

## Moments

The crane in the image below looks unstable, as though it should topple over. There appears to be too much of the boom on the left-hand side of the tower.



It doesn't fall because of the presence of a **counter balance weight** on the right-hand side. The boom is therefore balanced.

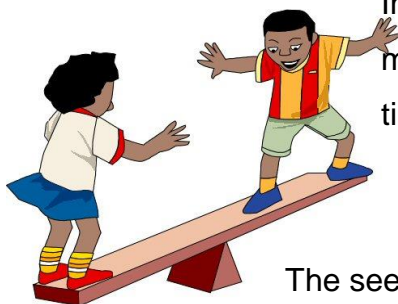
In order to understand this better, we need to understand **pivots**, **moments** and **equilibrium**.



The **pivot point** or **fulcrum** is the point at which something rotates.

The weights on the scales are at equal points from the pivot point.

When something is **balanced** it is said to be **in equilibrium**.



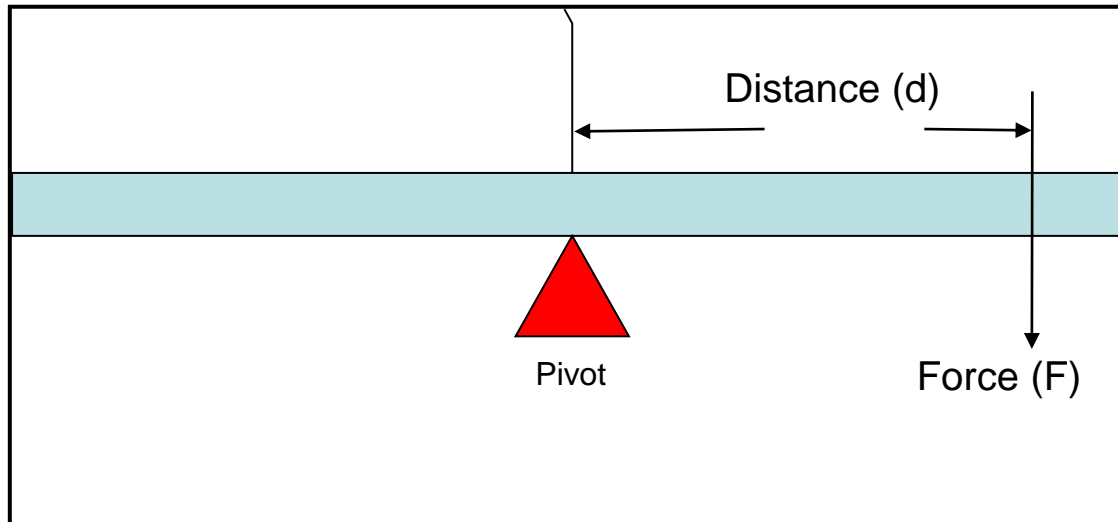
In the example of the see-saw, if one of the people moves backwards or forwards, the balance is tipped one way or the other.

The see-saw is no longer in equilibrium.

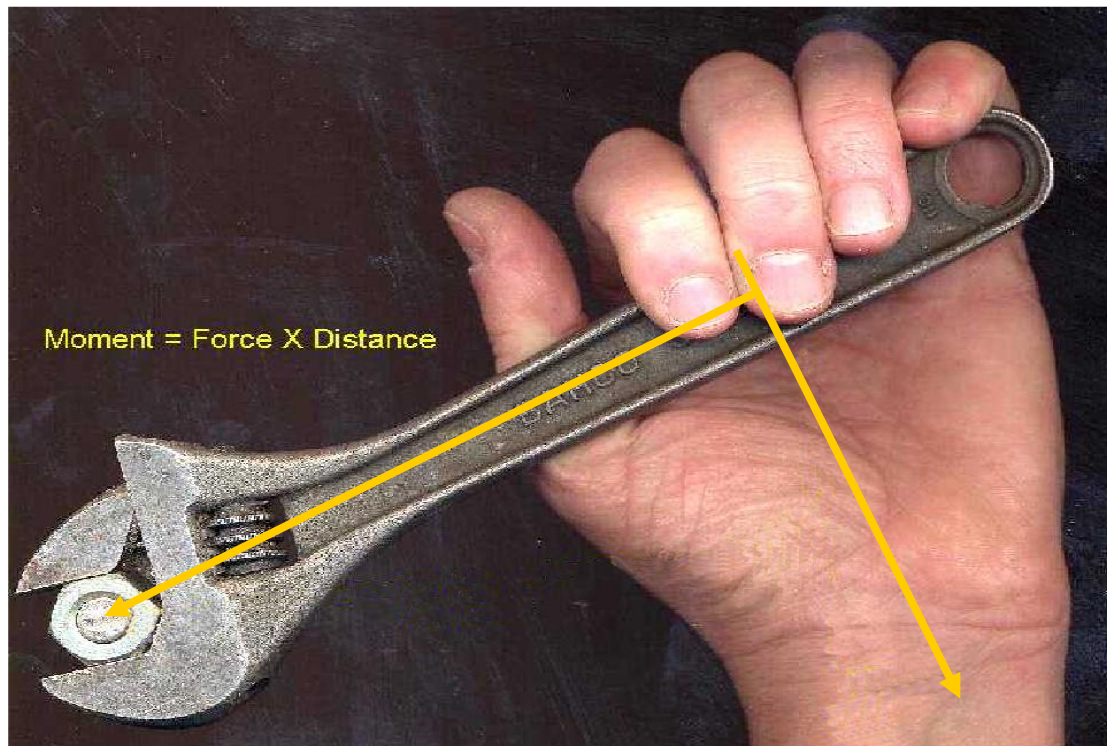
When something is in equilibrium, the moments of a force are balanced.

The **Moment of a Force** is calculated as the force multiplied by the distance from the pivot point.

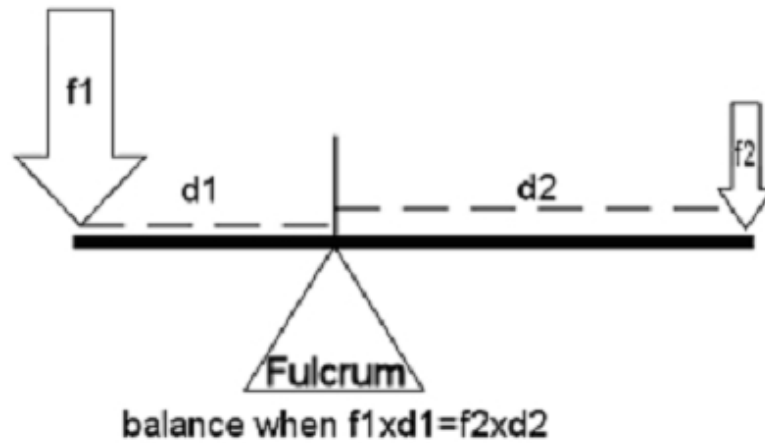
$$\text{Moment} = F \times d$$



This can also be represented as illustrated below:

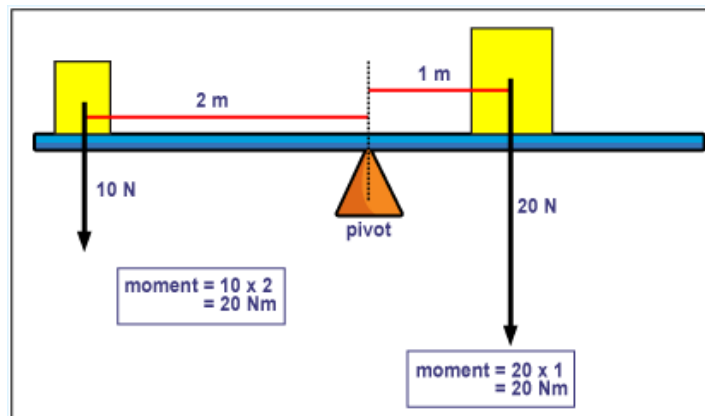


The **Principle of Moments** states that for there to be equilibrium, the clockwise moments must equal the anti-clockwise moments.



