 = 48 m.

(b) Efficiency $= \dfrac{M.A.}{V.R.} \times 100\%$

$$75 = \frac{M.A.}{4} \Rightarrow M.A. = \frac{75 \times 4}{100} = 3$$

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

$$3 = \frac{1200}{Effort}$$

$$Effort = \frac{1200}{3} = 400N$$

(c) Work done by load = L Ã— D_L
= 1200 Ã— 12
= 14,400 J
Work done by effort = E Ã— D_E
= 400 Ã— 48
= 19,200 J

(d) Work done against friction W
W = 19,200 – 14,400 = 4800J

Wheel and axle

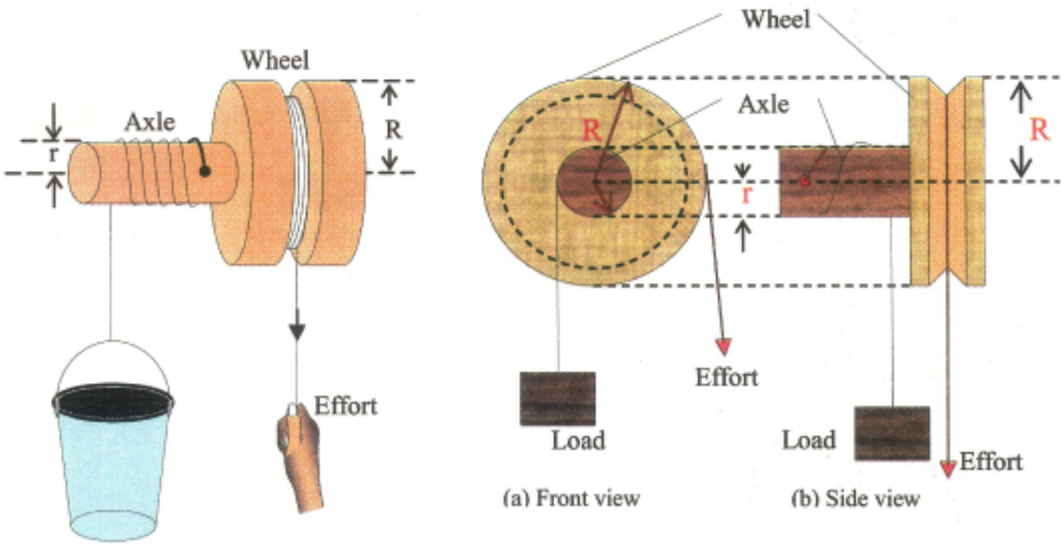


Figure 7.13: Wheel and axle

Wheel and axle is another form of a lever. A small effort applied on the wheel continuously gives a large force on the axle to lift a load attached to it.

Wheel and axle is made of an axle rigidly fixed to the wheel. The diameter (radius) of the wheel is bigger than the diameter (radius) of the axle. The effort is applied on the wheel through a rope as shown in Figure 7.13 while the load is fixed to the rope wound on the axle. The winding of the rope on the wheel is in the opposite direction to the winding of the rope on the axle. When the wheel and axle makes one complete turn, the effort travels a distance equal to the circumference of the wheel (2Ï€R) while the load covers a distance (2Ï€r) which is the circumference of the axle. The velocity ratio of the wheel and axle is given by:

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

$$V.R. = \frac{2\pi R}{2\pi r} \text{ or } V.R. = \frac{\pi D}{\pi d}$$

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

R = radius of the wheel *($D = 2R$)*, r = radius of the axle *($d = 2r$).*

Higher velocity ratio is obtained by increasing the radius of the wheel and decreasing the radius of the axle. Examples of wheel and axle are the steering wheel of a vehicle, a spanner turning a nut, a screwdriver unscrewing a nut or a screw, the doorknob and the windlass.

