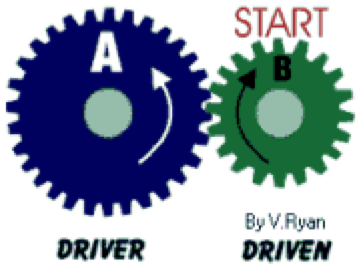
GEARS AND PULLEYS

This file aims to introducing basic concepts of gears and pulleys. Areas covered include spur gears, compound gears, chain drive, rack/pinion systems and pulley systems.

GEARS AND GEAR SYSTEMS

Gears can be found in many machines in a workshop or factory and at home they are often an important part of mechanical devices. In a car the gears help the driver to increase and decrease speed as he/she changes the gears with the gear stick.

The gears opposite are called spur gears because they mesh together. As shown in the figure, Gear ‘A’ is called the ‘driver’ because this is turned by a motor. As gear ‘A’ turns, it meshes with gear ‘B’ and it begins to turn as well. Gear ‘B’ is called the ‘driven’ gear.

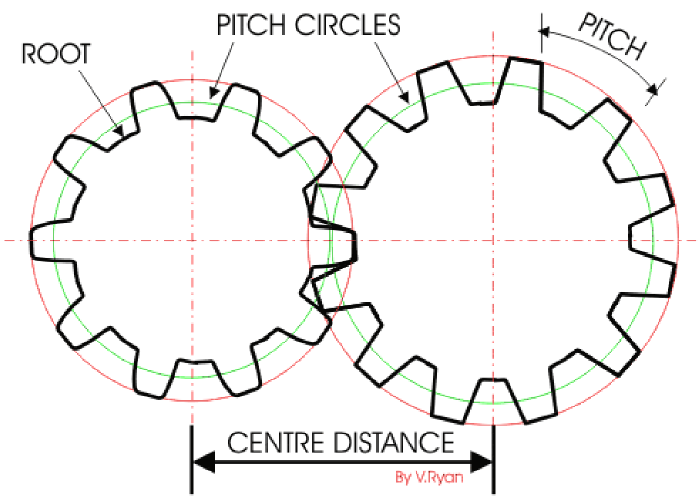


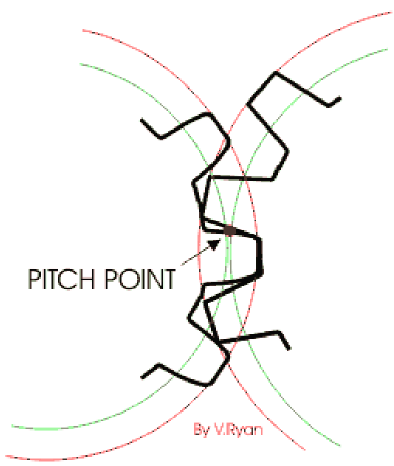
Gear ‘A’ has 30 teeth and gear ‘B’ has 20 teeth. If gear ‘A’ turns one revolution, how many times will gear ‘B’ turn? Which gear revolves the fastest?

$$\frac{\text{GEAR A} = \text{30 TEETH}}{\text{GEAR B} = \text{20 TEETH}} = \frac{30}{20} = 1.5 \text{ (GEAR B)}$$

When gear ‘A’ completes one revolution, gear 'B' turns 1.5 revolutions (1½ times). You should have also found the gear ‘B’ revolves the fastest. A basic rule of gears is - if a large gear (gear ‘A’) turns a small gear (gear ‘B’), the speed increases. On the other hand, if a small gear turns a large gear, the opposite happens and the speed decreases.

GEARS DETAILS

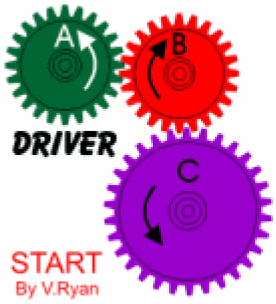




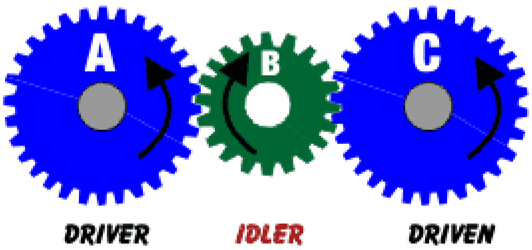
The gears above are known as ‘spur gears’. The circle marked in red shows the outer limit of the teeth, whilst the green circles are known as the ‘pitch circles’. The ‘pitch circle’ of a gear is very important as it is used by engineers to determine the shape of the teeth and the ratio between gears (ratios will be explained later). The ‘pitch’ of a gear is the distance between any point on one tooth and the same point on the next tooth. The ‘root’ is the bottom part of a gear wheel. The pitch point is the point where gear teeth actually make contact with each other as they rotate.