**Clockwise Moments =  $F_2 \times d_2$**   
**Anti-Clockwise Moments =  $F_1 \times d_1$**   
**If  $F_2 \times d_2 = F_1 \times d_1$  there is equilibrium**

**Example**

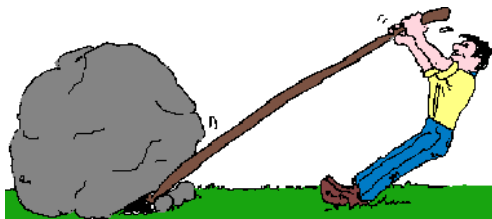


Clockwise Moments =  $20\text{N} \times 1\text{m}$       Anti-Clockwise Moments =  $10\text{N} \times 2\text{m}$   
 $20\text{Nm} = 20\text{Nm}$   
 Therefore, the scales is in equilibrium.

## Levers

A **lever** is a rigid rod, pivoted about a fixed point or axis, which is known as a **fulcrum**.

- **Fulcrum** or pivot – the point about which the lever rotates
- **Load** – the force applied by the lever system
- **Effort** – the force applied by the user of the lever system



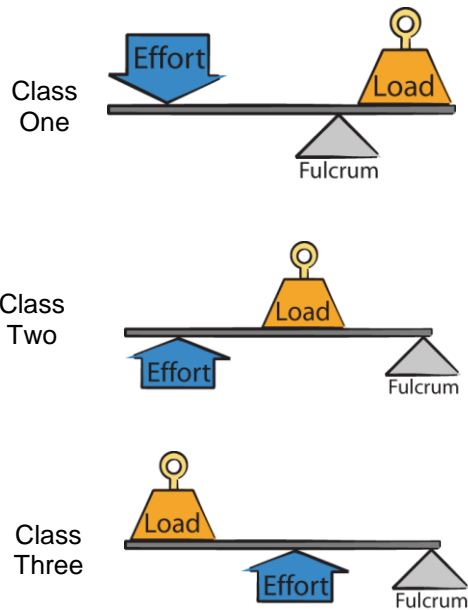
A lever can be used to move a large load with a small effort.

The way in which a lever will operate is dependent upon the type of lever.

There are three types or class of lever, referred to as:

1. Class One e.g. See-saw
2. Class Two e.g. Wheelbarrow
3. Class Three e.g. Shovel

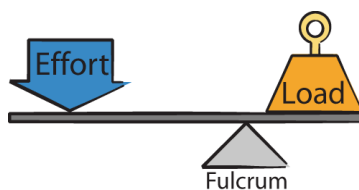
In each class the position of the **Load**, **Effort** and **Fulcrum** are changed.



Can you give three examples for each class?

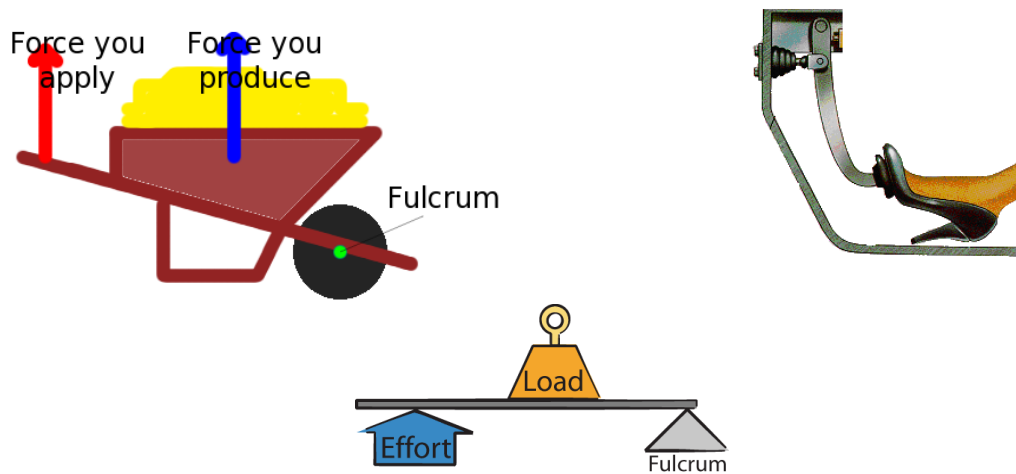
### Class One Levers

- This is the most common type of lever, with the fulcrum in the middle, the effort on one side and the load on the other
- A see-saw is an example of a Class One Lever. Other examples are a crowbar, scissors or weighing scales.
- The distance between the effort and the fulcrum, and the distance between the load and the fulcrum, determine the mechanical advantage and the velocity ratio of the Class One Lever.



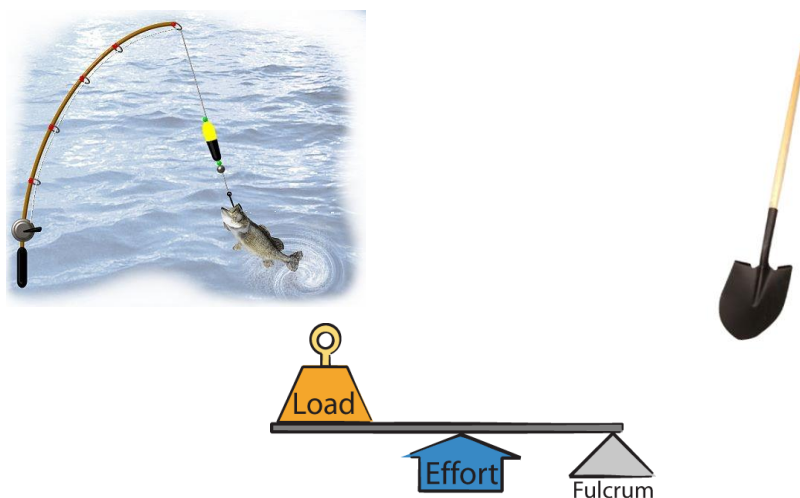
## Class Two Levers

- With a Class Two Lever, the fulcrum is at one end, the effort is at the other end and the load is in the middle
- A wheelbarrow is an example of a Class Two Lever. Other examples include bottle openers, nut crackers and foot pumps
- A Class Two Lever allows a large load to be lifted by a smaller effort. Because the load is always closer to the fulcrum, the effort is always less than the load



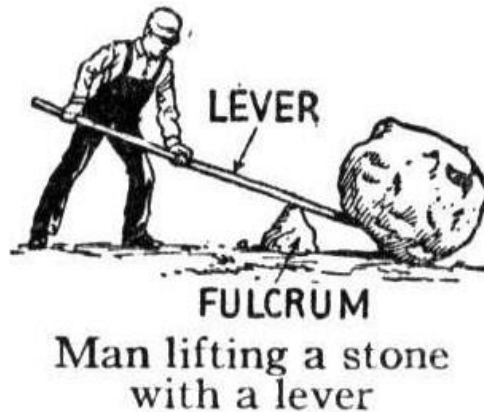
## Class Three Levers

- With a Class Three Lever, the pivot is at one end, the load is at the other and the effort is in the middle
- A shovel is an example of a Class Three Lever. Other examples are a pair of tweezers and a fishing rod
- A Class Three Lever allows a small load to be lifted by a larger effort