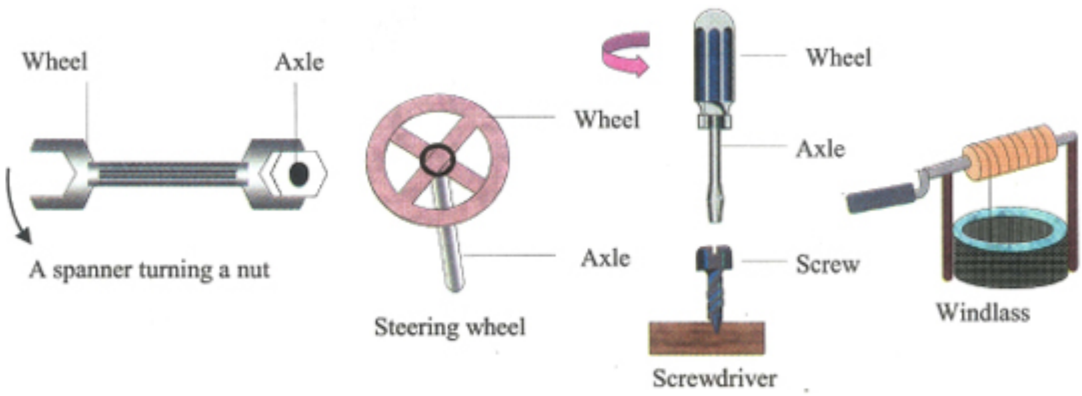


Figure 7.14: Wheel and axle

Worked example

1. A wheel and axle has an axle of radius 7 cm and a wheel of radius 42 cm. Calculate the:
   (a) velocity ratio.
   (b) distance travelled by the load and effort.
   (c) load lifted by the effort of 30 N if the efficiency is 70%. $\{\pi = \frac{22}{7}\}$

Solution

(a) $V.R. = \frac{R}{r} = \frac{42\ cm}{7\ cm} = 6$

(b) Distance moved by the load = 2 Ï€ r D_L = 2 Ï€ Ã— 7 = 44 cm
Distance moved by the effort = 2 Ï€ R D_E = 2 Ï€ Ã— 42 = 264 cm.

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

$$70 = \frac{M.A.}{6} \times 100\%$$

$$M.A. = \frac{70 \times 6}{100} = 4.2$$

$$4.2 = \frac{\text{Load}}{30}$$

$$\Rightarrow \text{Load} = 4.2 \times 30 = 126\ N$$

Gears

A gear is a lever in which effort is continuously applied. A gear magnifies both the effort and the distance covered. It consists of two wheels the **driving wheel** and the **driven wheel**.

Figure 7.15: Gears

In Figure 7.15, the smaller wheel is the driving wheel and the bigger wheel is the driven wheel. The velocity ratio of a gear is given by:

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

If the driving wheel has 16 teeth and driven wheel has 32 teeth, then the velocity ratio (V.R.) = 2. This means that when the driving wheel completes two revolutions in the clockwise direction, the driven wheel completes just one revolution in the anticlockwise direction. The torque produced by the driven wheel is more than the torque produced by the driving wheel because the radius is greater than the radius of the driving wheel. The gain in momentum is paid for by the low speed of the driven gear. The efficiency of a gear is very high that the mechanical advantage is almost the same as the velocity ratio.

The inclined plane

The inclined plane is the easiest of the simple machine. It is used to lift heavy loads vertically by gradually moving up the slope of a plane or a ramp. The hill, slope and a ramp (Planck inclined at angle to the ground) are examples of an inclined plane.

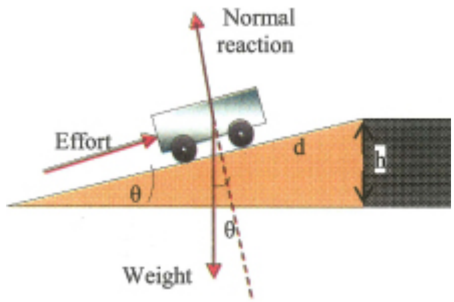


Figure 7.16: Inclined plank

Figure 7.16 illustrates an easy way to move a load up to a height *(h)* above the ground. Moving an object up to a height *(h)* requires an effort. The effort is much less when we push the object along the length *(d)* of a ramp or an inclined plane than direct lifting from the ground. The inclined plane gives us a mechanical advantage because a small effort is required to lift a big load.

$$V.R. = \frac{\text{Length of inclined plane}}{\text{Height of inclined plane}}$$

$$V.R. = \frac{d}{h} = \frac{1}{\sin\theta}$$

The velocity ratio of an inclined plane can be increased by increasing the angle Î¸ of the inclined plane. The mechanical advantage gained is paid for by the effort travelling a longer distance to lift the load through a small height (h).

