15 Simple Machines

Since ancient time, man used machines to make their jobs easy. Let us recall some instances where simple machines are used.

As you know, it is difficult to lift and remove a large log or a rock with hands. You may have experienced in your day-to-day life, that one end of a metal rod is kept under the rock or the log and pushed down from the other rod. This mechanical device is known as a **lever** (Figure 15.1).

Figure 15.1 – A lever

Can a single person lift a barrel of oil on to the deck of a lorry? It is difficult. Let us find out the amount of force that has to be applied to lift an object directly upwards.

Hang a piece of metal on a spring balance and take the reading. Then lift the piece of metal vertically up with your hand, while it is on the spring balance and observe the reading of the balance.

When the piece of the metal was hanging on the balance, a force which is equal to the weight of the piece of metal is exerted downwards on the balance. While you are lifting the piece of metal, you are applying a force, which is equal to the weight of it, upwards. Then, you will observe that the reading of the balance reaches zero. Thus, it is clear that a force which is equal to the weight of an object should be applied upwards to lift it vertically up.

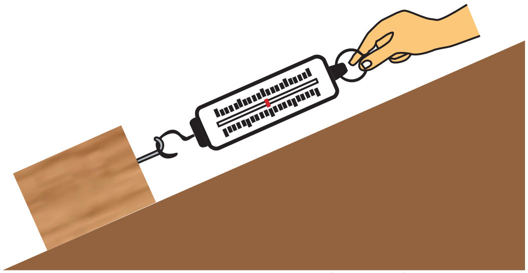


Figure 15.2 – Drawing an object along an inclined plane

Now keep a piece of long plank, inclined to the horizontal surface and draw the same piece of metals along it, as shown in the figure 15.2. Observe the reading of the spring balance. You will realize that the force exerted to draw the piece of metal along the ramp is less than the force exerted to lift it directly upwards. Here the job is made easy.

Figure 15.3 – Loading a barrel of oil to a lorry using an inclined plane

Here the device used to lift the piece of metal is known as **inclined plane**. When a barrel of oil is to be loaded to a lorry, it is easy to push it along a ramp as shown in the figure 15.3.

When you want to pull a bucket of water from a well, you can tie one end of a rope to the bucket, send the bucket into the well and draw it upwards by pulling it from the other end of the rope. Here the force that should be applied is equal to the weight of the bucket full of water.

Let us consider an easier way to do this job. Lifting the bucket of water can be easily done by sending the rope round a **pulley** and drawing the other end of the rope downwards, as shown in the figure 15.4. Drawing sometimes down is easier than drawing it up. Pulley is used to change the direction of force as we want.

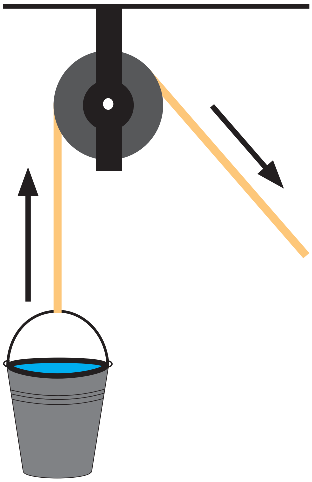


Figure 15.4 – Lifting an object using a pulley

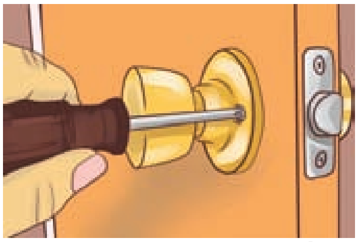


Figure 15.5 – Using a screw driver

To sink a screw nail into something, the force is applied by turning the handle of screw driver (figure 15.5). It is common experience that this job is made easier by the screw driver. Here the device used is known as the **wheel and axle**.

Strategies used to make the job easy are known as simple machines.

There are four types of simple machines;

- Lever
- Inclined plane
- Pulley
- Wheel and axle

Let us discuss about these simple machines, in detail.

15.1 Lever

Figure 15.6 – Using a crowbar

As we have discussed earlier, a metal rod or a crowbar can be used to lift a wooden log or a rock. Let us consider it again.

It is difficult to lift the rock to some height. The force that should be applied to do it is very large, that a single person cannot do it.

It is easy to lift the rock or the log by using a crowbar as a lever (figure 15.6).

Here, why did the lever make the job easy? Let us do the activity 15.1 to find out about this.