## Mechanical Advantage

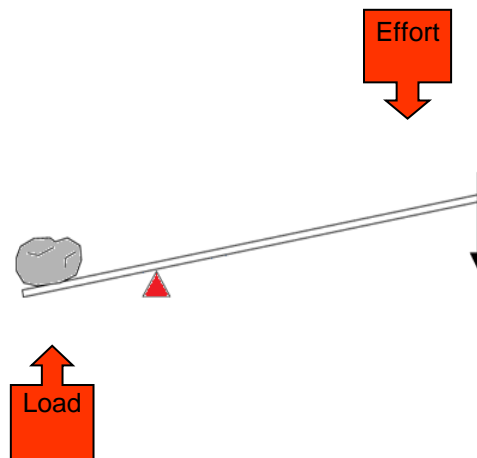
The image below shows a man using a stake to lift a rock. This is an example of a mechanism. As the man exerts a small amount of effort to the end of the lever, the rock is moved. This gain in effort is known as ***Mechanical Advantage***.



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

## Mechanical Advantage – Calculation

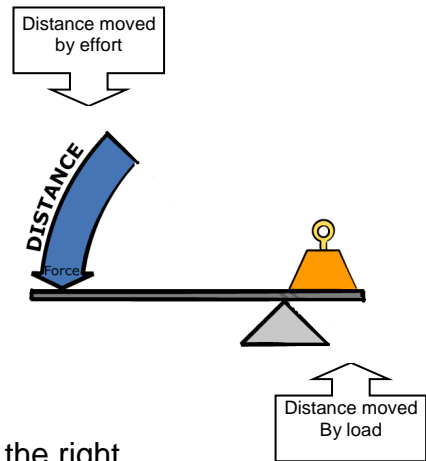
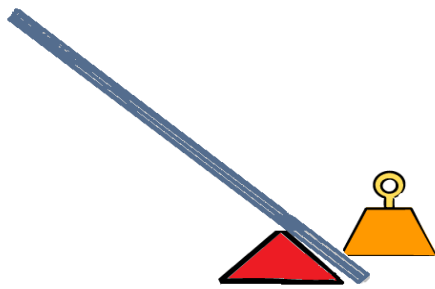
The mechanism shown is being used to raise a weight of 400N. By adjusting the lever, it was found that the weight could be lifted with an effort of 100N.



What is the Mechanical Advantage of this mechanism?

$$\frac{\text{Load}}{\text{Effort}} = \frac{400\text{N}}{100\text{N}} = 4:1 \quad \text{or} \quad 4$$

## Velocity Ratio



The image above shows the position of weight prior to force being applied. The image on the right demonstrates the distance moved by the weight on application of force.

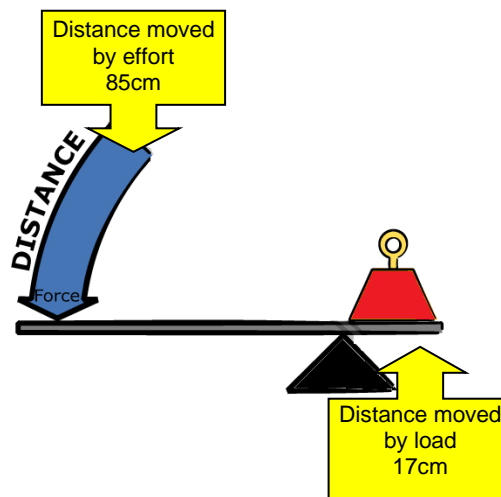
When enough effort is applied to the lever, the weight will move. The distance moved by the effort is greater than that moved by the load.

The difference is known as the **Velocity Ratio**.

The Velocity Ratio = $\frac{\text{Distance moved by effort}}{\text{Distance moved by load}}$
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### Velocity Ratio – Calculation

- The mechanism shown is being used to lift a weight.
- The 500N weight is moved with 100N of effort.
- The effort is moved 85cm in order to raise the weight (load) 17cm.



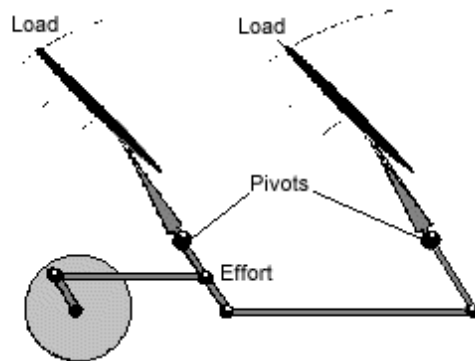
**What is the Velocity Ratio of the mechanism?**

Velocity Ratio = $\frac{\text{distance moved by effort}}{\text{distance moved by load}} = \frac{85\text{cm}}{17\text{cm}} = 5:1 \text{ or } 5$
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## Linkages

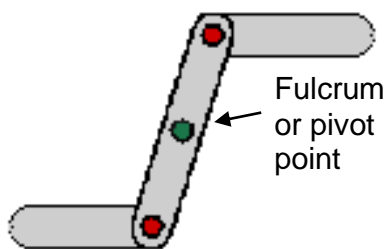
A linkage is a mechanism made by connecting two or more levers together. A linkage can be used to change the direction of a force or to make two or more things move at the same time.



Windscreen wipers on a car operate using linkages

## Reverse Motion Linkages

Linkages can be used to make things move in opposite directions. The movement is reversed by using a lever to form the linkage. If the pivot point (fulcrum) is at the centre of the connecting lever, then the output movement will be the same as the input movement, but it will act in the opposite direction



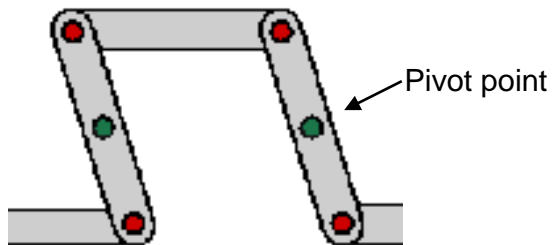
A Reverse Motion Linkage



A Clothes Horse

## Push-Pull Linkages

Push-pull linkages are used to move the output in the same direction as the input. This consists of levers with two fixed pivot points.



A Push-Pull Linkage



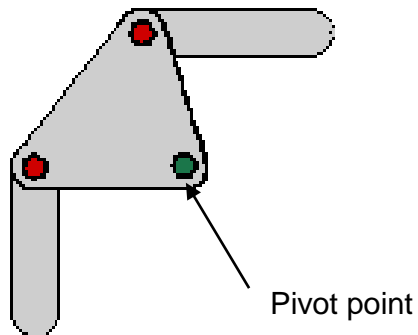
Windscreen Wipers

## Bell Crank Levers

Bell Crank Levers are used when it is necessary to change the direction of movement or force through  $90^\circ$ . If the fulcrum is at an equal distance from the input and output, then the movement of the output will be equal to the movement of the input. Otherwise, the movement will be different and the system will have Mechanical Advantage.