Worked example

An inclined plane of length 12 m is used to lift a load of 1500 N to a vertical height of 3 m. If an effort of 500 N is required to move the load to the desired height, calculate:

(a) the mechanical advantage;

(b) the velocity ratio;

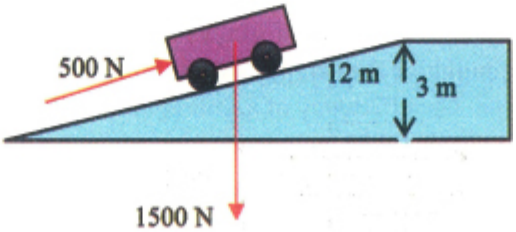
(c) the work done by the load;

(d) the work done by the effort;

(e) the work done against friction;

(f) the efficiency of the inclined plane.

Solution



(a) $\text{Mechanical advantage} = \dfrac{\text{Load}}{\text{Effort}}$

$\text{Mechanical advantage} = \dfrac{1500\text{ N}}{500\text{ N}} = 3$

(b) $V.R. = \dfrac{\text{Length of inclined plane}}{\text{Height of inclined plane}}$

$V.R. = \dfrac{12\ m}{3\ m} = 4$

(c) Work done by the load $= L \times D_L$

$= 1500 \times 3 = 4500\text{ J.}$

(d) Work done by the effort $= E \times D_E$

$= 500 \times 12$

$= 6000\text{ J.}$

(e) Work done against friction = W

$W = 6000\text{ J} - 4500\text{ J} = 1500\text{ J.}$

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

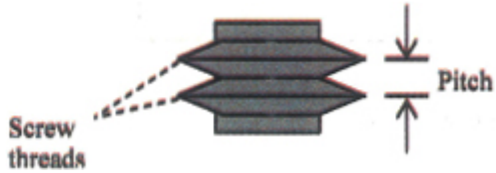
$\text{Efficiency} = \dfrac{3}{4} \times 100\% = 75\%.$

The screw

A screw is made up of a rod with a thread on it. The thread of a screw is an inclined plane wound round a rod as illustrated in Figure 7.17.

Figure 7.17: Link between inclined plane and a screw

The distance P measured between two close threads is called the pitch of the screw. One complete turning of the screw moves the load through a distance of one pitch. A screw is used to apply large force on the load in simple machines like screw jack, nut and bolt, vice, etc.



The screw Jack

The screw jack consists of two simple machines; the **lever** and the **inclined plane.** The lever arm or handle is called the **Tommy bar** while the inclined plane is wrapped on a rod to form the **threads** of the screw jack. Turning the Tommy bar through one complete rotation moves the effort a distance of 2Ï€r (r = length of the Tommy bar) and the load is lifted through a height equal to the pitch **Î¡** of the screw. The velocity ratio of a screw jack is given by:

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

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

The velocity ratio of a screw jack is high because the length of the Tommy is much longer than the pitch. The velocity can be increased by increasing the length of the Tommy bar and decreasing the pitch of the screw jack. The efficiency of a screw jack is very low because large friction is needed to stop the load from sliding down if the effort is removed.

Worked example

A screw jack of efficiency 25% is used to lift a load 15,710 N. The tommy bar of a screw jack is 50 cm long and the pitch is 0.5 cm. Calculate the:

(a) velocity ratio of the screw jack;

(b) mechanical advantage of the screw jack;

(c) effort needed to lift the load. $\{\pi = \frac{22}{7}\}$

Solution

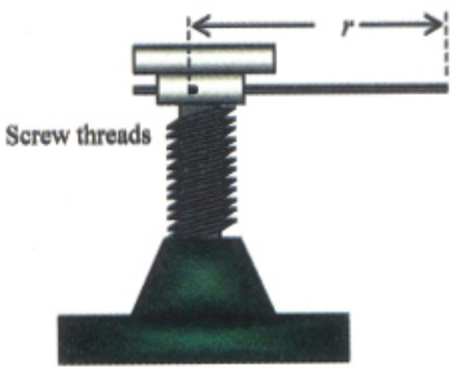


Figure 7.18: The screw jack

(a) $V.R. = \frac{2\pi r}{P} = 2 \times \frac{22}{7} \times \frac{50}{0.5} = 628.6$

