

IFA BORU
SPECIAL BOARDING SECONDARY SCHOOL

PHYSICS HANDOUT
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Contents

1 Simple Machines **2**
1.1 Introduction 2
1.2 The purposes of Machines 3
1.3 Principles of Simple Machines 5
1.4 Types of simple machines 10
1.5 Review Exercise 24

1

Simple Machines

1.1 Introduction

A **machine** in the broad sense of the word is any device designed or engineered to translate some form of energy into useful work or a machine is a device that makes work easier by transmitting or transforming energy.

They have been used since ancient times to help people move heavy objects, bring substances like water from one place to another and fasten materials to one another in construction.

Today, machines are used for a huge number of tasks, including transportation, communication and entertainment. Machines can make work easier by decreasing the force necessary to move an object or increasing the speed of an object. They can also make work easier by changing the direction in which force must be applied to do work.

Most machines consist of a number of elements, such as gears and ball bearings that work together in a complex way. Nevertheless, no matter how complex they are, all machines are based in some way on six types of simple machines. These six types of simple machines are the lever, the wheel and axle, the pulley, the inclined plane, the wedge, and the screw.

Machines can be either simple or complex(compound).
Simple Machines Simple machines are machines that only use one type of machine, such as a lever or an inclined plane.
Simple machines are used in everything such as from cutting food and wood, to hanging a picture on the wall.
Without machines there is no way our relatively weak body could lift blocks weighting thousands of tons or even travel much faster than 5m/s for long period of time.

A **simple machine** is a device

- that only requires a single force to work
- for doing work that has only one part
- that uses a single effort to do work against a single load

Examples of simple machines include levers, knife, spoon, Spade, an axle, chopper, pulleys, ramps, wedges, gears, and chain/sprockets.



Figure 1.1: Different Machines

The **Complex (Compound) machines**

- Complex machines are machines that use multiple types of simple machines together.
- Most machines used in daily life are complex machines or compound machines, which are made up of two or more simple machines.
- Complex machines make work easier, by changing either the force or the distance over which workis done.
- Complex machines have advantages over simple machines. They often are provide a better solution than just a simple machine alone.
- For example, a roller coaster is many steep inclined planes with lots of wheels, pulleys and gears to keep the car's moving.
- More complex machines include such examples as electric motors, heat engines, pumps, compressors, and refrigerators.

1.2 The purposes of Machines

Since work is defined as the product of force acting on an object in the direction of motion or the displacement ($W = FS$), a machine makes it easier to do work by performing one or more of the following functions

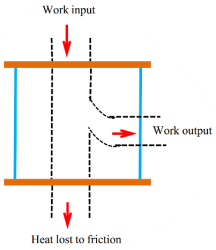
- transferring a force from one place to another,
- changing the direction of the applied force,
- increasing the magnitude of the applied force, or

- increasing the distance or speed of the applied force.

No machine can create extra energy or power, if it does the work you put in is greater than the work you get out but, this is impossible the amount of useful work performed by a machine can never be greater than the work supplied to it. However; it is possible to get more force out than you put in. There will always be some loss of energy due to friction or other dissipative forces.

For example, in pumping up a bicycle tire with a small hand pump we exert a down force on the plunger, causing air to be forced into the tire, that some of the input work is lost to friction can easily be verified by feeling how warm the wall of the hand pump becomes.

The smaller we can make the friction loss in a machine, the greater the return for our effort. In other word, the effectiveness of a given machine can be measured by comparing its output work with the work supplied to it. No machine can multiply both force and distance/speed at the same time.



In order to use a simple machine you have to apply a force to the machine. The input force applied to operate the machine is called **Effort (E)** or **force input**; whereas the weight the body upon which the machine does work is called the **Load (L)** or **Force output**.

The work done on the machine at the effort end is called the **work input** and the work done by the machine at the load end is called the **work output**.

Work done on the machine

$$Work\ input = Effort \times distance\ moved\ by\ Effort$$

$$W_i = E \times S_E$$

Work done by the machine

$$Work\ output = Load \times distance\ moved\ by\ Load$$

$$W_0 = L \times S_L$$

The load and effort usually differ in magnitude and direction as well as location. In the ideal world, mechanical energy is never lost to other forms and work input equals work output. If there were no energy losses inside the machine, then we have

$$W_i = W_0$$

$$E \times S_E = L \times S_L$$

In the real world, however, mechanical energy is always lost due to dissipative forces, so work input is strictly greater than work output.

$$Wi > W0$$

$$E \times S_E > L \times S_L$$

According to the **principle of conservation of energy**, the above functions are related as follow:

$$Work\ input = work\ output + work\ done\ against\ friction$$

$$W_i = W_o + W_f$$

So, if the machine has been designed so the distance moved by the load is less than distance moved by the effort then the load can be greater than the effort. This means a smaller effort can be used to move a large load.

For example, suppose a machine that when an effort of 300N is moved through a distance of 2m and it moves a load through a distance of 0.4m. What is the maximum load that the machine lifts?
$E = 300N$, $S_E = 2m$, $S_L = 0.4m$, $L =$?

$$E \times S_E = L \times S_L \implies L = \frac{E \times S_E}{S_L}$$

$$L = \frac{300N \times 2m}{0.4m} = 1500N$$

In the same manner, it is possible to move a smaller Load a bigger distance than the distance moved by the effort.

1.3 Principles of Simple Machines

A machine simply transmit mechanical work from one part of a device to another part. A machine multiplies a force and controls the direction and the motion of the force, but it cannot create energy.

All machines have different abilities of doing work. Some of them are more effective than others. For example, one types of a force multiplier machine might be able to move a 200 N load with a 25N of effort.

Another might be able to move a 1000N load with the same effort. No, matter which type of simple machine depending on their functions we deal with they will fit into one or more of the following categories.

i. Force multiplier

ii. Distance or speed multiplier

iii. Direction changer

Force multipliers
Force multipliers are devices that reduce the amount of force necessary to move an object.
Force multipliers are useful for lifting heavy objects or doing other things that require large amounts of force.

This is only possible if the load moves through a smaller distance than the effort at the same time or simultaneously.

$$S_L < S_E$$

Some examples of force multipliers are inclined planes and most levers.

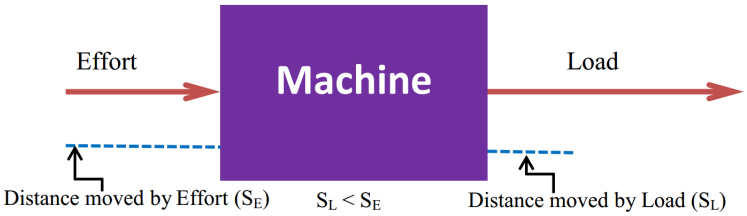


Figure 1.2: Force Multiplier Machines

Speed multipliers
Speed multipliers are devices that increase the speed of, or distance travelled by, an object.

Here, the distance moved by the load is greater than the distance moved by the effort.

$$S_L > S_E$$

Although more force than usual is required to move the object in these cases, the extra force is changed into more kinetic energy. Speed multipliers are useful when an object needs to move a further distance or at a higher speed.

This is only possible if the load is smaller than the effort a at the same time. Some examples are wheels and axles and third class levers.

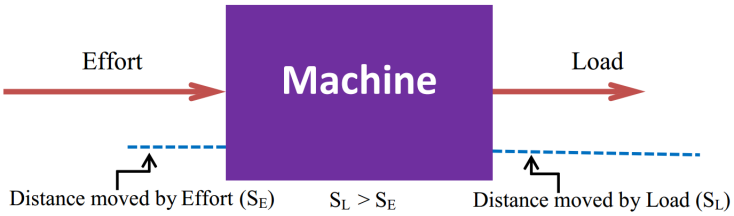


Figure 1.3: Speed Multiplier Machines

Direction changers
These are machines designed so that the load is moved in a different direction to the effort.

Depending on how they are designed some machines can act as both force or speed multipliers and direction changer.

However, a machine cannot multiply both the force and the speed at the same time. This would mean that the workout put would be greater than the work input. Energy conservation is still obeyed.