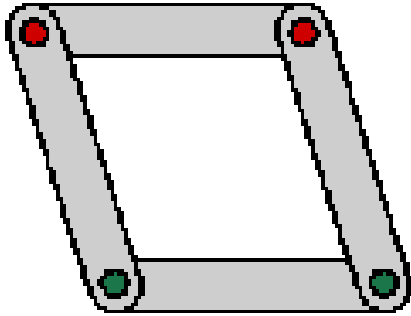
Bicycle Brake



A Bell Crank Lever

## Parallel Motion Linkage

This linkage can be used to make things move in the same direction at a set distance apart. Parallel motion is only achieved if the levers at opposite sides of the parallelogram are equal in length.



Parallel Motion Linkage



Toolbox

### Task

#### *How do linkages work?*

Reconstruct each of the above linkage types using strips of card and paper pins.

Examine the effect moving the positions of the pins (or pivot points) will have on the movement of the pieces of card. (Note increase or decrease in distances moved)

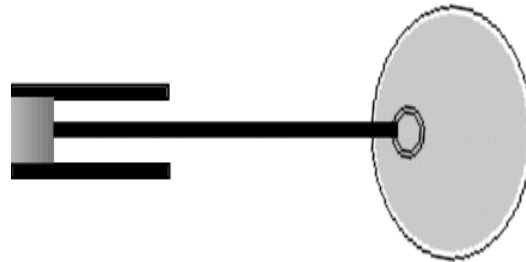
**Note:** If the pivot point of a reverse motion linkage is not in the centre of the connecting levers, then the movement of the output will not be equal to the movement of the input. It is also possible to design a reverse motion linkage which will provide mechanical advantage.

Can you observe any similar traits in any of the other linkage types?

## Crank and Slider

A Crank and Slider mechanism changes rotary motion to reciprocal motion or vice versa. In a car engine, the reciprocating motion of the piston caused by exploding fuel is converted into rotary motion, as the connecting rod moves the crankshaft around.

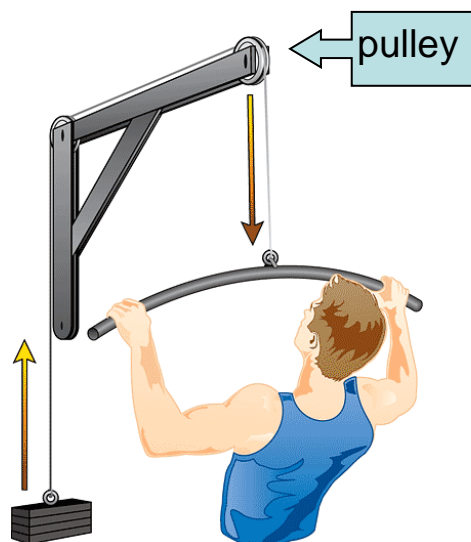
A pneumatic air compressor uses this principle in reverse – an electric motor turns the crankshaft and the piston moves up and down to compress the air.



Crank and Slider

## Pulleys

A pulley wheel is a mechanism which helps move or lift objects. Like most wheels, pulley wheels spin or rotate on an axis. The centre of a pulley wheel features a groove. Nested in this groove is a rope, belt or cable.



Exercise Machine

The man in this image is pulling downwards on a bar, which is attached to a cable.

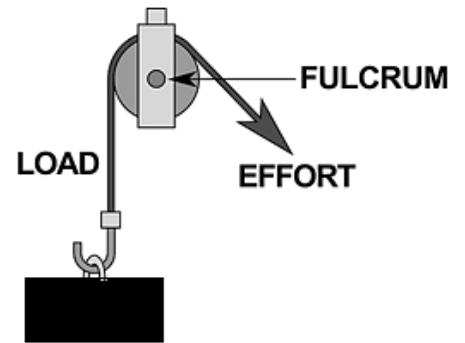
Tracing the cable's path through the machine, it can be seen that the cable passes through the pulley wheels, and its opposite end is connected to the weights at the bottom.

## Parts of a Pulley System

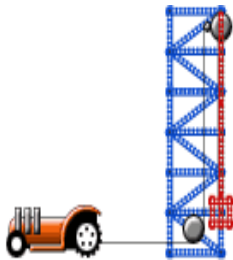
**Effort** – the force the man is applying to the bar

**Load** – the weight being lifted

**Fulcrum** – the pivot point of the pulley



## Direction of Force



Notice that the pulleys change the direction of the applied force. Although the machine is pulling sideways, the weights are moving upwards.

## Types of Pulley

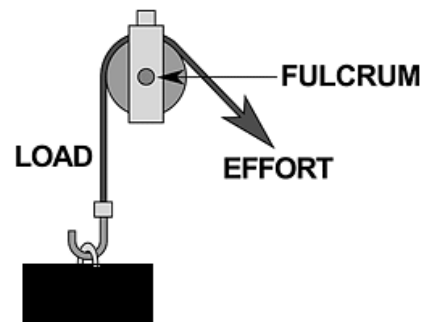
There are three basic types of pulley. These types of pulley are classified by the number of pulley wheels and their positioning.

### 1. A Fixed Pulley

This does not rise or fall with the load being moved. It also changes the direction of the applied effort.



A ski-lift operates on a fixed pulley system

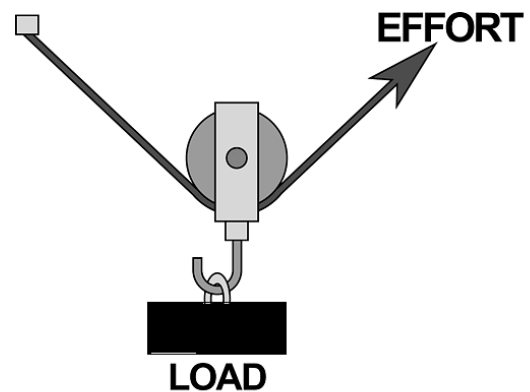


## 2. A Moveable Pulley

This type of pulley rises and falls with the load being moved.



Pulley on Weight-Lifting Machine



## 3. A Block and Tackle Pulley

This consists of two or more pulleys (fixed and moveable). The block and tackle is capable both of changing the direction and creating a *Mechanical Advantage*.



Block and Tackle in use on a Boat



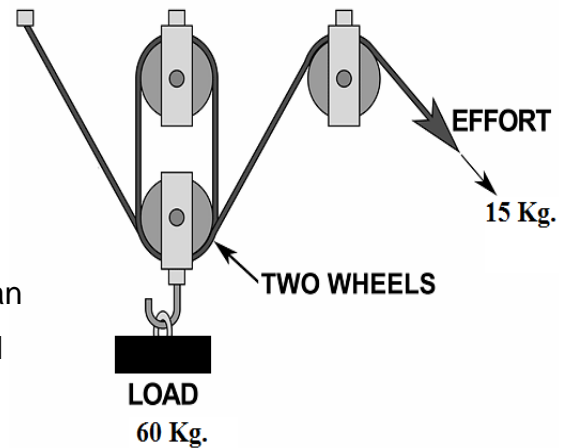
Block and Tackle Pulley

## The Pulley Advantage

This pulley arrangement features a 4:1 Mechanical Advantage.

How can pulleys assist work?

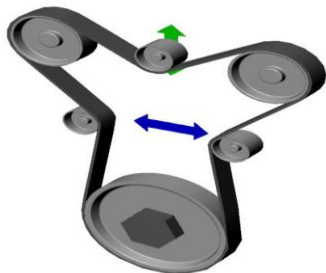
Just like other simple machines, pulleys can change the relationship between force and distance.