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

$$25 = \frac{M.A.}{628.6} \times 100\%$$

$$M.A. = \frac{25 \times 628.6}{100} = 157.2$$

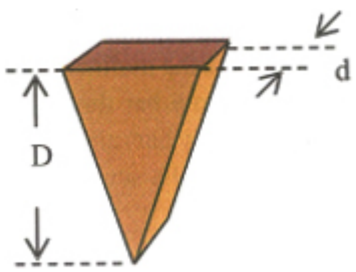
(c) $\text{Mechanical advantage} = \frac{\text{Load}}{\text{Effort}}$

$$157.2 = \frac{15710}{\text{Effort}} \Rightarrow \text{Effort} = \frac{15710}{157.2} = 99.99\ N$$

The wedge

The wedge is an inclined plane with double sides. If a force (effort) is applied on the wedge, it moves it a distance D into the wood and at same time the wood (load) splits apart by d. D is the distance moved by the effort while d is the distance moved by the load.

The velocity ratio of a wedge is given by:



igure 7.19: Wedge

$$\text{Velocity ratio} = \frac{D}{d}$$

The velocity ratio (V.R.) is increased by increasing D and decreasing d. The wedge like a screw jack is a machine with low efficiency or mechanical advantage because friction is very high. The high friction is needed to keep the wedge in position when the driving force or effort is removed.

Worked example

A wedge of length 25 cm and thickness 5 cm is used to split a log of wood. If the efficiency of the wedge is 25% and the resistance of the wood 750 N, calculate the:

(a) velocity ratio of the wedge;

(b) mechanical advantage of the wedge;

(c) effort required to overcome the load.

Solution

(a) $V.R. = \frac{D}{d} = \frac{25\ cm}{5\ cm} = 5$

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

$25 = \frac{M.A.}{5} \times 100\%$

$M.A. = \frac{25 \times 5}{100} = 1.25$

(c) $\text{Effort} = \frac{\text{Load}}{M.A.} = \frac{750}{1.25} = 600\ N$

Summary

â€¢ A lever is a simple machine which magnifies the effort applied at one end to lift a load at the other end.

â€¢ A pulley is a first class lever where an effort is applied continuously through the rope at one end to lift a load.

â€¢ V.R. of a pulley = the number of ropes supporting the load or weight. V.R. is equal to the number of ropes attached to the movable pulley or the number of pulleys if the direction of the effort is downwards.

- The velocity ratio of wheel and axle is given by:

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

- The velocity ratio of gears is given by:

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

- The velocity ratio of inclined plane is given by:

$$V.R. = \frac{\text{Length of inclined plane}}{\text{Height of inclined plane}}$$

â€¢ The velocity ratio of a screw is given by:

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

â€¢ The wedge is an inclined plane with double sides.

Practice questions 7b

1. (a). What is a **lever**? Why is a lever regarded as a force multiplier?
   (b) State the classes of levers and give two examples of each.
   (c) A crowbar of length 10 m is supported at 2m mark in order to lift a load of 500 N at one end when an effort of 300 N is applied at the other end. Calculate the:
      (i) velocity ratio of the lever;
      (ii) mechanical advantage of the lever;
      (iii) efficiency of the lever.

2. (a) Explain the terms **work** and **efficiency**.

(b) For the pulley systems shown below, calculate the mechanical advantage and efficiency of each.

(c) What are the effect of friction and the weight of the pulleys on the efficiency for each of the pulley systems?