Activity 15.1

You will need :- A book, a Newton spring balance, a ruler or a wooden strip

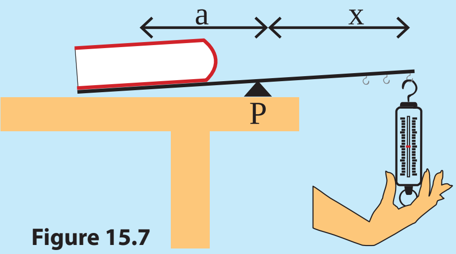


Figure 15.7

Method :-

- Weigh the book, using the Newton spring balance.
- Keep the wooden strip on a piece of wood as a support **P** to balance it.
- Place the book on the end of the strip as shown in figure 15.7. Couple the Newton balance to the other end of the strip using a book and pull the balance vertically downwards, holding its stem.
- Take the reading of the balance.
- Keep the distance from the book to the support **a** constant and take several readings by changing the distance from the support to the place where the balance **x** is coupled. (Take several readings by keeping the value of greater than a and less than **a**).
- In each situation, observe the movement of the place attached to the wooden strip when the book lifts a vertical distance comparatively.
- Measure the distance **x** and keep records.

You may have observed that the force necessary to lift the book is less than the weight of the book when **x** is greater than **a**. Here the lever helps to ease the job. When **x** is smaller than **a**, the force necessary to lift the book is greater than the weight of the book. But, in this case the book moves further than the point where balance is attached moves. This distance is advantageous in some instances.

In all the above instances, the force applied on the lever is downwards to lift the book upwards. This change of direction of force is also another advantage of a lever.

Parts of a lever

Let us consider the activity 15.1.

Here, the wooden strip is used as a lever. The force applied on the lever downwards is known as the **effort**. The lever lifts the weight of the book. Thus weight lifted by the lever is **load**.

Load is balanced by the effort other the wooden support. The point of the wooden strip that contact with the lever is called **fulcrum**.

Here we have considered three points of a lever. Load is at one end of the lever. Effort is at the other end. Load is balanced by the effort over the fulcrum.

Let us consider the lever shown in the figure 15.8 AB is a metal rod. Effort is applied downwards at B. Rod is balanced on C. So, C is the fulcrum.

Effort arm and load arm

The part of the lever from effort to fulcrum (CB) is known as effort arm. The part of the lever from load to the fulcrum (CA) is known as load arm.

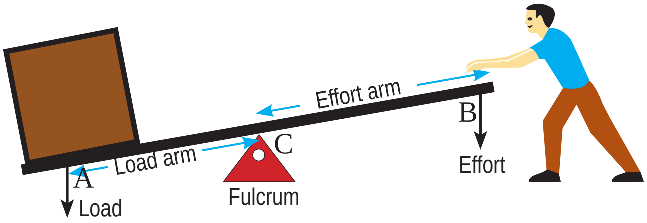


Figure 15.8 - Parts of a lever

Mechanical advantage

Mostly a large load can be balanced by applying a small effort on a machine. In the above activity, when the length of effort arm (x) is greater than that of load arm (a), the book could be lifted by applying a force less than the weight of the book. This advantage of the machine is calculated as the ratio of load to effort. This ratio is known as **mechanical advantage**.

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

According to the figure 15.8, if a load of 36 N is lifted by applying an effort of 12 N, then the mechanical advantage is;

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

$$= \frac{36\text{ N}}{12\text{ N}}$$

$$\underline{3}$$

To remove the lid of a tin can, you can lift it with your fingers. But, it is difficult. An easier way is shown in figure 15.9.

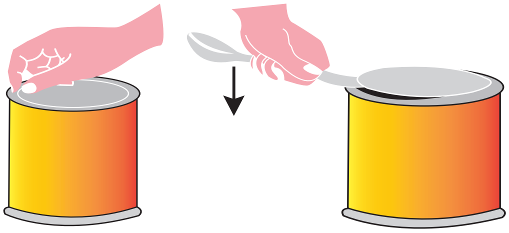


Figure 15.9

Here the handle of a spoon is used as a lever. One end of the handle of spoon holds the lid of tin (load). One point of the handle rests on the edge of tin can. This point is the fulcrum. When a small force (effort) is applied at the free end and of the handle, the lid is thrown up. So, the load of the can is removed easily.

Consider the position of the fulcrum of the levers mentioned above. It is positional between the effort and the load.

Let us consider following situation where effort arm is greater than load arm.

Thus, levers can be divided into three orders according to the positions of effort, load and fulcrum.

- First order lever
- Second order lever
- Third order lever

First order levers

Levers, in which the fulcrum acts between load and effort are called first order levers. All the levers we considered in this lesson, up to now, are first order levers. Figure below shows a first order lever.

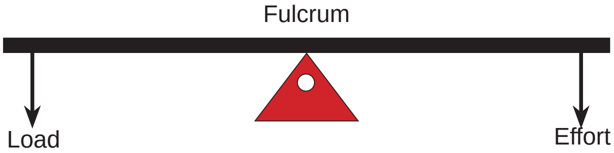


Figure 15.10

Some examples for first order levers are given below.