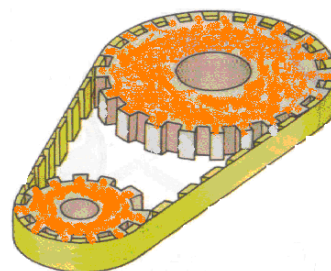
For example, pulling the rope 2m in order to lift a load 0.5m, the output distance is divided and the output force is multiplied by the same factor. Therefore, a load of 60kg can be lifted by only 15kg of effort!

The Mechanical Advantage is calculated like so:  
**Mechanical Advantage = Load / Effort = 60kg / 15kg**  
**Mechanical Advantage = 4:1 or 4**

As already stated pulleys are used for transferring motion and force from one shaft to another. Many machines are often driven by round grooved pulleys and rubber belts. The vacuum cleaner uses a pulley to transmit power from the electric motor to the rotating brushes. If both pulleys are the same diameter, then they will both rotate at the same speed. If one pulley is larger than another, then mechanical advantage and velocity ratio are introduced. A large drive pulley will cause a smaller driven pulley to rotate faster. In situations where no slip between the driven and driver pulleys can be allowed a vee pulley and vee belt will provide less slippage than a flat belt pulley system. If more positive drive is required a toothed belt and pulley can be used.



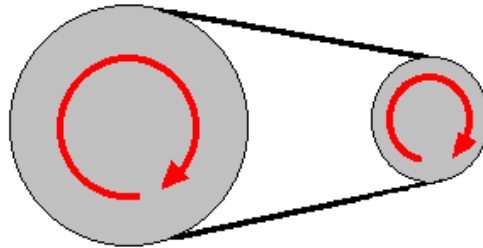
Pulleys and belt



Toothed belt and pulleys

### Calculation 1

If a 120mm diameter pulley drives a 60mm diameter pulley for each revolution of the driver pulley, the driven pulley does two, as  $120\text{mm} \div 60\text{mm} = 2$



### Calculation 2

The diameter of a motor pulley is 40mm and it revolves at 280 rev/min. The diameter of the driven pulley is 70mm. What is its rotational speed?

**Note:** As the driven pulley is larger than the motor pulley, it will revolve more slowly

$$\text{Speed of driven pulley} = \frac{280 \times 40}{70} \text{ rev/min} = 160 \text{ rev/min}$$

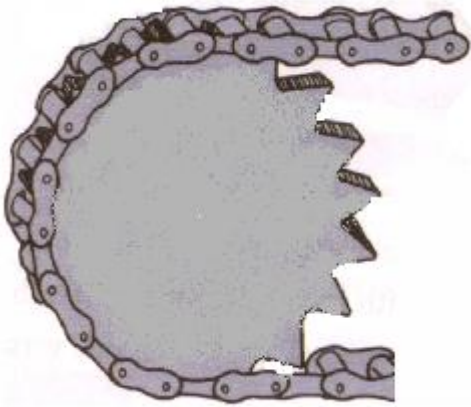
### Chain and Sprockets

Chains and sprockets provide direct drive with no slippage. They are usually used on bicycles, camshafts and motorcycles. When compared to the pulley and belt systems chain and sprocket will be far more reliable.





### Calculation 1



The sprocket on a bicycle has 45 teeth and the sprocket on the back wheel has 15 teeth. So, for every revolution of the front sprocket, the rear one will complete three full revolutions, as  $45 \div 15 = 3$

### Calculation 2

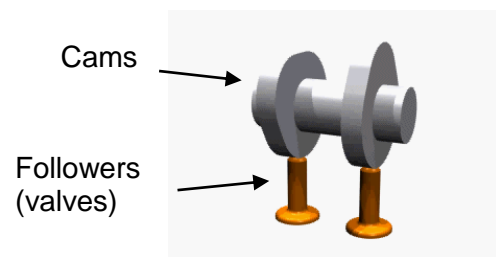
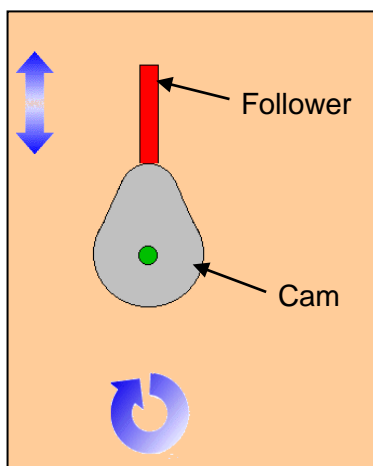
The sprocket on an engine of a moped has 15 teeth and the sprocket on the back wheel has 120 teeth. If the engine revolves at 3200 rev/min, what is the rotary speed of the rear sprocket?

**Note:** The rear sprocket is larger, therefore it revolves more slowly.

Speed of rear sprocket	=	3200	x	$\frac{15}{120}$
	=	3200	x	$\frac{1}{8}$
	=	400	rev/min	

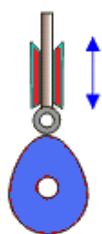
## Cam and Follower

- The **Cam and Follower** is a device which can convert rotary motion (circular motion) into linear motion (motion in a straight line).
- A cam is a specially shaped piece of material, usually metal or hard-wearing plastic, which is fixed to a rotating shaft.
- There are several different types of cam, but most of these can be placed into two groups, namely **rotary** or **linear**.
- Many machines use cams. A car engine uses cams to open and close valves.

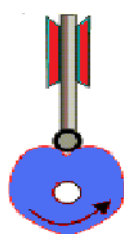


## Cams

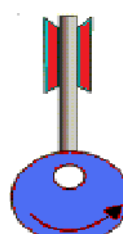
- A cam can have various shapes. These are known as **cam profiles**.
- Cam profiles can be pear, heart, circular or drop shaped.



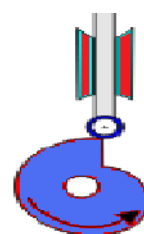
Pear



Heart



Circular

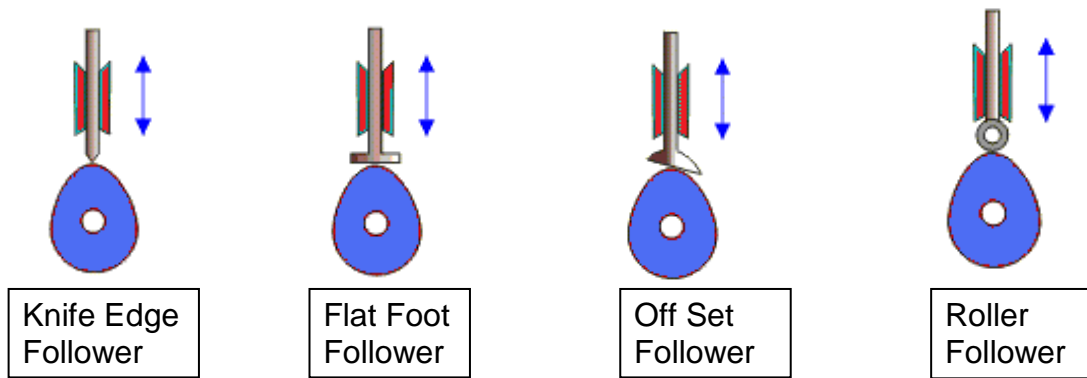


Drop

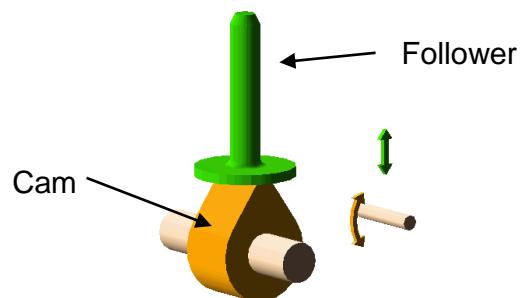
- One complete revolution of the cam is called a cycle.
- As the cam rotates, there will be one distinct event per revolution.