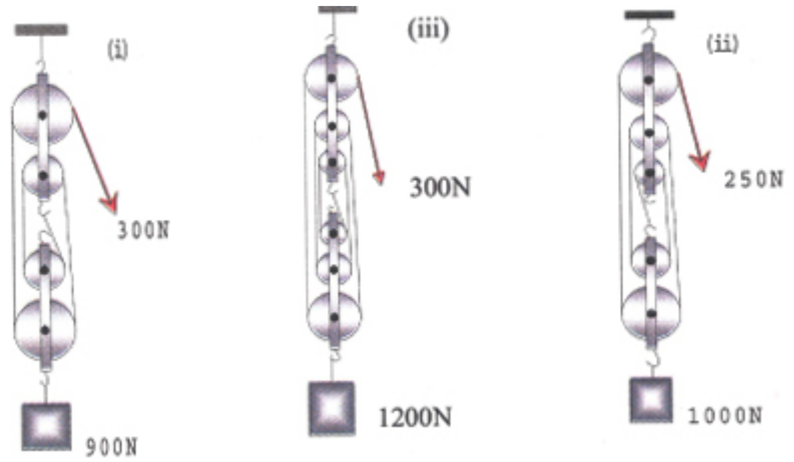


Figure 7.20: Pulleys

3. (a) Explain:

(i) why the mechanical advantage of a machine is less than its velocity ratio;

(ii) how to increase the velocity ratio of a wheel and axle.

(b) A wheel and axle is made up of a wheel of diameter 24 cm and axle of diameter 6 cm. When an effort of 100 N is applied to the wheel a load of 300 N is lifted through a vertical height of 3 m, calculate the:

(i) velocity ratio of the wheel and axle;

(ii) mechanical advantage of the wheel and axle;

(iii) efficiency of the wheel and axle;

(iv) work done to overcome friction.

4. (a) Draw a diagram of a pulley system with velocity ratio of 5;

(b) State two factors that may affect the mechanical advantage of a pulley system.

(c) The pulley in question (a) is used to lift a load of 400 N through a vertical height of 8 m by exerting an effort of 100 N. Calculate the:

(i) work done by the effort;

(ii) efficiency of the pulley system.

5. (a) Explain the terms **work** and **efficiency** as applied to a machine. Write the formula connecting them.

(b) The efficiency of the wheel and axle shown in Figure 7.21, is 80%, calculate:

(i) the mechanical advantage;

(ii) the velocity ratio;

(iii) the diameter of the wheel;

(iv) energy used to overcome friction when the wheel is turned through 20 revolutions.

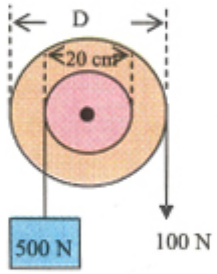


Figure 7.21: Single wheeled pulley

6. (a) Define the terms **mechanical advantage** and **efficiency** of a machine;
   (b) State how friction affects the mechanical advantage and efficiency of a machine.
   (c) A gear wheel has 20 teeth and is used to drive another gear wheel with 60 teeth. Calculate the:
      (i) velocity ratio of the gear system;
      (ii) the number of revolution per second of the driven gear if the driver gear rotates 9 times each second.
      (iii) the mechanical advantage of the gear system if its efficiency is 80%.
7. A roadside mechanic uses a spanner of length 24 cm to loose a nut whose diameter is 4 cm. if the efficiency of the spanner is 60%, calculate its:
   (i) velocity ratio;
   (ii) mechanical advantage;
   (iii) the resistance of the nut if the mechanic applies an effort of 50 N to loose it.
8. (a) Explain why a screw jack requires high friction to work very well;
   (b) A carpenterâ€™s vice has a pitch of 7.5 Ã— 10^{-3} m and a handle of length 0.5 m. If an effort of 50 N is used to overcome a load of 4000 N, calculate the efficiency of the vice.
9. (a) Define velocity ratio and force ratio and show that the velocity ratio of an inclined plane is given by $V.R. =. \frac{1}{\sin\theta}$
   (b) A force of 100 N is needed to push a load of 250 N to a platform 3 m above the level ground. If the length of the inclined plane is 15m, calculate the:
      (i) gain in potential energy of the load;
      (ii) efficiency of the inclined plane.
10. (a) What do you understand by the terms **work** and **efficiency**?

(b) Describe a wedge and explain why it is considered a simple machine.

(c) A wedge of length 50 cm and thickness 5cm at the end is used to split a log of wood. If the force exerted by the hammeron the wedge is 500 N, calculate the sidewise force of the wedge on the wood if the efficiency is 40%.