A machine's ability to do work is compared by the following terms. These are:

- mechanical advantage

- Velocity ratio
- efficiency

Mechanical advantage (MA)
The machine can increase the amount of the output force, at the cost of a proportional decrease in the distance moved by the load.

The term Mechanical advantage refers to how much a simple machine multiplies an applied force (effort or input force).

It is described by the ratio of the output force (**Load**) to the applied force or input force (**Effort**).

Mechanical Advantage has no unit it is unit less, because its the ratio of two force.

Mechanical Advantage is most frequently used to compare force multipliers.

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

$$MA = \frac{L}{E}$$

For example, if a machine moves a 800N load when an effort of 100N is applied, the Mechanical Advantage is eight. In other words, you get 8 times the force out of the machine.

Under mechanical advantage the distance the load moved will only be a fraction of the distance through which the effort is applied.

While machines can provide a mechanical advantage of greater than 1(and even less than 1 if desired), no machine can never do more mechanical work than the mechanical work put into it.

Mechanical advantage is mostly used to compare whether or not a machine is a force multiplier.

For example, if the MA is 1, this means that the effort equals the load. If the MA is 3, the load is 3 times of the effort. This is only possible when the load is greater than the Effort.

Generally, if the MA is greater than one ($MA > 1$), then the machine can be considered as a **force multiplier**. There are two kinds of Mechanical Advantages.

Actual Mechanical Advantage (AMA)
The Actual Mechanical Advantage (AMA) is the mechanical advantage determined by physical measurement of the input and output forces.

Actual mechanical advantage takes into account energy loss due to deflection, friction, and wear.

The AMA of a machine can be calculated as the ratio of the measured force output to the measured force input,

$$AMA = \frac{Load}{Effort} = \frac{L}{E}$$

Ideal Mechanical Advantage (IMA)
The Ideal Mechanical Advantage (IMA), or theoretical mechanical advantage, is the mechanical advantage of a device with the assumption that its components do not flex, there is no friction, and there is no loss of energy. It is calculated using the physical dimensions of the device and defines the maximum performance the device can achieve.

In this case

$$IMA = AMA$$

We can represent this ideal case by setting

$$W_f = 0$$

$$Work\ input = work\ output + work\ done\ against\ friction$$

$$W_i = W_o + W_f \implies W_i = W_o \implies E \times S_E = L \times S_L$$

Since this equation represents an ideal case, we define the Ideal Mechanical Advantage as:

$$IMA = \frac{L}{E} = \frac{S_E}{S_L}$$

This implies that

$$IMA = AMA$$

Velocity Ratio (VR)

- The term velocity ratio refers to the ratio between the distance moved by the effort and the distance moved by the load.

$$Velocity\ Ratio(VR) = \frac{distance\ moved\ by\ the\ Effort}{distance\ movedby\ the\ load}$$

$$VR = \frac{S_E}{S_L}$$

- Just like MA, VR has no unit since it is a ratio. It is used to compare between the distance moved by the load and the effort.
- For example, if the VR is 1 this means that the effort and the load both move the same distance. If the VR is 2, then the effort has to move twice as far as the load.
- VR is also used to compare whether or not a machine is a speed multiplier. For example, if the VR is less than 1, then the machine can be considered as a speed multiplier. This is true only when the distance moved by the load is greater than the distance moved by the effort.

Efficiency of machines

- No machine can increase both the magnitude and the distance of a force at the same time. When a machine provides an increase in force there must always be a decrease in the distance of the force is moved. The reverse is also true, if a machine provides an increase in the distance the force moves then there will be a decrease in force. In both cases we have understood that no machine can produce more work than the amount of work that is put into the machine.

- The efficiency of a machine is the ratio between the works it supplies or work output and the work put into it or work input. Although friction can be decreased by oiling any sliding or rotating parts, all machines produce some friction. Simple machines always have efficiencies of less than 1 due to internal friction.

$$efficieny = \frac{Work\ output}{Work\ input} \times 100\%$$

$$\eta = \frac{W_o}{W_i} \times 100\%$$

- The Efficiency of a machine can also be expressed in terms of MA and VR, We know $W_o = LxS_L$ and $W_i = ExS_E$

$$\eta = \frac{W_o}{W_i} \times 100\% = \frac{LxS_L}{ExS_E} \times 100\% = \frac{AMA}{VR} \times 100\%$$

- Another useful expression for efficiency can be noted from the definition of power as work per unit time.

$$Power = \frac{Work}{time} \implies Work = Power \times time = Pt$$

- The efficiency in terms of power input P_i and Power output P_o is given by:

$$\eta = \frac{P_o}{P_i} \times 100\%$$

- Like MA and VR, in all case efficiency has no units it is unitless.

Example

1. A simple machine is used to move a 600N load through a distance of 25cm when an input force of 30N is moved through a distance of 5m. Determine the a) work input b) work output c) Actual Mechanical Advantage d) Velocity Ratio e) Ideal Mechanical Advantage f) Is it force/speed multiplies g) Efficiency of the machine h) What type of machine is it? Is it ideal or real machine?

- Given: $L = 600N$, $E = 30N$, $S_L = 25cm = 0.25m$, $S_E = 5m$

a) $W_i = ExS_E = 30Nx5m = 150J$
b) $W_o = LxS_L = 600Nx0.25m = 150J$
c) $AMA = \frac{L}{E} = \frac{600N}{30N} = 20$
d) $VR = \frac{S_E}{S_L} = \frac{5m}{0.25m} = 20$
e) $IMA = \frac{S_E}{S_L} = \frac{5m}{0.25m} = 20$
f) Force multiplier
g) $\eta = \frac{AMA}{VR} \times 100\% = \frac{20}{20} \times 100\% = 100\%$
h) It is ideal machine

1.4 Types of simple machines

Commonly there are six different types of simple machines such as the lever, the wheel and axle, the pulley, the inclined plane, the wedge, and the screw. They can be categorized into two groups (inclined planes and Levers).

Inclined planes include

- Inclined plane
- Wedge
- Screw

Levers include

- Levers
- Pulley
- Wheel and axle

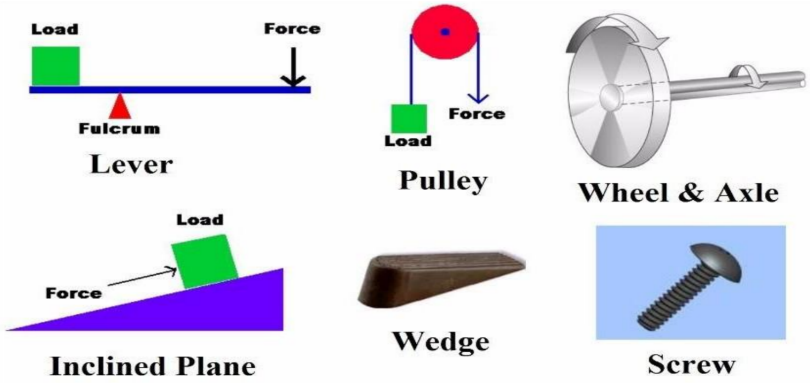


Figure 1.4: The Six Simple Machines

I) Inclined plane
An inclined plane or a ramp is a simple device that hardly looks like a machine at all. It is used to lift an object to a height (h) by sliding it up the length of the slope (l).

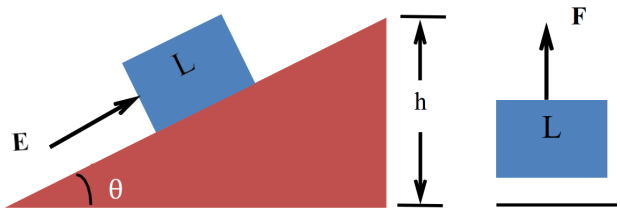


Figure 1.5: An Inclined Plane

We know it is easier to push an object up a ramp than it is to lift it to the same height. This is because inclined planes reduce the force necessary to move a load. In other words, the effort required is less.

However, the amount of work done must stay the same since the distance involved increases. The mechanical advantage increases as the slope of the incline decreases. But the load will then have to be moved a greater distance.