## Followers

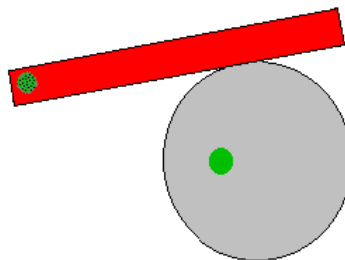
- A follower is a component which is designed to move up and down as it follows the edge of the cam.
- Follower profiles can be knife edge, flat foot, off set or roller.



- As the cam rotates, the follower moves accordingly. The exact distance it moves depends on the shape and size of the cam.

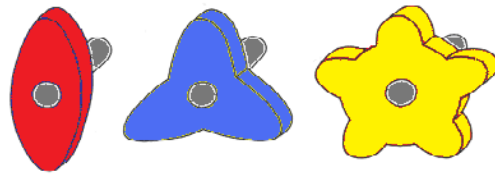
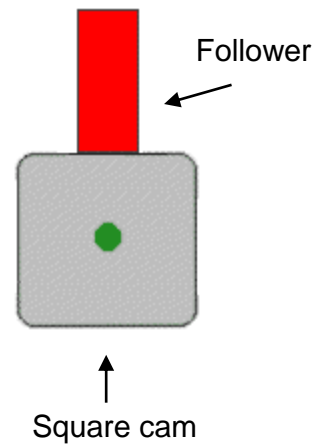


- The cam follower does not have to move up and down – it can be an oscillating lever, as shown below.



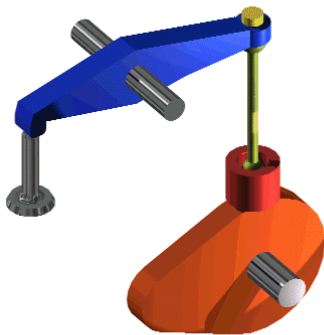
## Rotary Cams

- **Rotary Cams** change rotary motion into reciprocating (backwards and forwards) motion.
- The 'bumps' on a cam are called **lobes**.
- The square cam illustrated, has four lobes, and lifts the follower four times each revolution.



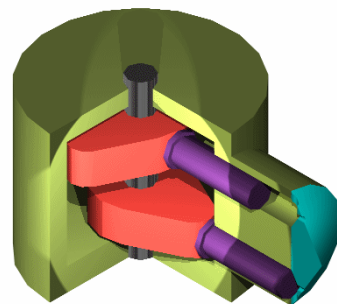
Examples of other rotary cam profiles

## Rotary Cams in Operation

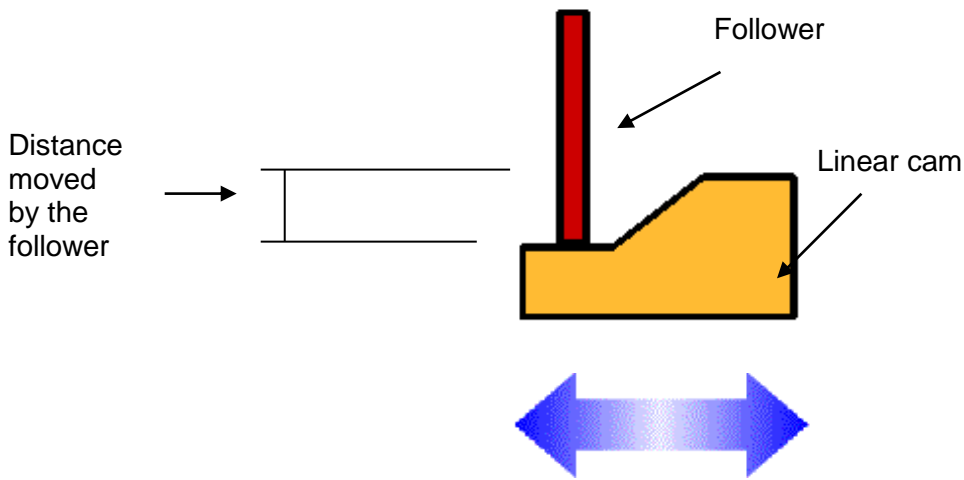


This image depicts a cam used in an engine to control the movement of the valves.

These cams are used in a pump to control the movement of the valves.



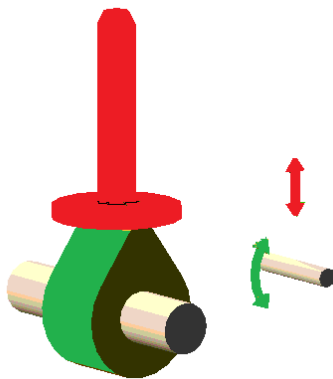
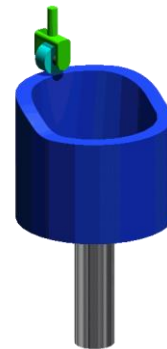
## Linear Cams in Operation



- The linear cam moves backwards and forwards in a reciprocating motion.
- Linear cams change the direction (and magnitude) of reciprocating motion
- The shape of the surface of the cam determines how far the follower moves.

## Cylindrical Cams in Operation

- Cams can also be cylindrical in shape.
- The cylindrical cam rotates on an axis.
- The profile of the cylindrical cam decides the movement of the follower, which is fixed.



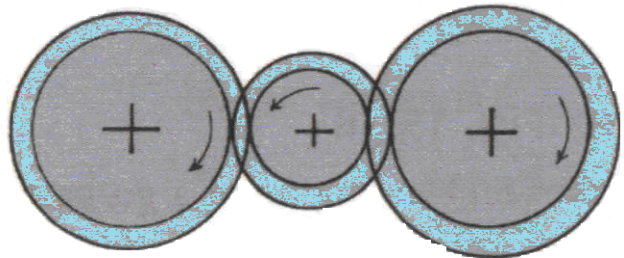
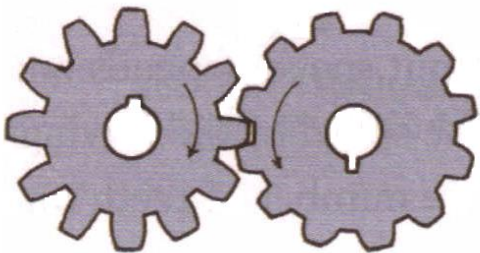
Here, we can see the two different displacements represented by the red and green arrows.

The red arrow shows the displacement of the follower, i.e. the distance travelled up or down by the follower.

The green, curved arrow shows the angular displacement travelled by the cam.