Past questions

1. Which of the following statements correctly defines a simple machine? A device

   A. that can provide electric current.

   B. which can only carry people from one place to another.

   C. with which work can be done easily.

   D. which changes the state of rest or uniform motion of an object along a straight line.

   WASSCE

2. A machine with a velocity ratio of 5 is used to raise a load with an effort of 500 N. If the machine is 80% efficient, determine the magnitude of the load.

   A. 2500 N

   B. 2000 N

   C. 1200 N

   D. 625 N

   WASSCE

3. An 80% efficient crane raises a cargo of mass 3.0 Ã— 10^3 kg through a height of 10 m in 120 s, calculate the power input. {$g = 10\ ms^{-2}$}

   A. 3125 W

   B. 2500 W

   C. 2000 W

   D. 200 W

   WASSCE

4. A block and tackle system of pulley has 6 pulleys. If the efficiency of the machine is 60%, determine its mechanical advantage.

   A. 12.0

   B. 10.0

   C. 3.6

   D. 1.8

   WASSCE

5. Which of the actions will improve the efficiency of a pulley system?

   A. Reducing the mass of the pulley.

   B. Increasing the frictional force between the string and the pulley.

   WASSCE

C. Increasing the mass per unit length of the string of the pulley.

D. Increasing the mass of the pulley.

6. In which of these simple machines is the effort applied between the load and fulcrum?

A. Claw hammer

B. Nut crackers

C. Pliers

D. Sugar tongs

E. Wheel barrow.

NECO; WAEC

7. A simple machine with efficiency of 75% lifts a load of 5000 N when an effort of 500 N is applied to it. Calculate the velocity ratio of the machine.

A. 10.0

B. 13.3

C. 17.5

D. 25.0

WASSCE

8. A screw jack with a Tommy bar of length 12 cm is used to raise a car through a vertical height of 25 cm by turning the Tommy bar through 50 revolutions. Calculate the approximate velocity ratio of the jack. $\{\pi = \frac{22}{7}\}$

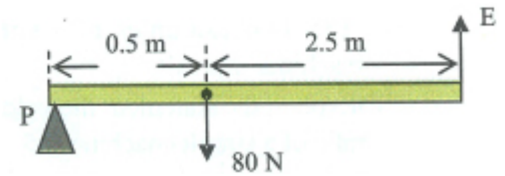
A. 21

B. 38

C. 48

D. 151

WASSCE 2001 J

9. 

A beam PQ pivoted at P carries a load of 80 N as shown above. Calculate the effort Î• required to keep it horizontal. [Neglect the weight of the beam]

A. 32 N

B. 26.7 N

C. 16.0 N

D. 13.3 N

WASSCE

10. The statement that the mechanical advantage of machine is 3 means that the

A. efficiency is $33\frac{1}{3}$%.

B. effort is three times as large as the load.

C. mechanical advantage is three times as large as

NECO

the velocity ratio.

D. ratio of effort to load is 1:3. velocity ratio is 3.

11. Lubricant are used in machines to reduce friction

A. decrease the mechanical advantage.

B. increase the mechanical advantage.

C. increase the velocity ratio.

D. decrease the velocity ratio. **WASSCE**

12. A block and tackle system of five pulleys has an efficiency of 70%. Calculate the effort that will be required to raise a load of 42.00 N.

A. 6.00 N

B. 12.00 N

C. 24.00 N

D. 29.40 N

E. 58.80 N **NECO**

13. 5000 J of work done on a machine results in the lifting of a load of 800 N through a vertical distance of 5 m. Calculate the efficiency of the machine.

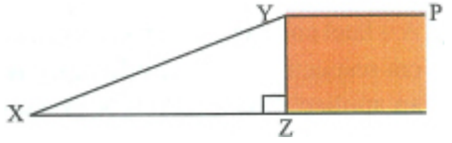
A. 100%

B. 90%

C. 80%

D. 75% **WASSCE**

14.



In the diagram above XY represents a plank used to lift a load from a point X on the ground onto a horizontal platform YP. What is the velocity ratio of the Planck?