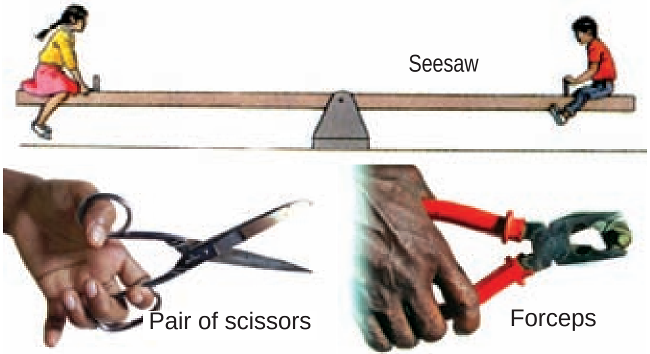


Figure 15.11 – First order levers

Second order levers

Levers in which the load acts between effort and fulcrum are referred to as second order levers. Nut cracker is an example.

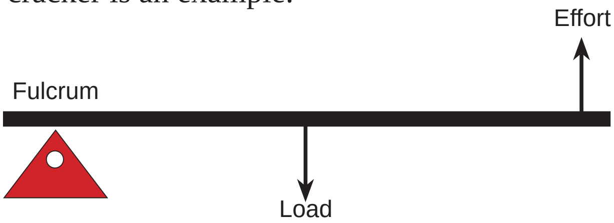


Figure 15.12

Some examples for second order levers are given in figure 15.13.

Figure 15.13 – Second order levers

The blade and the rod of the nut cracker turns round the pin, by which they are coupled. Therefore, that pin is the fulcrum. Load acts on the object that is to be cut. Effort is applied at the far end of the handle.

Third order levers

In third order levers, effort acts between the load and the fulcrum (figure 15.14). Broom, fishing rod (figure 15.15) and human arm are some examples for third order levers.

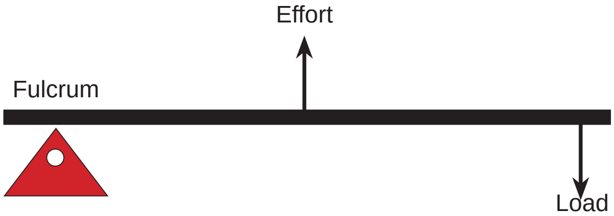


Figure 15.14

Figure 15.15 - Fishing rod

Load arm is always longer than the effort arm in third order levers. Therefore, an effort which is greater than the load has to be applied to balance that rod. Thus, the mechanical advantage is always less than one. But, these levers are advantageous because load moves more for a small motion of the effort.

Velocity ratio of a lever

Let us consider the lever device used to high a load up.

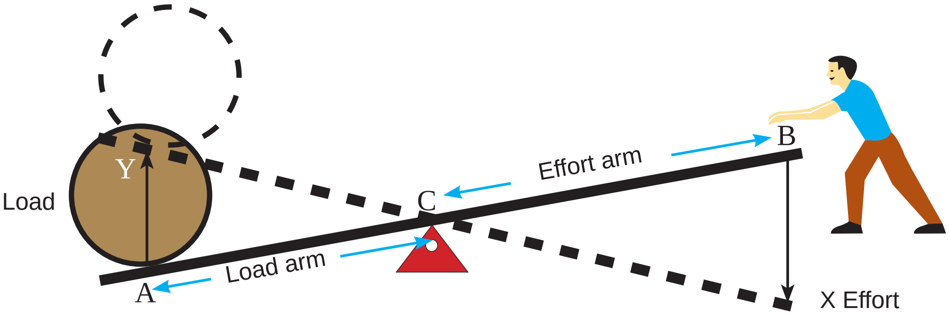


Figure 15.16

Effort is applied on the point B of this lever. Let the point B travels to point X, which is the displacement of effort. Sometimes load is lifted from A to Y. Therefore, A Y is the displacement of load.

Velocity ratio of a machine is the ratio of the displacement of effort to the displacement of load during the same time.

$$\text{Velocity ratio} = \frac{\text{Displacement of effort}}{\text{Displacement of load}}$$

According to mathematics, same value can be obtained by dividing the length of effort arm by the length of load arm.

The larger the velocity ratio of a machine the smaller the effort that should be applied on it.

If BX = 60 cm and AY = 15 cm in the above example,

$$\text{The velocity ratio of that lever} = \frac{60\text{ cm}}{15\text{ cm}}$$

$$= \underline{4}$$

If a velocity ratio of a machine is 4, then theoretically, the effort that should be applied to lift a load using that machine is 1/4 th of the load.

But, in practice the effort does not decrease down that much (1/4th of the load). The reason for this is the friction in the system. Thus the mechanical advantage of a machine is always less than its velocity ratio.