## Gears

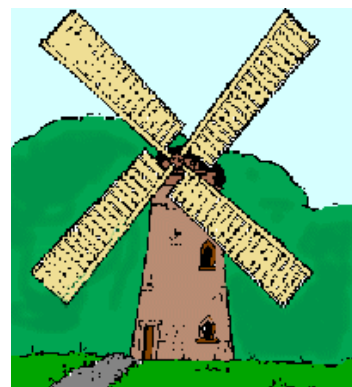
- A gear is a wheel with teeth on its outer edge
- Gears rotate on a central axis and work with other gears to transmit turning force
- The teeth of one gear mesh (or engage) with the teeth of another, as depicted below



- Gears are used to transmit turning force
- They can also change the amount of force, speed and direction of rotation

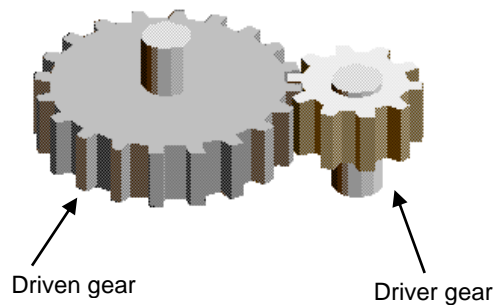


The rotating force produced by an engine, windmill or other device, needs to be transferred or changed in order to do something useful.



## Driver and Driven

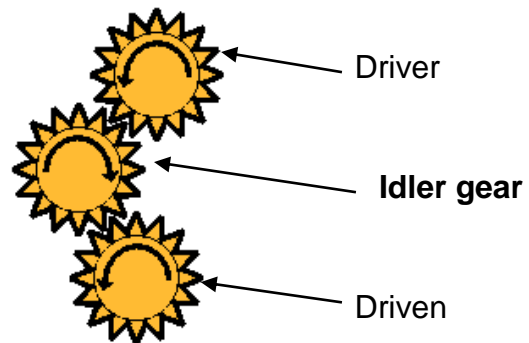
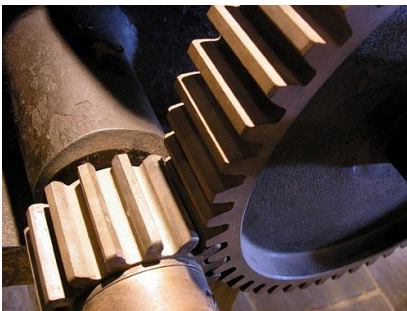
- Two meshed gears always rotate in opposite directions.



- In the above image, the smaller gear is the **driver** or input gear.
- The driver's teeth engage the teeth of the **driven** gear causing it to rotate.
- In other words, the driver drives the driven, thus providing the input force; the driven gear follows the driver, thus yielding the output force.

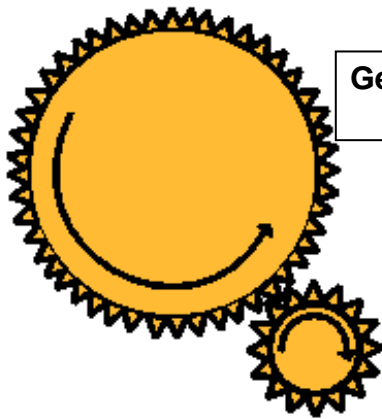
## Direction of Rotation

- The driver and the driven rotate in opposite directions. This is always the case when two gears are meshed directly together.
- Sometimes it's necessary to reverse the direction of rotation. The reverse gear in a car is a practical example of this.
- In other cases, however, it's necessary for the driver and driven to rotate in the same direction.
- Inserting an **idler gear** between the driver and the driven is the simplest way to achieve this.



## Gear Ratio

- If a pair of meshed gears has a driver and driven of the same size, then there will be no change in speed or force of input or output. This is stated as 1:1 Gear Ratio – one turn of the input yields one turn of the output.
- Generally, the Gear Ratio is calculated by counting the teeth of the two gears and applying the following formula:

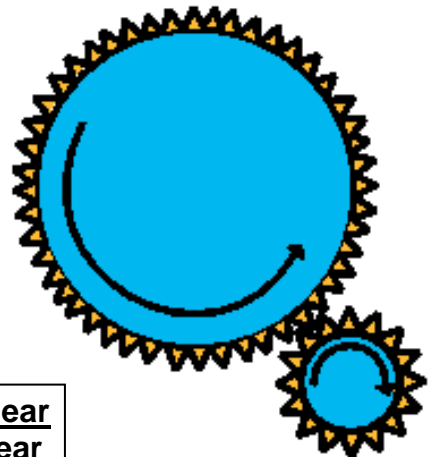


$$\text{Gear ratio} = \frac{\text{Number of teeth on driven gear}}{\text{Number of teeth on driver gear}}$$

## Gear Ratio – Calculation

A 100 tooth gear drives a 25 tooth gear.

Calculate the Gear Ratio for the meshing teeth.



$$\text{Gear ratio} = \frac{\text{Number of teeth on driven gear}}{\text{Number of teeth on driver gear}}$$

(Velocity Ratio)

$$\text{Gear ratio} = \frac{\text{Driven}}{\text{Driver}} = \frac{25}{100} = \frac{1}{4}$$

This is written as 1:4

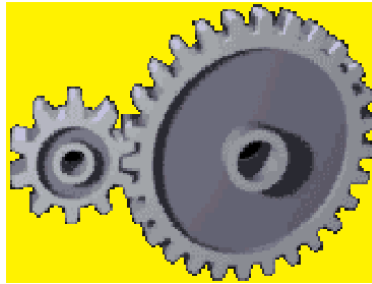


### Speed of Driven Gear – Calculation

A motor gear has 28 teeth and revolves at 100 rev/min.

The driven gear has 10 teeth.

What is its rotational speed?

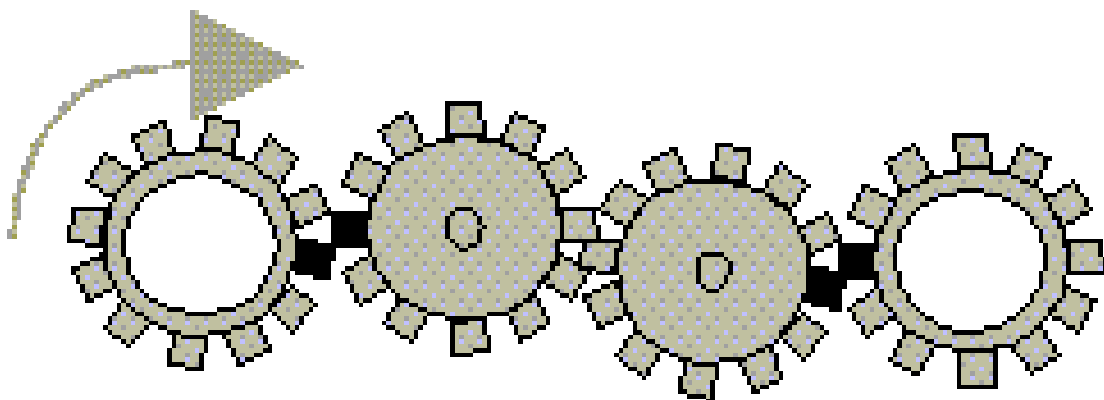


<b>Speed of driven gear =</b> $\frac{\text{Number of teeth on driver gear}}{\text{Number of teeth on driven gear}} \times 100$
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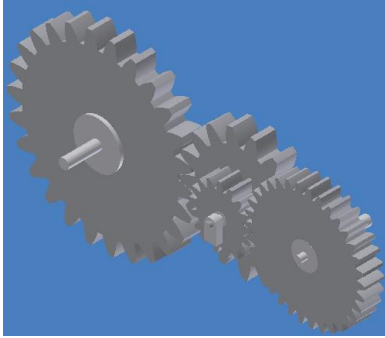
Speed of driven gear = $\frac{\text{Driver}}{\text{Driven}} = \frac{28}{10} \times 100$
<b>= 280 rev/min</b>

### Gear Trains

- Multiple gears can be connected together to form a **Gear Train**
- If there is an odd number of gears in the Gear Train, the output rotation will be the same direction as the input
- If there is an even number, the output will rotate in the opposite direction to the input.