The ideal mechanical advantage (IMA) of an inclined plane is the length of the incline divided by the vertical rise.

$$IMA = \frac{length\ of\ the\ slope}{height\ of\ the\ load\ rised} = \frac{l}{h}$$

$$IMA = \frac{l}{h} = \frac{l}{l\sin\theta} = \frac{1}{\sin\theta}$$

The Actual Mechanical Advantage (AMA) of an inclined plane can be defined as the ratio of Load to Effort. In the case of inclined plane, the load would be the weight of the object and the effort would be to force required to push it up the slope.

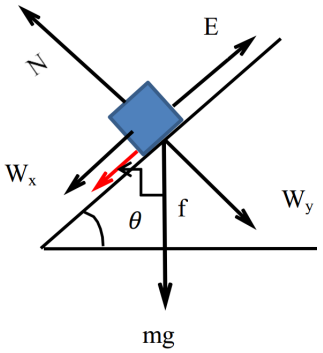


Figure 1.6: Free Body Diagram of an Inclined Plane

$W_x = mg\sin\theta$ and $W_y = mg\cos\theta$
If the block is moving up with constant velocity,

$$E - W_x - f = 0$$

$$E = mg(\sin\theta + \mu\cos\theta)$$

$$AMA = \frac{L}{E} = \frac{mg}{mg(\sin\theta + \mu\cos\theta)} = \frac{1}{(\sin\theta + \mu\cos\theta)}$$

Where μ is the coefficient friction between the block and the plane. The AMA of an inclined plane depends on the slope of the incline (θ) and the coefficient of friction between the block and the plane.

The mechanical advantage increases as the slope of the incline (θ) decreases. But the load will then have to be moved a greater distance.

Friction will be large if objects are slide along the surface of the inclined plane. Efficiency can be increase by using rollers in conjunction with the inclined plane.

The velocity ratio is:

$$VR = \frac{S_E}{S_L} = \frac{l}{h}$$

Then; the efficiency is:

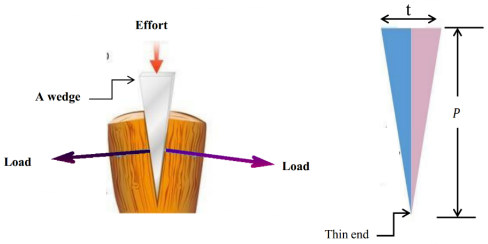
$$\eta = \frac{AMA}{VR} \times 100\% = \frac{h}{l(\sin\theta + \mu\cos\theta)} \times 100\%$$

II) A wedge

- A wedge is an adaptation of the inclined plane. It can be used to separate two objects (load) over a short distance or split objects (a log) apart. Examples of Wedges include Knives, Forks, Nails, Spears, Axes and Arrows heads.
- A wedge can either be composed of one or two inclined planes. A double wedge can be thought of two inclined plane joined together with their sloping surfaces outward.



- When using a wedge the effort is applied to the top of the wedge.
- The ideal mechanical advantage (IMA) of a wedge depends on the angle of the thin end. The smaller the angle, the less the force required to move the wedge a given distance through, say, a log. At the same time, the amount of splitting is decreased with smaller angles.



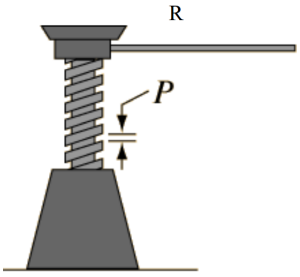
- Where; t: thickness of the wedge and P: the penetration length of the wedge.

$$AMA = \frac{L}{E} \text{ and } IMA = \frac{P}{t}$$

III) The Screw

- The term screwreally refers to any cylinder with a helical thread around it. This means it includes nuts and bolts as well as more traditional screws. The screw is a very useful machine; it can be used to hold objects together, to dig into the ground and to bore through rocks.
- You can think of a screw as like an inclined plane wrapped around a cylinder. In one turn of the screw it digs in and moves into the material a distance equal to the separation between the threads. This is referred to as the pitch (P) of the screw and it is analogous to the height of an inclined plane. If you could unravel a screw thread for each rotation you could see it moves up a distance equal to P. The length of the slope would be the same as the circumference of the screw shaft.

- The movement of the screw tip into the material provides the load, whereas the force used to turn the screw is the effort.
- The maximum theoretical mechanical advantage (IMA) for a screw can be calculated using the following equation:

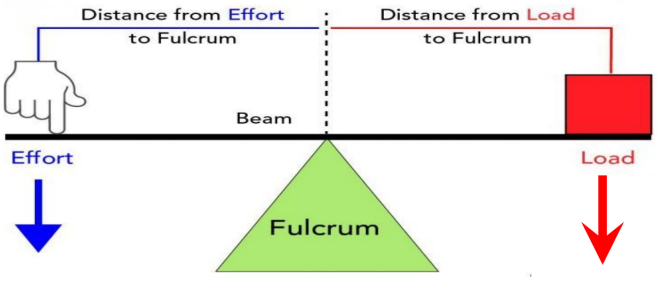


$$IMA = \frac{\pi d}{P} = \frac{2\pi R}{P}$$

- Where; d: the mean diameter of the screw shaft in m ($\pi d = 2\pi R$ is the circumference of the screw shaft, R is radius of screw shaft). P: the pitch of the screw in m.
- There is always a great deal of friction when using screws and the actual mechanical advantage is much less than the value calculated using the equation above. However, it is also worth noting mechanical advantage of a screw system is increased as the screwdriver (or other method for turning the screw) produces its own mechanical advantage.

IV) Lever

- A lever is a rigid bar that is free to pivot, or rotate, around a fixed point called the fulcrum. Applying a force to one end of the rigid bar causes it to pivot about the fulcrum, resulting in a magnification of the force at another point along the bar.



- A lever provides mechanical advantage. Mechanical advantage refers to how much a simple machine multiplies an applied force.
- The location of the effort, load, and fulcrum will determine the type of lever and the amount of mechanical advantage the machine has.
- The farther the effort is away from the fulcrum, the easier it is to move the load.

- In order to balance, the turning forces (moments) from both the objects must be equal. The force might be different but their turning effect must be the same. In order for an object to be balance:

$$anticlockwise\ turning\ force = Clockwise\ turning\ force$$

$$Effort \times Distance\ moved\ by\ Effort = Load \times Distance\ moved\ by\ Load$$

$$E \times S_E = L \times S_L$$

- Mechanical Advantage and velocity ratio can be calculated using this formula:

$$MA = \frac{L}{E}$$

$$VR = IMA = \frac{S_E}{S_L}$$

- If **E** is twice as large as **L**, then **L** will need to be twice as far away from the fulcrum in order for the see-saw to balance. The product of the force and distance for both the left hand side and the right hand side must be equal. If friction is considered, IMA is greater than AMA.

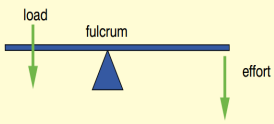
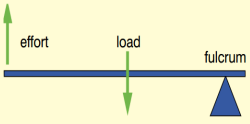
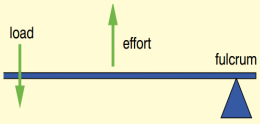
- The efficiency of the lever is given by

$$\eta = \frac{AMA}{VR} \times 100\%$$

- Depending on the relative distances levers can be force multiplier/ speed multipliers and /or direction changers.

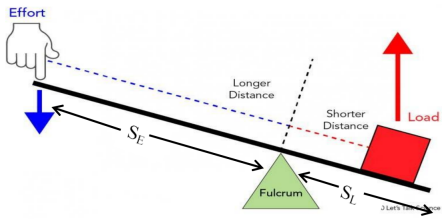
- There are three classes of levers, depending on where the input force, output force, and fulcrum are in relation to each other (i.e depending on the relative positions of the **load**, **fulcrum** and **effort**).