Work-input and work-output

When we have to get work done from a machine, we have to work on the machine. Work done on the machine is called work-input. When the work input is given to the machine, some amount of work is done by the machine also. That is known as work-output.

Let us consider the lever that we mentioned above.

Let the effort at B is 50 N and the load lifted at A is 150 N.

You already know, how to calculate the work done, when a force is acting along a certain distance.

Work done is the product of the force applied and the distance that the force travelled.

We can calculate the work done on the lever (work input) as follows.

Work done on the lever (work input) = effort × displacement of effort

$$= 50\ \text{N} \times 60\ \text{cm}$$

$$= 50\ \text{N} \times \frac{60}{100}\ \text{m}$$

$$= 30\ \text{J}$$

We can calculate the work done by the lever (work-output) as follows.

Work done by the lever (work output) = load × displacement of load

$$= 150\ \text{N} \times 15\ \text{cm}$$

$$= 150\ \text{N} \times \frac{15}{100}\ \text{m}$$

$$= 22.5\ \text{J}$$

Here, when 30 J of work is done on the machine, only 22.5 J of work is given out from the machine.

Therefore, the percentage of the work given out from the machine is for the work-input.

$$= \frac{22.5\ \text{J}}{30\ \text{J}} \times 100$$

$$= \underline{\underline{75\ \%}}$$

What we calculated here is the efficiency of the machine. It is 75%.

$$\text{Efficiency of a machine} = \frac{\text{Work-output}}{\text{Work-input}}$$

$$= \frac{\text{Load} \times \text{distance travelled by load}}{\text{Effort} \times \text{distance travelled by effort}}$$

$$= \frac{\text{Load}}{\text{Effort}} \times \frac{\text{distance travelled by load}}{\text{distance travelled by effort}}$$

We can obtain velocity ratio by dividing the distance travelled by effort to the distance travelled by load. But, here it says other way around. It is similar to the reciprocal of velocity ratio.

This is; $\dfrac{1}{\text{Velocity ratio}}$

$$\text{Therefore, efficiency} = \text{Mechanical advantage} \times \frac{1}{\text{Velocity ratio}}$$

$$\text{Efficiency} = \frac{\text{Mechanical advantage}}{\text{Velocity ratio}}$$

Generally efficiency of a machine is given as a percentage.

$$\text{Therefore, efficiency} = \frac{\text{Mechanical advantage}}{\text{Velocity ratio}} \times 100\%$$

Following formulas can be used not only for levers but also for other machines.

$$\text{Mechanical advantage} = \frac{\text{Load}}{\text{Effort}} \times 100\%$$

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

$$\text{Efficiency} = \frac{\text{Mechanical advantage}}{\text{Velocity ratio}} \times 100\%$$

15.2 Inclined plane

Inclined plane or a ramp can be used to make a job easy. Therefore, inclined plane is also a simple machine.

We realized earlier, that a force equal to the weight of an object should be applied to lift it up directly.

But less effort is enough to draw it along an inclined plane.

Let us do activity 15.2 to understand how effort that should be applied to draw an object along an inclined plane, changes with its inclination.

Activity 15.2

You will need :- A long piece of plank, a Newton spring balance, a block of wood, few bricks

Method :-

- Construct an inclined plane using several bricks and the piece of plank.
- Fix a loop to one side of the block of wood. Couple the block to the hook of Newton balance, find the force necessary to move the block of wooden along the plane.
- Reduce the inclination of the plane by removing one brick and repeat the above steps.
- Take several readings by reducing the inclination of the plane (by removing another brick).
- Compare how the effort changes with the inclination of the plane.

You may have realized that the effort decreases with the decrease of the inclination of the inclined plane and vice-versa. Mechanical advantage increases with the decrease of effort.

Examples for inclined planes used in day-to-day life

- The wedge
- The staircase
- The screw jack
- The screw nail
- The ladder

Let us consider the calculations regarding inclined plane.

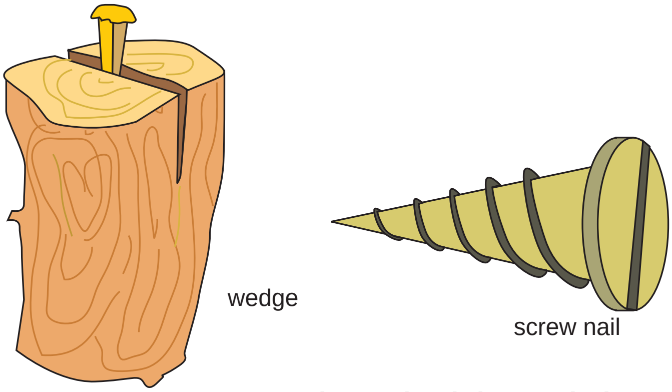


Figure 15.17 - Instance where inclined plane applied

The weight of a barrel of oil is 600 N. Using an inclined plane of 4 m long, it is lifted to the deck of lorry, which is 1 m high from the ground. The force exerted to push the barrel along the plane is 200 N.