## Compound Gear Trains



A compound gear train is one which has two or more gears attached to the same shaft. In actual fact, it is a combination of two or more gear trains.

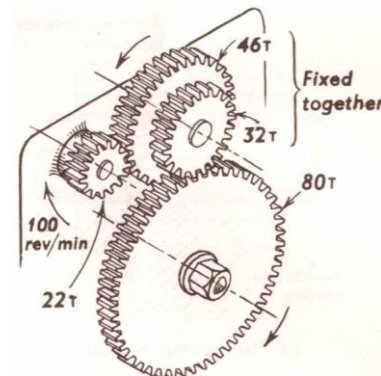
### Calculation

A gear of 22 T drives another of 46 T. Attached solidly to the second gear is a 32 T, which drives a gear of 80 T. If the first gear makes 100 rev/min, calculate the speed of the last.

The middle shaft turns at  $100 \times \frac{22}{46}$  rev/min

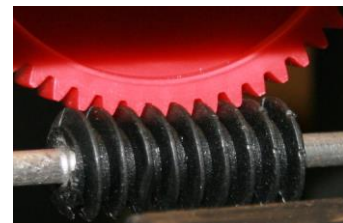
and the last gear makes  $100 \times \frac{22}{46} \times \frac{32}{80}$

= 19.13 rev/min



### Worm and Wheel

- In a simple Gear Train, very high or very low Gear Ratios can be achieved by combining very large and very small cogs, or by using a **worm and wheel**.
- The Velocity Ratio of a **Worm and Wheel** is easily calculated, because the worm has only one tooth. The worm gear is always the drive gear.



For example, if the wheel gear has 60 teeth and the worm gear has one tooth, then Velocity Ratio is  $1/60 = 1:60$

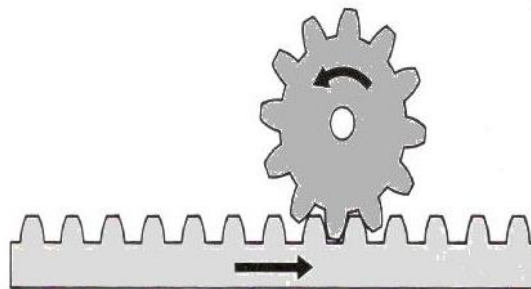
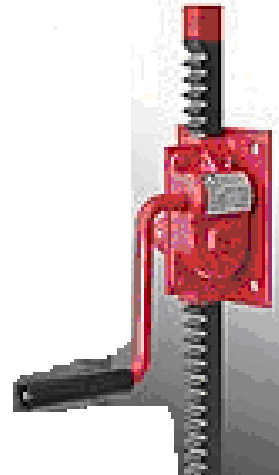
- A worm and wheel can be seen in everyday use in gear box systems, where large loads are to be lifted, e.g. bridge lifting mechanism.
- Its major advantage lies in the fact that the worm is always the drive gear, as mentioned above. This enables the worm and wheel to lift or lower significant weight without causing strain on the gearbox.

### **Rack and Pinion Gears**

The Rack and Pinion Gear is used to convert between rotary and linear motion.

Often the pinion rotates in a fixed position and the rack is free to move – this arrangement is used in the steering mechanisms of most cars.

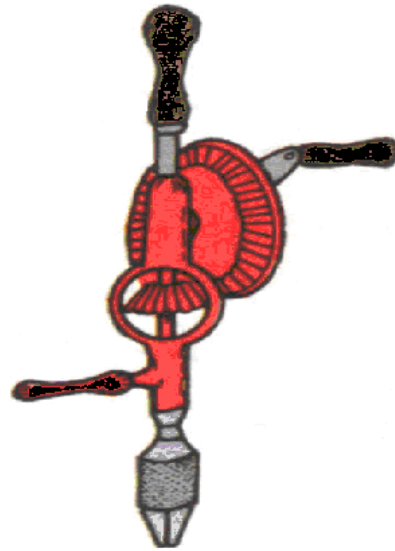
Alternatively, the rack may be fixed and the pinion rotates, moving up and down the rack.



**Note:** The distance moved by the rack corresponds directly with the number of teeth on the pinion. For example, if the pinion has 12 teeth, as in the illustration above, each anti-clockwise rotation of the pinion will result in a movement to the right of the rack, by a measure of 12 teeth.

## Bevel Gears

- Bevel gears are used to transfer drive through an angle of  $90^\circ$ . If both gears have the same number of teeth, they are called **mitre gears**.
- Bevel gears will provide some Mechanical Advantage or increase in Velocity Ratio.



Bevel Gears

**Work** exists everywhere, and although it cannot be seen, its effects can be felt all the time. It is only possible to do work if you have **energy**, which can be applied. Energy exists and cannot be destroyed, but energy cannot be created from nothing.

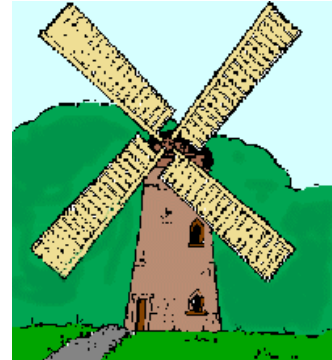
Work comes in a number of different forms. Three of these are:

1. *Mechanical Work* – e.g. allowing a car to run
2. *Electrical Work* – e.g. allowing lights to be turned on
3. *Heat Work* – e.g. providing warmth from a fire

$$\text{Work} = \text{force} \times \text{distance moved in direction of the force}$$

**Power** is the rate at which energy is converted from one form into another. All moving objects and machines only have limited power. They may be able to handle lots of energy, but it is only possible to do this at a certain rate.

$$\text{Average power used: } \frac{\text{total time taken}}{\text{total work done}}$$



A windmill converts wind energy into mechanical energy

The amount of power a machine can produce lots of energy is not the only factor to be considered when designing a moving object. It is also necessary to consider the **efficiency** of the machine.

**Efficiency** refers to the amount of energy lost through work. Some machines are very **efficient** because they lose very little energy. Some machines are less efficient, because they lose heat through **friction**, which can never be gotten rid of, but can be reduced.

$$\text{Efficiency (\%)} = \frac{\text{Power output}}{\text{Power input}} \times 100$$

**Friction** resists the movement of one surface over another.

Friction is increased as:

1. the surfaces become rougher
2. the pressure between the surfaces increases
3. less friction-resistant materials are used

Friction has a number of effects:

1. it produces heat
2. it causes parts to wear
3. it reduces a machine's power



The rough surface of the bicycle brake pads, creates friction when applied to the rubber of the tyre, thus causing the bicycle wheel to stop turning

Sometimes friction is advantageous, e.g. bicycle or car brakes would not work without friction. However, when smooth movement is necessary, friction must be reduced. This can be done by:

1. using low friction materials, such as bronze, brass, nylon or white metal
2. using a lubricant, such as oil or grease, to separate surfaces
3. ensuring that surfaces are as smooth as possible
4. using moving bearings, like a roller bearing