Different Types of Levers

Class	Diagram	Description	Examples
1st		Fulcrum is between the load and effort	• See-saw • Crowbar • Pliers (double lever) • Scissors (double lever)
2nd		The load is between the effort and the fulcrum	• Wheelbarrow • A rowing oar • Nutcracker (double lever)
3rd		The effort is between the load and fulcrum	• Catapult • Hoe or spade • Tongs (double lever)

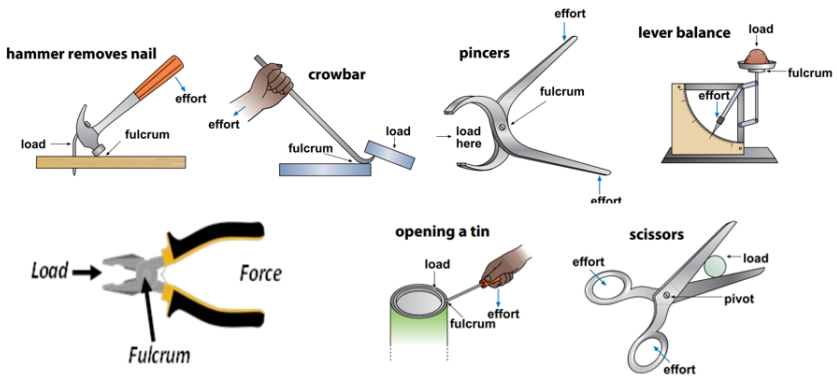
First Class Levers

- In a first class lever, the fulcrum is located between the load and the effort.
- If the fulcrum is closer to the load, then less effort is needed to move the load a shorter distance.



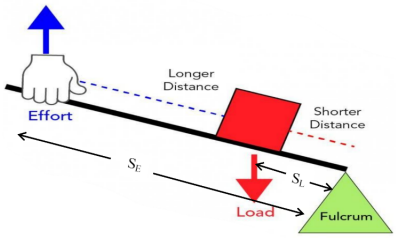
- If the fulcrum is closer to the effort, then more effort is needed to move the load a greater distance. A teeter-totter, a car jack, and a crowbar are all examples of first class levers. First class levers are very useful for lifting large loads with little effort.
- $VR = \frac{S_E}{S_L}$, Since $S_E > S_L$ and $VR > 1$, then the First class lever is considered as a **Force multiplier**.

examples of first class lever



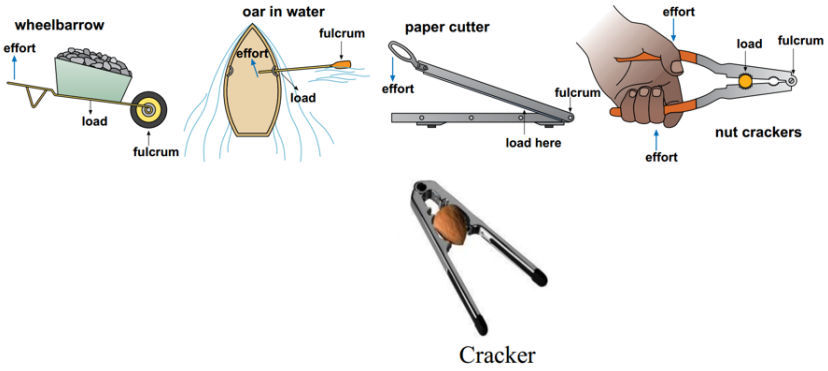
Second Class Levers

- In a second class lever, the load is located between the effort and the fulcrum.



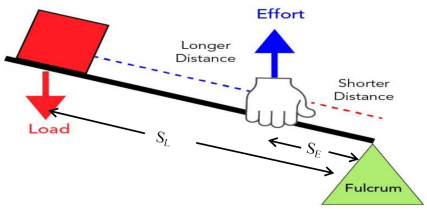
- If the load is closer to the fulcrum than the effort, then less effort will be required to move the load. If the load is closer to the effort than the fulcrum, then more effort will be required to move the load. A wheelbarrow, a bottle opener, and an oar are examples of second class levers.
- $VR = \frac{S_E}{S_L}$ Since $S_E > SL$ and $VR > 1$, then the Second class lever is considered as a **Force multiplier**.

examples of second class lever



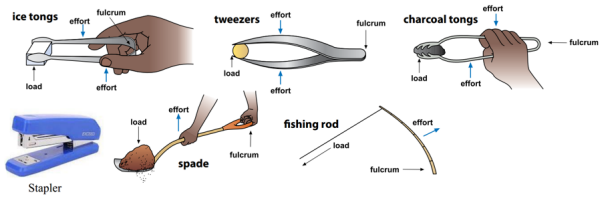
Third Class Levers

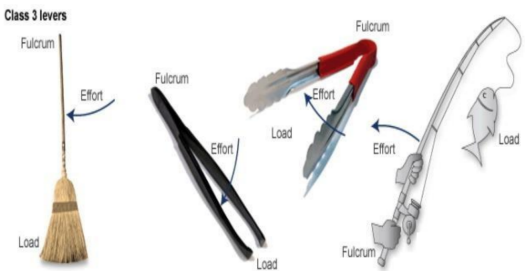
- In a third class lever, the effort is located between the load and the fulcrum.



- If the fulcrum is closer to the load, then less effort is needed to move the load. If the fulcrum is closer to the effort, then the load will move a greater distance. A pair of tweezers, swinging a baseball bat or using your arm to lift something, fishing rod are examples of third class levers. These levers are useful for making precise movements.
- Levers are very useful simple machines used for transferring force. You may not realize it, but you use levers every day.
- Since $S_E < S_L$ and $VR < 1$, then the Second class lever is considered as a **distance or speed multiplier**.

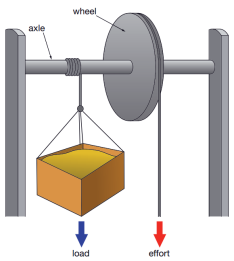
examples of third class lever



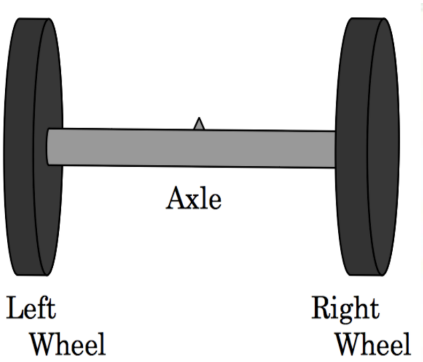


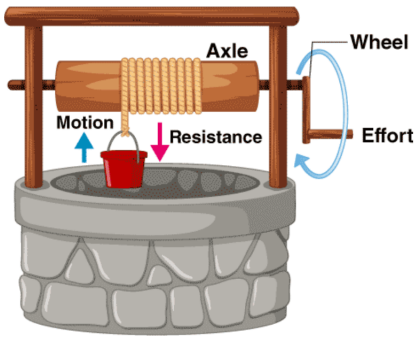
V) Wheel and Axle

- The wheel and axle is another type of simple machine. It is composed of a large wheel secured to a smaller wheel, which is called an axle.
- Wheels and axles do not just include the obvious: they also gears, door-knobs, steering wheels and even screwdrivers.
- An axle is a rod or pole centred in the wheel in such a way that it allows the wheel to turn around it.
- The wheel and axle rotates together and transfer force from one to the other. Sometimes, there may be two wheels attached to both ends of the axle.
- Gears are a form of the wheel and axle. An electric motor, electric fan, car, bicycle, a Ferris wheel are all examples of uses of wheel and axle.
- There are two main ways to use a wheel and axle.
- There are two main ways to use a wheel and axle. The first way can be seen in Figure. You can wrap a rope around a supported wheel and apply an effort to the end of the rope. This causes the wheel and attached axle to rotate. If a load is attached to the axle as it turns it lifts the load.



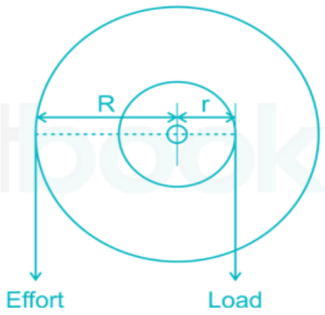
- The effort has to move a long way to complete one single revolution (as the diameter of the wheel is large).
- The load moves a much smaller distance as the axle has a much smaller diameter. This means the load can be much greater than the effort and so there is a mechanical advantage, i.e it acts as a force multiplier.
- The second way to use a wheel and axle is to have two wheels at the end of an axle. The wheel and axle then behaves like a type of rotating lever. In this case the fulcrum would be the centre point of the axle. As the wheels turn they can then be used to provide movement.