i.

$$\begin{aligned}\text{Mechanical advantage of an inclined plane} &= \frac{\text{Load}}{\text{Effort}}\\ &= \frac{600\text{ N}}{200\text{ N}}\\ &= \underline{\underline{3}}\end{aligned}$$

ii.

$$\begin{aligned}\text{Velocity ratio of an inclined plane} &= \frac{\text{distance travelled by effort}}{\text{distance travelled by load}}\\ &= \frac{4\text{ m}}{1\text{ m}}\\ &= \underline{\underline{4}}\end{aligned}$$

iii.

$$\begin{aligned}\text{Efficiency of an inclined plane} &= \frac{\text{Mechanical advantage}}{\text{Velocity ratio}}\\ &= \frac{3}{4} \times 100\%\\ &= \underline{\underline{75\%}}\end{aligned}$$

iv.

$$\begin{aligned}\text{Work-input} &= \text{Effort} \times \text{distance travelled by effort}\\ &= 200\text{ N} \times 4\text{ m}\\ &= \underline{\underline{800\text{ J}}}\end{aligned}$$

v.

$$\begin{aligned}\text{Work-output} &= \text{Load} \times \text{distance travelled by load}\\ &= 600\text{ N} \times 1\text{ m}\\ &= \underline{\underline{600\text{ J}}}\end{aligned}$$

Efficiency can be calculated by using work-input and work-output also.

vi. Efficiency of an inclined plane $= \frac{\text{Work output}}{\text{Work input}} \times 100\%$

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

$$= \underline{\underline{75\%}}$$

15.3 Wheel and axle

Wheel and axle is a simple machine which can be used to make a job easy. As wheel and axle are connected, force applied on the wheel can be transferred to axle to do the job. Windlass, is such a machine with wheel and axle.

This windlass is made by fixing an L shaped handle to a long cylindrical stem, which is rested on the stands, so that it can be freely turned (figure 15.18).

Figure 15.18 - Windlass

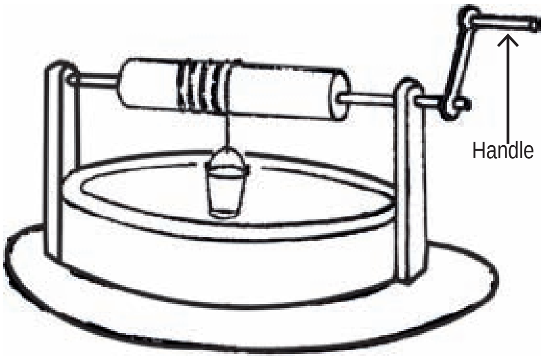


Figure 15.19

The rope is wound round the stem and a bucket is tied to the other end of the rope. When the handle of the windlass is turned, the bucket goes down into the mine. When the handle is turned the other way, bucket comes up with a load filled into it. When the handle is turned one round, the rope also winds once round the stem.

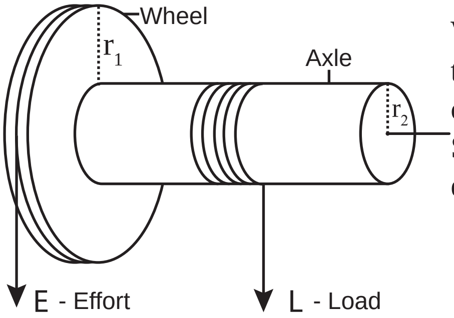


Figure 15.20

When the handle is turned once, the distance travelled by the effort is equal to the circumference of the circle of the handle turned. Same time load is lifted by a distance which is equal to the circumference of the stem.

Length of the handle equals to the radius of the circle (r_1). The diameter of the circle is $2r_1$. Then, its circumference is $2r_1 \times \pi$ $\left(\pi = \frac{22}{7}\right)$.

Therefore, the distance that effort travels for one turn of the handle is $2\pi r_1$

If the radius of the cylindrical stem is r_2, then its diameter is $2r_2$.

The distance that the load is lifted for one turn of the handle is $2\pi r_2$

$$\left.\begin{array}{c}\text{Therefore, the velocity}\\ \text{ratio of the wheel and axle}\end{array}\right\} = \frac{\text{Circumference of the circle with one turn of handle}}{\text{Circumference of the stem}}$$

$$= \frac{2\ \pi r_1}{2\ \pi r_2}$$

$$= \frac{r_1}{r_2}$$

$$\begin{array}{c}\text{Velocity ratio of}\\ \text{wheel and axle}\end{array} = \frac{\text{Radius of wheel}}{\text{Radius of axle}}$$

Therefore, the velocity ratio of wheel and axle can be calculated by dividing the radius of wheel by the radius of axle.