A. $\frac{XY}{ZY}$ B. $\frac{XY}{XZ}$

C. $\frac{XZ}{XY}$ D. $\frac{ZY}{XY}$ **WAEC**

15. Two spanners X and Y of lengths 15 cm and 20 cm respectively are used to give a screw of pitch 2 mm one complete rotation. If R_x and R_y are the respective velocity ratios of the spanners, then the ratio R_x:R_Y is

A. 1:50

B. 3:20

C. 3:4

D. 4:3

E. 20:3 **WAEC**

16. The efficiency of a wheel and axle system is 80% and the ratio of the radii is 5:1. What is the effort needed to lift a load of 280 N?

A. 25 N

B. 50 N

C. 70 N

D. 85 N

17. A body of mass 7.5 kg is to be pulled up along a plane which is inclined at 30Â° to the horizontal. If the efficiency of the plane is 75%, what is the minimum force required to pull the body up the plane? {g= 10 ms^{-2}}

A. 5.0 N

B. 20.0 N

C. 50.0 N

D. 75.0 N

E. 200.0 N

WAEC

18. A wheel and axle have radii 80 cm and 10 cm respectively. If the efficiency is 0.85, an applied force of 1200 N to the wheel will lift a load of

A. 8.0 N

B. 6.8 N

C. 8160.0 N

D. 9600.0 N

JAMB

19. Calculate the velocity ratio of a screw jack of pitch 0.3 cm if the length of the tommy bar is 21 cm

A. $\frac{1}{140}\pi$

B. 14Ï€

C. 70Ï€

D. 140Ï€

JAMB

20. An inclined plane of angle Î¸, acting as a simple machine has a velocity ratio

A. sin Î¸

B. $\frac{1}{\sin\theta}$

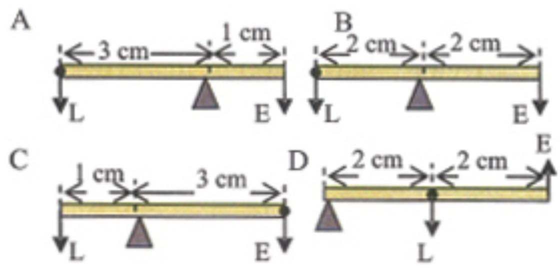
C. cosÎ¸

D. $\frac{1}{\cos\theta}$

E. sin *Î¸* cos *Î¸*

JAMB

21. Which of the following levers has the greatest mechanical advantage?



22. (a) (i) What is meant by a machine?
(ii) List two examples of a simple machine.
(iii)Explain the statement the velocity ratio of a simple machine is 5.
(b) (i) Define the efficiency of a machine.
(ii) Explain why a machine cannot be 100% efficient.
(d) A screw jack, 25% efficient and having a screw of pitch 0.4 cm is used to raise a load through a certain height. If in the process, the handle turns through circle of radius 40.0 cm, calculate the;
(i) velocity ratio of the machine;
(ii) mechanical advantage of the machine;
(iii) effort required to lift a load of 1000 N with the machine. {Ï€ = 3.14}

WASSCE

23. (a) Explain the term work.
(b) Draw a diagram of a pulley system with velocity ratio of 5.
(c) A man pulls up a box of mass 70 kg using an inclined plane of effective length 5 m onto a platform 2.5 m high at uniform speed. If the frictional force between the box and plane is 100 N, draw the diagram of forces acting on the box when in motion and calculate the;
(i) minimum effort applied in pulling up the box;
(ii) velocity ratio of the plane;
(iii) mechanical advantage of the plane;
(iv) efficiency of the plane;
(v) energy lost in the system;
(vi) work output of the man;
(vii) total power developed by the man given that the time taken to raise the box onto the platform 50 s. {g = 10 ms^{-2}}

WAEC

24. (a) (i) Explain what is meant by a machine.
(ii) Define the terms: mechanical advantage, velocity ratio and efficiency of a machine.
(b) Explain why the efficiency of a machine is usually less than 100%.
(c) A screw jack whose pitch is 4.4 mm is used to raise a body of

mass 8000 kg through a height of 20 cm. The length of the tommy of the jack is 70 cm. if the efficiency of the jack is 80%, calculate the:

(i) velocity ratio of the jack;

(ii) mechanical advantage of the jack;

(iii) effort required in raising the body;

(iv) work done by the effort in raising the body. $\{g = 10\ m\ s^{-2}, \pi = \frac{22}{7}\}$

WAEC