- A wheel and axle or a windlass used for lifting water from wells as shown in Figure.The rope tied to the axle and a bucket of water wound on an axle when the wheel rotates.
- The Velocity of Ratio of a wheel and axle can be determined by the ratio of the radius of the wheel to the radius of the axle.
- This is because as the wheel turns once it covers a distance equal to $2\pi R$; at the same time the axle turns $2\pi r$.
- Where **R** is the radius of the wheel and **r** is the radius of the axle.

$$VR = \frac{S_E}{S_L} = \frac{2\pi R}{2\pi r} = \frac{R}{r}$$



- Since $S_E > S_L$ and $VR > 1$, then in this arrangement the wheel and axle acts as a force multiplier.
- The mechanical Advantage of a wheel and axle can be calculated using the standard equation of:

$$AMA = \frac{Load}{Effort} = \frac{L}{E}$$

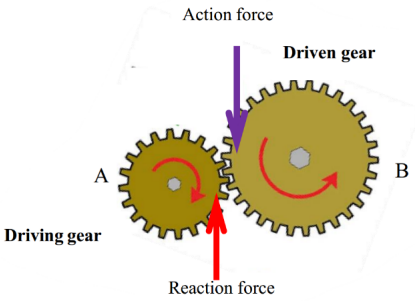
- If the machine was 100% efficient then $VR = MA = IMA$ so:

$$IMA = VR = \frac{R}{r}$$

- If the radius of the wheel is ten times greater than the radius of the axle, every time you turn the wheel once, the force will be multiplied by ten but it will also travel ten times the distance.
- Depending on the relative radii wheels and axles can be thought of as force multipliers/speed multipliers and/or direction changers.

Gears

- Gears are toothed wheels designed to transmit torque to another gear or toothed component. The teeth of gears are designed so as to minimize wear, vibration and noise, and to maximize the efficiency of power transmission. Gears and the use of gears are essential in daily life and can be found in mechanical devices as well as everyday household objects.
- Gears have been around for hundreds of years. The first mention of gears came from Aristotle in the year 330 BC, when he designed devices for various construction jobs. He observed that the direction of rotation is reversed when one gear wheel drives another gear wheel. At that time, gears were also used in making water-raising devices and to make catapults.
- Today, gears are used on a daily basis. They are found nearly everywhere in clocks, cars, odometers, scales, conveyor systems, just to name a few examples. Manufacturing companies rely on several various sizes of gears for production. Gears are essential parts of almost every mechanical device known to mankind.
- Gears are often used in conjunction with a wheel and axle. They can be configured to offer an increase in mechanical Advantage or an increase in the distance travelled, depending on the requirements of the system. As one gear turns its teeth lock into another gear and force it to rotate. The gear made to turn the other gear is called the **driving gear**. The effort is applied on the driving gear.
- Consider two gears whose teeth fit and are in contact as shown in Figure. At a point where the teeth of the two geared wheels make contact, equal and opposite forces acts on each other. The two forces are action and reaction forces.



- The action force is the force exerted by the driving gear (A) on the driven gear(B). The reaction force is the force exerted by the driven gear (B) on the driving gear(A). From Figure, see the driving gear rotates clockwise whereas the driven gear rotates anticlockwise.
- The driving gear is like the gear on the pedal wheel of a bicycle and the driven gear is like the gear on the back wheel of a bicycle.
- Many machines use gears. A very good example is a bicycle which has gears that make it easier to cycle, especially up hills. Bicycles normally have a large gear wheel which has a pedal attached and a selection of gear wheels of different sizes, on the back wheel. When the pedal is revolved the chain pulls round the gear wheels at the back.
- The driving gear is moved by the effort whereas the driven gear moves the load. That means, the distance moved by the effort (S_E) is equal to the number of rotation of the driving gear and the corresponding distance moved by the load (S_L) is the number of rotation of the driven gear.

- The velocity ratio of geared wheels is given by the ratio of the number of their teeth, which is called **gear ratio**.

$$VR = \frac{number\ of\ teeth\ on\ driven\ wheel}{number\ of\ teeth\ on\ driving\ wheel} = \frac{N_{driven}}{N_{driving}}$$

- If the left hand wheel (Gear-A) was the driving gear, then there would be a VR of greater than one because $N_{driving} < N_{driven}$ and then, the gear is speed multiplier.

$$VR = \frac{N_{driven}}{N_{driving}} > 1$$

- If the right hand wheel (Gear-B) was the driving gear, then there would be a VR of smaller than one because $N_{driving} > N_{driven}$ and then, the gear is force multiplier.

$$VR = \frac{N_{driven}}{N_{driving}} < 1$$

- If the machine was 100% efficient then VR = MA = IMA so:

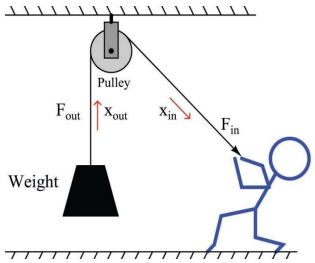
$$IMA = VR = \frac{N_{driven}}{N_{driving}}$$

- Two or more gears together are called **Transmission**. Depending on gear ratio, transmission can produce a change the speed, magnitude and direction of a force.
- Some uses of gear wheel, Gear wheels are used for
  - To reverse the direction of rotation
  - To increase or decrease the speed of rotation
  - To move rotational motion to a different axis
  - To keep the rotation of two axes synchronized
- Depending on the gear ratio, transmissions can produce a change the speed, magnitude and direction of a force.
- The most common application of gears involves one gear causing another to rotate. However, in a rack and pinion a gear causes a linear toothed track (called a rack) to move. This leads to a movement in a straight line rather than a rotation.

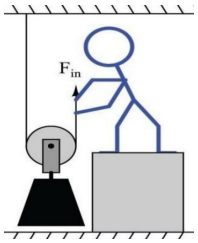


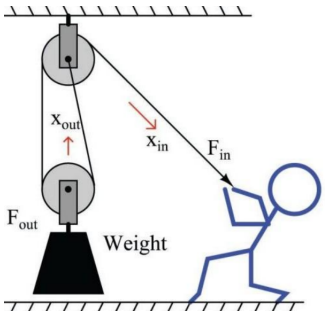
VI) Pulley system

- Another simple and useful machine is a pulley and rope. A "pulley" is nothing more than a wheel with a groove cut around its circumference to guide a rope or cable, a bearing and axle supporting the wheel and allowing it to freely turn.

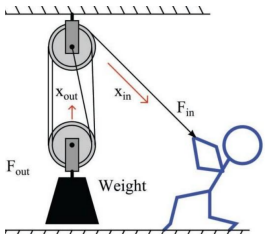


- There are several different kinds of pulleys. The most simple comprises a fixed axle with a rope looped over the top is called **Single Fixed Pulley**.
- The Single fixed pulley will not provide a Mechanical Advantage more than one. That means, it does not multiply either force or speed. The only purpose of Single fixed pulley is to change the direction of the force.
- In a single movable pulley, in Figure, there is only one pulley and the axle is free to move up and down in the system, yet the weight is being supported by the tension in two ropes and the person pulling on the rope only feels the tension of one rope, which means the system has a velocity ratio of 2.





- In Figure, the weight is being supported by the tension within two ropes, not just one rope. Since the person's force on the rope is what generates the rope's tension, is equal to rope tension, while is equal to twice the rope's tension.
- Thus, this simple machine has a velocity ratio equal to 2. It also means the person's motion while pulling the rope will be exactly twice the motion of the hoisted weight.
- Remember that we cannot violate the Law of Energy Conservation: work input cannot be less than work output. If the output force is twice as much as the input force due to mechanical advantage, the output motion can only be half as much as the input motion.
- The mechanical advantage of a pulley system may be extended beyond two by adding even more pulleys. In Figure, this pulley system has a mechanical advantage of 4, since the weight is being supported by the tension of four ropes, while the person pulling only feels the tension of a single rope.