Here are some examples for wheel and axle.

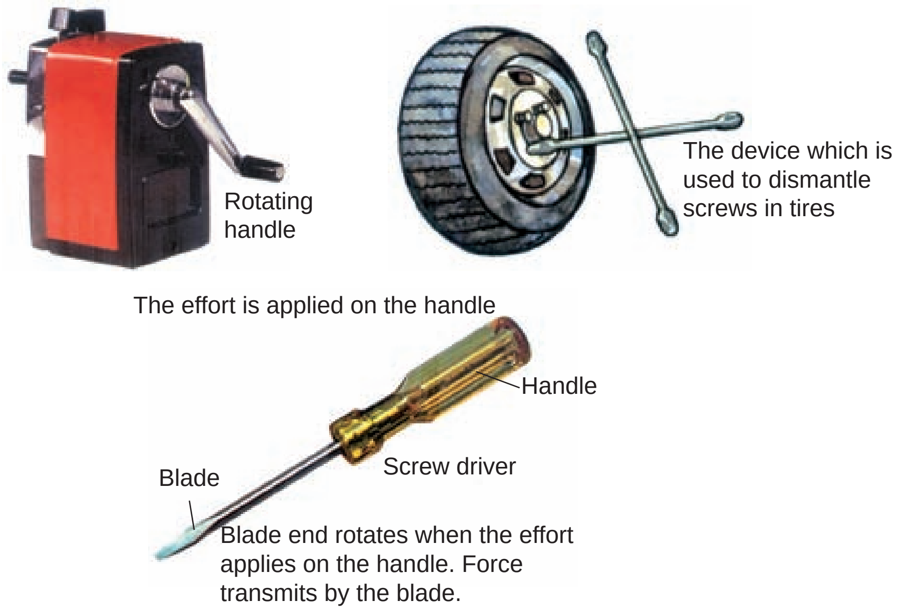


Figure 15.21 - Use of wheel and axle

15.4 Pulleys

It is mentioned earlier is this lesson, that it is easier to pull a bucket of water from a well using a pulley rather than pulling the bucketful of water directly with a rope. Thus you know that **pulley** is a simple machine.

Let us do activity 15.3 to compare the force that should be applied in the two situations above.

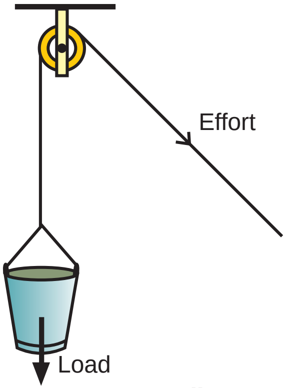


Figure 15.22 - Pulley as a simple machine

Activity 15.3

You will need :- A pulley, a suitable string, a Newton spring balance, a piece of stone or a suitable load

Method :-

- Measure the weight of stone using the Newton spring balance.
- Now tie the string to the stone and pull it over the pulley using the Newton spring balance as shown in the figure 15.23. Note down the reading of the balance.

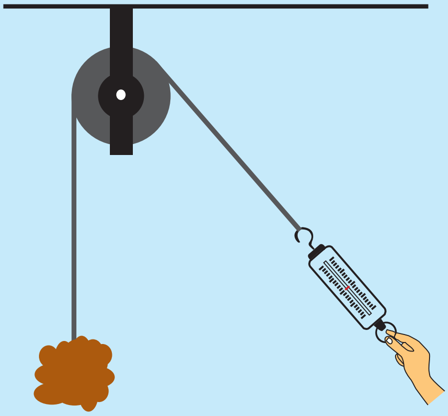


Figure 15.23

Compare the weight of the stone and the force necessary to pull it over the pulley. You will realize that both readings are more or less the same. (There may be a slight difference due to the friction of the pulley)

When we are lifting something straight upwards, the force should be applied upwards. However, when we are using a pulley for this purpose, the pulling force can be turned appropriately. Applying a force downwards is easier than applying it upwards. Therefore, it is easy to use a single pulley to lift a load.

Let us solve a simple problem associated with the simple machine, pulley.

The weight of a bucketful of water is 12 N. It is lifted up using a pulley (Assume that the pulley has no friction.)