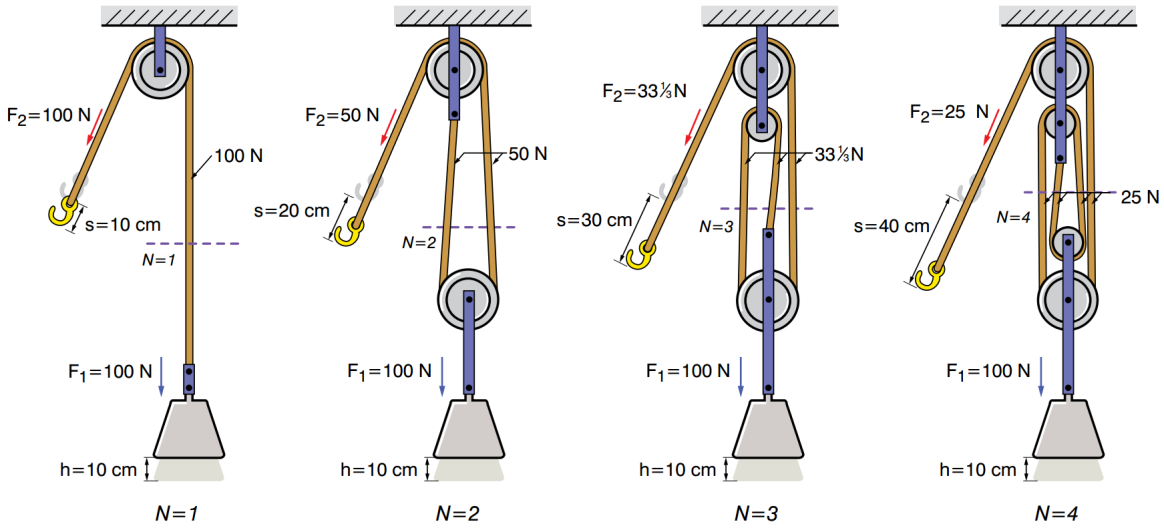


- For both a fixed and movable pulleys there will be energy losses due to friction. As a result, the MA will always be less than the VR. If there is no energy losses in the pulley system, then the $VR = MA = IMA$.

- Generally, the velocity ratio of a pulley system depends on the number of sections of rope used to lift the load. If there is only one section, then the $VR = 1$, if there are two sections of rope, then the $VR = 2$, and so on. Therefore, the VR of the pulley system is given by

$$VR = number\ of\ sections\ of\ rope\ that\ lift\ or\ support\ the\ load = N$$

$$VR = N$$



More complex Machines

- A complex machine is one where two or simple machines are combined together to function as a single machine. Examples include Scissors, Wheelbarrow, bicycles, the differential pulley and the jackscrew. Let us discuss more detail about the differential pulley and the jackscrew.

  The differential pulley

- A differential pulley is a pulley in combination with a wheel and axle. It is sometime called a "Chain hoist" and it can be used to lift extremely large masses over a short distance.

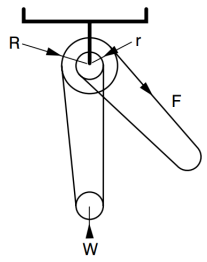
- It is composed of two fixed pulleys at the top. These are attached to each other and both rotate together. However, they have different radii (R and r) One long loop of rope (or commonly a chain) passes around the pulleys. The excess hangs off the pulley in a loop. To lift a load you pull on the loop, causing the pulleys to rotate and slowly lift the load.

- The mechanical Advantage is

$$AMA = \frac{Load}{Effort} = \frac{W}{F}$$

- The velocity ratio is

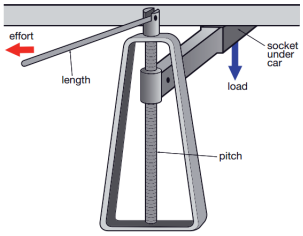
$$VR = \frac{2R}{R-r}$$



- As R-r approaches to zero, the IMA increases. If R is about the same as r it almost gets to the stage where the weight looks like it is no longer lifting as you end up pulling long lengths of chain or rope downward for a very small vertical movement. However, you are able to lift very heavy loads.

The jackscrew

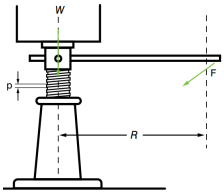
- A jackscrew is a screw in combination with a lever. The MA from the lever allows large weights to be lifted by the screw. The mechanical advantage is calculated using the standard equation:



$$AMA = \frac{Load}{Effort} = \frac{W}{F}$$

- Where, $load = W$ and the $Effort = F$ (the force applied at the end of the lever).
- The velocity ratio of a jackscrew is given by

$$VR = IMA = \frac{2R}{P}$$



- The longer the handle (R) and the smaller the pitch (P) the greater the VR or IMA, but it would take even more turn in order to lift the Car.

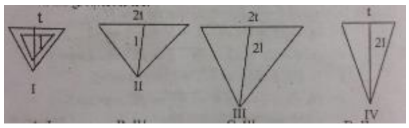
1.5 Review Exercise

Part-I **Write true if the statement is correct and false if the statement is wrong.**

1. In real world there is a machine which is 100% efficient.
2. Efficiency is the ratio of work input to work output.
3. A fixed pulley is used to multiply a force.
4. Wedge is a double inclined plane.
5. The separation between each thread in the screw is known as a pitch.

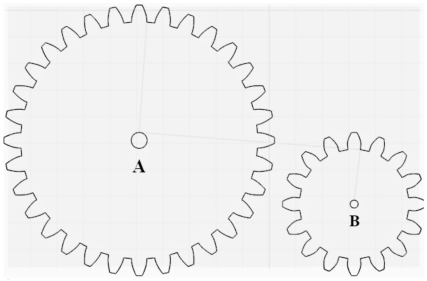
Part II. **Multiple choice**

6. Which one is NOT correct about simple machine?
   A) Machines help us to make work easier
   B) Machines create energy to help us
   C) Machines act as force multipliers
   D) Machines act as speed multipliers
7. Which one of the following is the purpose of a simple machine?
   A) Increasing volume C) Changing mass
   C) Multiplying energy D) Multiplying force
8. If a machine raises a load to height of 8 m when effort is moved by 2m, then the machine is
   A) Distance multiplier B) Force multiplier
   C) Both force and speed multiplier D) Direction changer
9. An effort of 30 N is applied on a machine to raise a load of 150 N. By how much does the machine multiply the force?
   A) 3 B) 5 C) 7 D) 95.
10. A machine used 50 N effort through a distance of 8 m in order to lift a load of 100 N through a distance of 4 m. What is the efficiency of the machine?
    A) 70% B) 80% C) 90% D) 100%
11. Which of the following double wedges with different length 'l' and thickness 't' offers the greatest IMA?



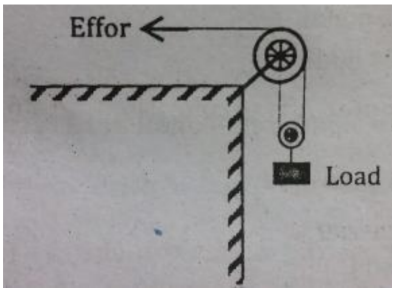
A) I B) II C)III D) IV

12. The diagram below shows a pair of gear wheels. The number of teeth on gear A is 32 and on B is 16. Which of the following statement is correct when B is the driving gear?



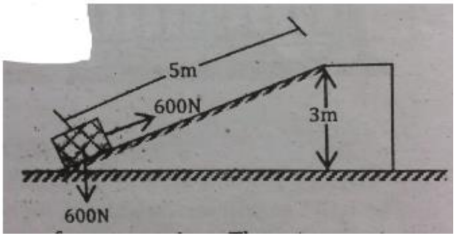
A) the load is less than the effort and A rotates slower than B
B) the load is less than the effort and A rotates faster than B
C) the load is greater than the effort and A rotates slower than B
D) the load is greater than the effort and A rotates faster than B

13. The figure below represents a pulley system. If the pulley masses and frictional losses are ignored, the machine is;



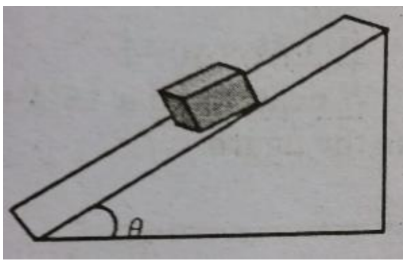
A) neither speed nor force multiplier
B) both speed and force multiplier
C) force multiplier
D) speed multiplier

14. Due to the presence of friction, the effort needed to slide a 600N load along the inclined plane is 600N as shown in the diagram below. What is the efficiency of the inclined plane in lifting the load to the 3m height?