Solved problem 1

i. Here, the effort is 12 N, to lift up the load.

$$\text{Mechanical advantage} = \frac{\text{Load}}{\text{Effort}} = \frac{12\ \text{N}}{12\ \text{N}} = \underline{\underline{1}}$$

ii. Velocity ratio

When the effort travels same distance, load also travels the same distance. Therefore, velocity ratio is 1.

iii. Let us see the work-input for the machine.

$$\text{The work-input for the machine} = \text{Effort} \times \text{distance travelled by effort}$$

Let us take the distance travelled by the effort as 0.8 m.

$$\text{Then, work-input} = 12\ \text{N} \times 0.8\ \text{m} = \underline{\underline{9.6\ \text{J}}}$$

iv. Let us see the work-output of the machine

$$\text{Work-output of the pulley} = \text{Load} \times \text{distance travelled by load} = 12\ \text{N} \times 0.8\ \text{m} = \underline{\underline{9.6\ \text{J}}}$$

v.

$$\text{The efficiency of the pulley} = \frac{\text{Mechanical advantage}}{\text{Velocity ratio}} \times 100\% = \frac{1}{1} \times 100\% = \underline{\underline{100\ \%}}$$

Pulley systems

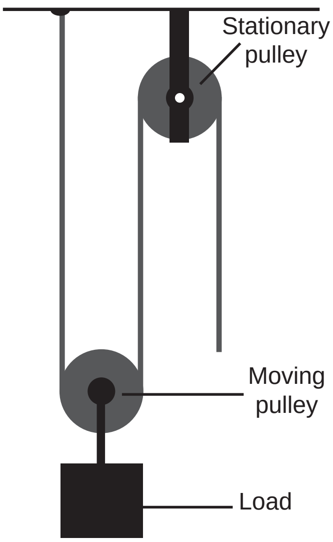


Figure 15.24

The motion of a pulley used to draw water from a well is turning round its axis only. Such pulleys are known as **stationary pulleys**. Other than these, there are pulley systems with moving pulleys.

The figure 15.24 shows a pulley system with a stationary pulley and a moving pulley.

Here the force is exerted upwards by two strings on the moving pulley. Therefore, one string has to apply only a force which is equal to a half of the load. That force is directed downwards by the string running over the stationary pulley. Therefore, the mechanical advantage of this pulley system is 2. This mechanical advantage is gained only because of the moving pulley. The task of the stationary pulley is the change of direction of the force applied.

In any simple machine, velocity ratio increases with the increase of mechanical advantage. In the above pulley system, when the effort travels down with the string a certain distance, load travels only a half of that distance. Therefore, its velocity ratio is 2.

Mechanical advantage of a pulley system can be increased largely by using several stationary and moving pulleys. Crane is a complete machine that consists of pulley systems.

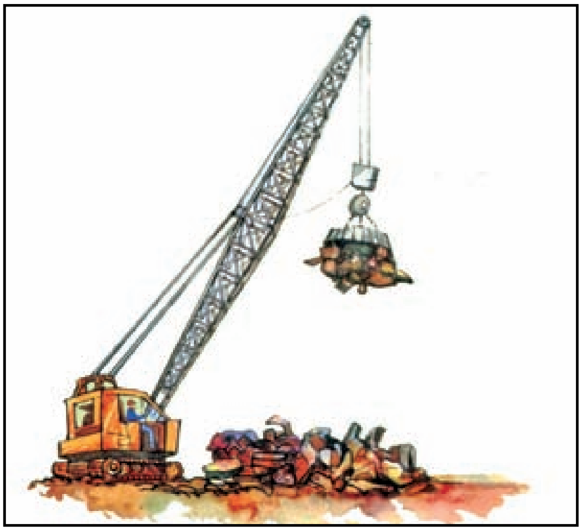


Figure 15.25 - Crane

Complex machines are assembled using several simple machines.
e.g. Bicycle

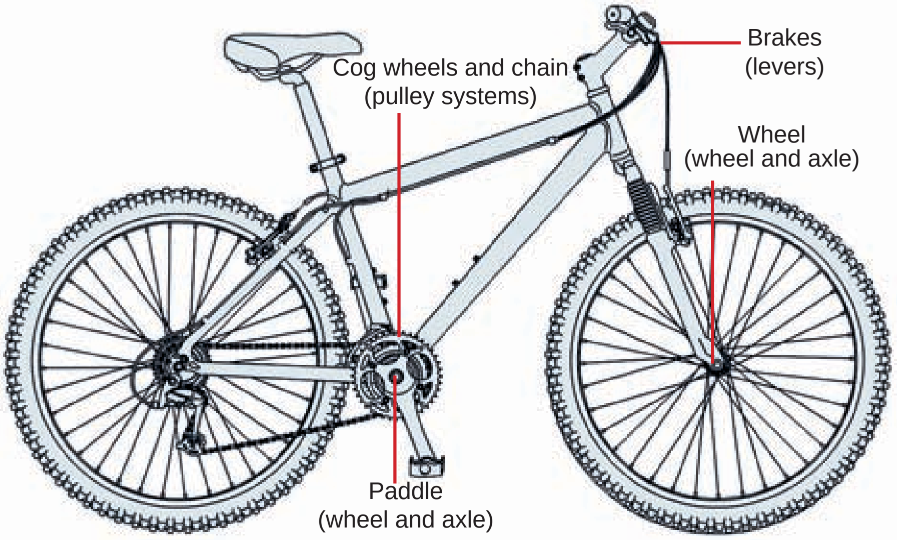


Figure 15.26 - Bicycle

Assignment 15.1

Observe and study about various machines (e.g sewing machine) used in daily activities. Name the simple machines applied in these machines.