A) 50% B) 60% C) 75% D)100%

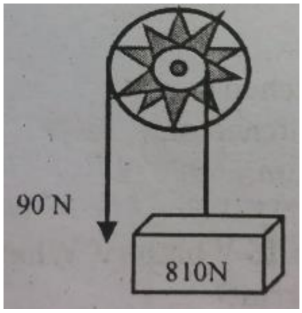
15. A block is sliding down on a surface inclined at an angle θ with the horizontal as shown in the figure below. If the coefficient of friction between the block and the surface is μ , what is the mechanical advantage of the inclined plane?



A) $\frac{1}{\cos\theta}$ B) $\frac{1}{\sin\theta}$ C. $\frac{1}{\sin\theta+\mu\cos\theta}$ D) $\frac{1}{\mu\cos\theta}$

16. A weightlifter raised 210kg barbell from the ground to a height of 2m in 3s. what is the average power output of the weightlifter? (Use $g = 10m/s^2$)
A) 1400W B) 4200W C) 700W D) 1260W

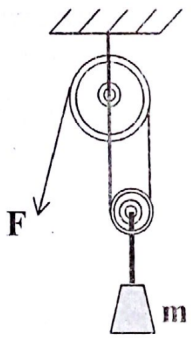
17. The diameters of the wheel and axle machine shown in the diagram below are 60cm and 6cm, respectively. A 90N force applied to the rim of the wheel can lift a load of 810N on the axle. The efficiency of machine is:



A) 81% B) 90% C) 10% D) 60%

18. Which of the following actions increases the efficiency of a machine?
A) decreasing the VR
B) decreasing the AMA
C) decreasing distance moved by the load
D) decreasing the load

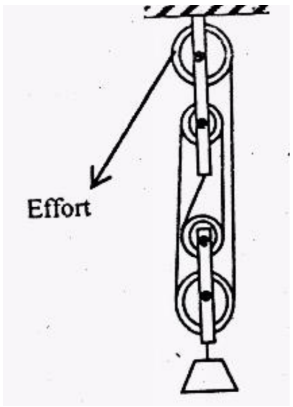
19. The following figure shows a simple machine that consists of a light inflexible rope, light and frictionless pulley, block of mass m, and applied force F. If the upper pulley is fixed and the lower one is movable which of the following statements is not true?



A) the velocity ratio is 2.
B) the mechanical advantage is 2.
C) if m is raised vertically by h, then the rope where F is applied will move by a distance of h.
D) if m is raised vertically h, then the rope where F is applied will move by a distance of 2h.

20. A metallic wedge of thickness $t = 1.5cm$ and length $L = 9cm$ is used to split a wooden log (wood). If a force $F_E = 80N$ applied on the wedge results to a load of $F_L = 320N$ on the log, then which of the following statements is correct about the wedge.
A) the velocity ratio is 1/6
B) the mechanical advantage (MA) of the wedge is 1/4
C) the input work is 480J
D) the efficiency of the wedge is 66.7%

21. Consider the pulley system shown in the figure below Which of the following is correct about the pulley system? (mass of pulleys and frictional forces are negligible)



A) Distances moved by the load and moved by the effort are equal.
B) If the effort moves 8cm, then the load will move 2cm
C) The mechanical advantage of the system is 1/4
D) The mechanical advantage of the system is 5

22. The mechanical advantage of any machine is the ratio of the
A. Force exerted by the machine to the force applied on it
B. Force applied to the machine to the force exerted by it
C. Work done on the machine to the work done by it
D. Work done by the machine to the work done on it

Part-III **Work out and Short answer questions**

23. A simple wheel and axle is used to lift the bucket of water out of a well. The radii of the wheel and axle are 30 cm and 5 cm respectively. Determine:
a) The velocity ratio
b) The effort required to lift a load of 40 N assuming no energy losses.
c) The efficiency if the actual effort required is 20 N.

24. A block of weight 6000 N is pushed up the slope by a force of 300 N. Assume there is no energy losses. Determine:
    a) The actual mechanical advantage
    b) The velocity ratio
    c) The length of the slope if the height of the slope is 10 m.

25. A 12 cm long and a 3 cm wide wooden wedge is pushed into a soft wood block. Calculate:
    a) The velocity ratio of the wedge.
    b) The load on the soft wood if the effort applied is 20 N (assume there is no energy losses).

26. What is the mechanical advantage of a lever that can lift 100 N load with an input force of 20 N?

27. A single movable pulley is being used to move a 140 N load. The pulley is a little dirty, so it adds another 5 N of frictional force.
    a) Can this load be moved with a 75 N input force? Explain your answer.
    b) Would a single fixed pulley work? Explain your answer.

28. List six types of simple machines.

29. Define the terms: effort, load, work input, work output, AMA, V.R, and efficiency.

30. For every simple machine $AMA < IMA$. Why? Explain it.

31. Describe the three classes of lever and give practical example of each. Give two examples of wedges.

32. What are simple machines?

33. Which concepts do we need to understand simple machines?

34. What type of simple machines do you use in your home?

35. What is the purpose of using simple machines?

36. How can we change the direction of force?

37. Is it possible to multiply energy?

38. How can we multiply a force or a speed?

39. What is the purpose of using a fixed single pulley to take water from a deep well?

40. What is the purpose of using an inclined plane to raise different objects in the truck?

41. What is the purpose of using a bicycle instead of walking or running on feet?

42. Does a machine multiply a force and distance at the same time? Explain.

43. Explain about the mechanical advantage of a simple machine.

44. What is the actual mechanical advantage?

45. What is the ideal mechanical advantage?

46. The hammer produces an output force 15 times greater than the force you apply to it (the input force). What is the mechanical advantage of hammer?

47. A load of 400 N is lifted by applying a force of 160 N on the lever. What is the mechanical advantage of the lever?

48. Complete the following table

Load (N)	M.A	Effort (N)
	3	600
40		160
	0.5	480
900	0.3	
2000		500

49. A load of 200 N is lifted by applying a force of 80 N on the lever. If the load is 10 cm from the fulcrum and the effort is 40 cm from the fulcrum, calculate the V.R of the lever.

50. What is the purpose of a machine if:
a) $V.R > 1$ b) $V.R < 1$ c) $M.A > 1$ d) $M.A < 1$

51. Complete the following table

Distance moved by effort	V.R	Distance moved by the load
0.2	4	
0.8		2
6	0.6	
	0.3	6
12	2	

52. A simple machine provides a work output 80 J for every 400 J of work input.
a) What is the efficiency of a simple machine?
b) What will be the work output of this simple machine if 2000 J of work goes to a machine?

53. The efficiency of a machine is 0.75 (or 75%). What is the physical meaning of this statement?

54. What is the efficiency of a machine with M.A = 3 and V.R = 6?

55. What you conclude if M.A = V.R? Write your conclusion in a piece of paper and present it to the whole class.

56. Is it possible for a machine to increase both the magnitude and the distance of a force at the same time? Explain.

57. Simple machines in real world are not 100% efficient. Why?

58. Is it possible to transfer all input energy to output energy using simple machines?

59. Name the different parts of lever.

60. List some examples of lever that people are use in your local area.

61. Is lever speed multiplier or force multiplier?

62. Lever can be used as a force multiplying or speed multiplying simple machine with different arrangements. write the cases.

63. A load of 200 N is lifted by applying a force of 80 N on the lever. If the load is 10 cm from the fulcrum and the effort is 40 cm from the fulcrum, calculate:
    a) The V.R of the lever
    b) The M.A of the lever
    c) Efficiency

64. For what purpose do people use an inclined plane in your local area? Observe and discuss.

65. Why is it easier to push a heavy object up an inclined plane than directly lifting it?

66. How can you can make your inclined plane have large value of velocity ratio?

67. Calculate the velocity ratio (V.R) of:
    (a) A slope of length 30 m that raises an object to a height of 5 m.
    (b) A slope that makes an angle of 37^0 to the horizontal and raises an object to a height of 60 m.