Summary

- Machines are used to make the jobs easy.
- A force is applied on the machine which is transmitted to the load to perform work.
- Force applied on the machine is effort.
- Force applied by the machine is load.
- There are four types of simple machines. such as lever, inclined plane, wheel and axel and pulley.
- Complex machines are constructed by assembling simple machines.
- For simple machines the following formula can be used:

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

$$\text{Velocity ratio} = \frac{\text{Distance travelled by effort}}{\text{Distance travelled by load}}$$

$$\text{Efficiency} = \frac{\text{Mechanical advantage}}{\text{Velocity ratio}} \times 100\ \%$$

Exercises

(01) Select the correct or most suitable answer.

1. Which one of these is **not** a function of a machine?
   1. Effort is decreased than the load.
   2. Change the direction of effort appropriately.
   3. Getting a job done by applying a force on the machine
   4. More work is obtained by doing less work on the machine.

2. Which one out of the following is **not** a simple machine?

   1. Nut cracker 2. Pulley 3. Wedge 4. Engine of a motor vehicle

3. A lever can lift a load of 48 N by applying an effort of 12 N on it. What is the mechanical advantage of this lever?

   1. 1 2. 2 3. 3 4. 4

4. Which are of the following is an inclined plane?
   1. Screw driver, wedge, staircase
   2. Screw driver, staircase, crowbar
   3. Screw driver, wedge, ladder
   4. Staircase, screw driver, forceps

5. Following statements are forwarded by two students during a discussion on instances where effort is greater than the load.

   A - Effort is greater than load when screw jack is used.

   B - Effort is grater than load when single pulley is used.

   C - Effort is always greater than load when third order lever is used.

   What is the correct choice of the following?

	Statement A	Statement B	Statement C
1	Correct	Incorrect	Correct
2	Incorrect	Incorrect	Incorrect
3	Incorrect	Correct	Correct
4	Correct	Correct	Correct

(02) Copy into your exercise book and fill in the blanks.

The force exerted on a machine is the (a) …………………………….. and the force controlled by the machine is the (b) ……………………………..

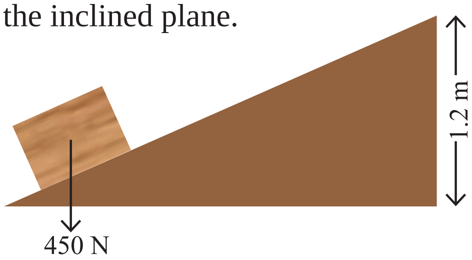
(03)

1. What are the two ways that a machine makes a job easy?
2. Draw lever diagrams separately to show the effort, load and fulcrum of the three orders of levers.
3. Mention two instances in day-to-day life where inclined plane is used.

(04) The figure here shows how a piece of plank, kept inclined, is used to lift a load of 450 N to a height of 1.2 m.

The effort applied is 150 N and the efficiency of the inclined plane is 60%.

i. Find the mechanical advantage of the inclined plane.
ii. Calculate the length of the plane.
iii. Find the velocity ratio.
iv. How much is the work-input?
v. How much is the work-output?



Technical Terms

Simple machines	-	සරල යන්ත්‍ර	-	எளியபொறி
Levers	-	ලීවර	-	நெம்புகோல்
Fulcrum	-	ධරය	-	பொறுதி
Load	-	භාරය	-	சுமை
Effort	-	ආයාසය	-	எத்தனம்
Inclined plane	-	ආනත තලය	-	சாய்தளம்
Pulleys	-	කප්පි	-	கப்பி
Mechanical advantage	-	යාන්ත්‍ර වාසිය	-	பொறிமுறை நயம்
Velocity ratio	-	ප්‍රවේග අනුපාතය	-	வேக விகிதம்
Efficiency	-	කාර්යක්ෂමතාව	-	திறன்
Work input	-	ප්‍රදාන කාර්යය	-	பொறி மீது செய்யப்பட்ட வேலை
Work output	-	ප්‍රතිදාන කාර්යය	-	பொறியினால் செய்யப்பட்ட வேலை
Complex machines	-	සංකීර්ණ යන්ත්‍ර	-	சிக்கலான பொறி