68. A slope of length 40 m raises an object to a height of 8 m above the ground. An effort of 80 N is needed to push a 240 N object up the inclined plane. Calculate:
    (a) M.A (b) V.R (c) Efficiency

69. What is a wedge?

70. For what purpose do people use wedge in your community?

71. List examples of wedges used in your surroundings.

72. What is the difference between an inclined plane and a wedge?

73. For what purpose do people use a screw?

74. For a wheel and axle, discuss the distance moved by the effort in comparison to the distance moved by the load.

75. The diameter of the wheel is 20 times greater than the diameter of the axle. What is the mechanical advantage of this wheel and axle system?

76. What is a pulley?

77. List different types of pulleys?

78. What is the purpose of using fixed and movable pulleys?

79. In a compound pulley discuss the purposes of a fixed pulley and a movable pulley?

80. Construct or design pulley systems with:
    a) $V.R = 3$ b) $V.R = 4$ c) $V.R = 5$ d) $V.R = 6$

81. Suppose a machine when an effort of 300N is moved through a distance of 2m and it moves a load through a distance of 0.4m. What is the maximum load that the machine lifts?

82. A simple machine is used to move a 600N load through a distance of 25cm when an input force of 30N is moved through a distance of 5m. Determine the
    a) work input
    b) work output
    c) Actual Mechanical Advantage
    d) Velocity Ratio
    e) Ideal Mechanical Advantage
    f) Efficiency of the machine

83. Derive the formula for Efficiency of inclined plane.

84. Calculate the IMA or the VR for the following
    a) A slope of length 20m that rises to a height of 5m.
    b) A slope length 100m that rises to the same height.
    c) A slope that is at an angle of 300 to the horizontal and rises to a height of 50m.

85. A slope of 50m rises to a height of 10m above the ground. An effort of 100N is needed to push a 250N object up the ramp, determine the
    a) AMA b) VR c) Efficiency of the machine

86. a) A lever of 2m long is used to pull out a stone. If the load is 25cm away from the fulcrum, what is the velocity ratio of the lever?
    b) If the efficiency of this machine is 80%, what effort is required to pull out a 560N stone?

87. A 2m long lever is used as a second class lever to move a 240N load.
    a) If the distance between the load and the effort is 160cm, what is the velocity ratio of this lever?
    b) What effort is required to move this load if the lever is 100

88. A wheel and axle used to lift water weighting a 570N from a well has a wheel of radius 40cm and radius of axle 10cm.
    a) What is the velocity ratio of the machine if the effort is applied on the wheel?
    b) What is the efficiency of this machine if the effort applied to the load is one-thirds of the load

89. A simple machine supplies a work output of 250J for every 1250J of work input. What is the efficiency of the machine?

90. The mechanical Advantage of a windlass is 4. What effort will be applied to the windlass to raise a 24kg water from a well?

91. A certain simple machine is used to lift a 400N load through a distance of 20cm when a force 50N is moved through a distance of 2m.
    i) Calculate the
    a) work output
    b) work input
    c) AMA
    d) VR

e) IMA
f) efficiency of the machine
ii) Is it a force multiplier or a speed multiplier?

92. a) What is the MA of a simple machine having a velocity ratio of 15 and efficiency of 80%?
b) What is the load if the effort applied is 150N?

93. The efficiency of a certain machine is 85%. What work input is supplied into this machine to get 1700J of work output?

94. The screw shaft makes a full circumference of 24.6πcm while it is driven 0.6πcm into a wooden block. What is the IMA of the screw?

95. An inclined plane is used to rise a load to a height of 6m through a distance of 10m. If the coefficient of friction between the load and the surface is 0.5, calculate the
i) VR or IMA of the inclined plane.
ii) AMA of the inclined plane.
iii) efficiency of the inclined plane.

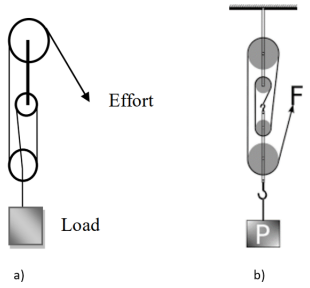
96. The handle of a screw is 40cm long. If the screw has 4 threads for every cm, find the velocity ratio of the machine.

97. Write down at least five examples of
i) force multiplier machines
ii) speed multiplier machine.

98. The efficiency of the pulley system shown figure (a) below is 70%. What effort is applied on it in order to lift a 1050N load?

99. If the pulley system given in Figure (b) to the right is frictionless and F=30N, what is the
a) VR of the system? b) weight suspended at P?

100. If the efficiency of the pulley system in Figure (b) is 80%, what is the a) AMA of the pulley system? b) weight suspended at P if F=20N?



101. List the six kinds of simple machine.

102. Define the terms: effort, load, work input, work output, AMA, VR, efficiency and IMA.

103. A simple machine is able to move a 400 N load a distance of 20 cm when a force of 20 N is moved through a distance of 5.0 m. Calculate:
a) the work input
b) the work output
c) the actual mechanical advantage
d) the velocity ratio
e) the efficiency of the machine
f) the ideal mechanical advantage.

104. A simple machine has an efficiency of 0.75 and a VR of 12. Determine the MA and the load that can be moved if an effort of 100 N is applied.

105. Calculate the VR (and so the IMA) for the following:
a. A slope of length 20 m that rises to a height of 5 m.
b. A slope of length 100 m that rises to the same height.

106. A slope that is at an angle of 30° to the horizontal and rises to a height of 50 m.

107. A slope of length 50 m rises to a height of 10 m above the ground. An effort of 100 N is needed to push a 250 N object up the ramp. Calculate:
a. AMA b. VR c. efficiency

108. For an inclined plane derive $\eta = \frac{l}{h}$.

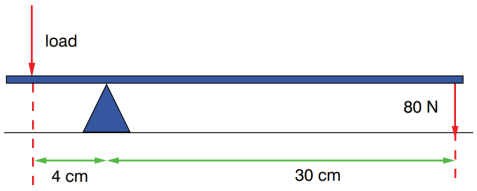
109. A block of weight 5000 N is pushed up a slope by a force of 250 N. Assume there is no friction. Calculate:
a) the actual mechanical advantage
b) the velocity ratio
c) the length of the slope if the height of the slope is 10 m.

110. An inclined plane is 100 m long and at an angle of 20° to the horizontal. The AMA of the slope is two. Calculate:
a) the effort required to push a 7200 N block up the slope
b) the ideal mechanical advantage
c) the efficiency of the slope.

111. Describe the differences between a wedge and an inclined plane.

112. Explain how a lever can act as a force multiplier.

113. For the following simple see-saw calculate:
a) the load that could be lifted
b) the mechanical advantage (assume the lever is 100efficient).



114. A simple wheel and axle is used to lift a bucket of water out of a well. The radii of the wheel and axle are 20 cm and 4 cm, respectively. Determine:
a) the velocity ratio (and so the IMA)
b) the theoretical effort required to lift a load of 30 N assuming no energy losses
c) the efficiency if the actual effort required is 10 N.

115. Describe the three different types of pulley.

116. Explain why for every simple machine the actual mechanical advantage is less than the ideal mechanical advantage.

117. By giving an example of a simple machine (including its dimensions) explain what is meant by force multiplier, speed multiplier and direction changer.

118. An inclined plane rises to a height of 2 m over a distance of 6 m. Calculate:
a) the angle of the slope
b) the VR (and so IMA) of the inclined plane
c) the theoretical force required to push an object with a mass of 200 kg up the slope.

119. Give three examples of wedges.

120. A 10 cm long, 2 cm wide wooden wedge is pushed into a soft wood block. Calculate:
a) the velocity ratio of the wedge
b) the load on the soft wood if the effort applied is 30 N (assuming the wedge is 100% efficient).

121. Explain how screws could be considered to be similar to inclined planes.

122. Describe the three classes of lever and give a practical example of each.

123. Explain how a jackscrew is used and how to calculate its ideal mechanical advantage.