GEAR TRAINS

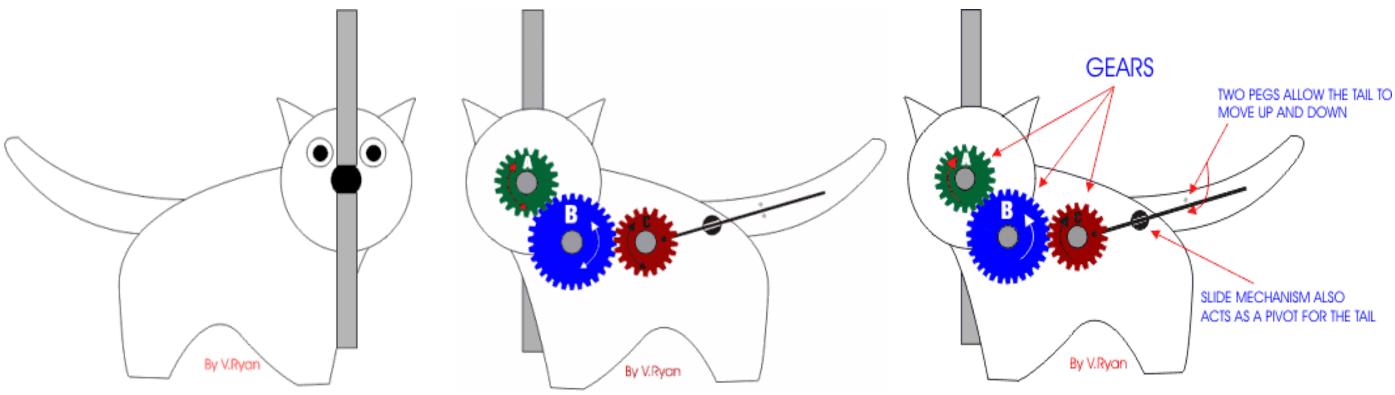
This is a good example of a 'gear train'. A gear train is usually made up of two or more gears. The driver in this example is gear 'A'. *If a motor turns gear 'A' in an anticlockwise direction; Which direction does gear 'B' turn? Which direction does gear 'C'' turn?*



So far you have read about 'driver' gears, 'driven' gears and gear trains. An 'idler' gear is another important gear. In the example opposite gear 'A' turns in an anticlockwise direction and also gear 'C' turns in an anticlockwise direction. The 'idler' gear is used so that the rotation of the two important gears is the same.

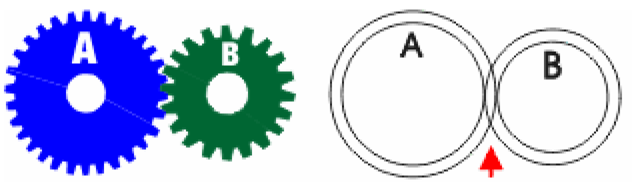


The following is a practical exercise based on wind power, gears, and linkages. The nose of the cat is part of a propeller which rotates when the wind blows (front view). As it rotates, gears at the back of the model cat also rotate and a wire linkage moves the tail up and down. The back view below shows the arrangement of gears at the back of the cat needed to provide the right movement.

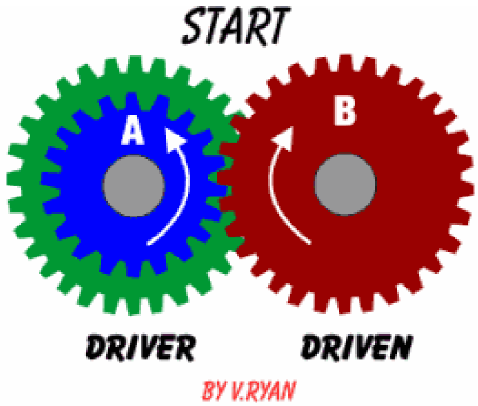


DRAWING GEARS

It would be very difficult to draw gears, if you had to draw all the teeth every time you wanted to design a gear system. For this reason a gear can be represented by drawing two circles.

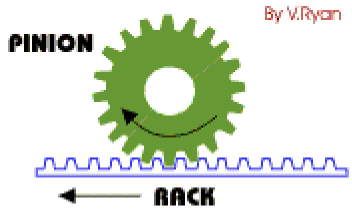


COMPOUND GEARS



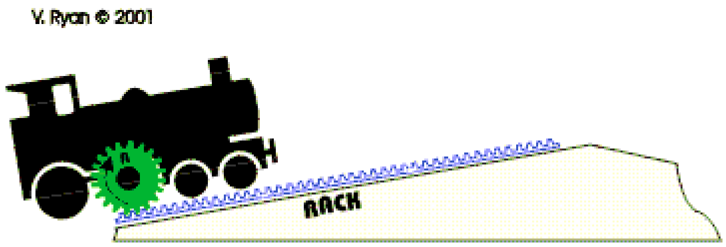
Compound gears are used in engines, workshop machines and in many other mechanical devices. In the diagram, gear ‘A’ is actually two gears attached to each other and they rotate around the same centre. Sometimes compound gears are used so that the final gear in a gear train rotates at the correct speed.

RACK AND PINION

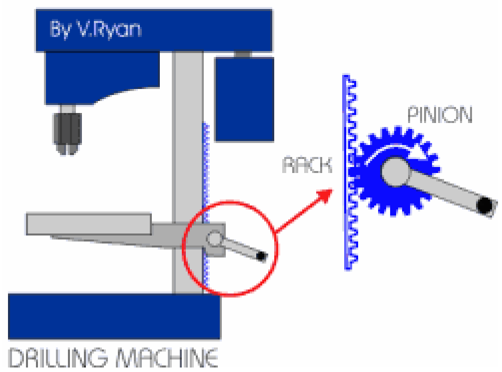


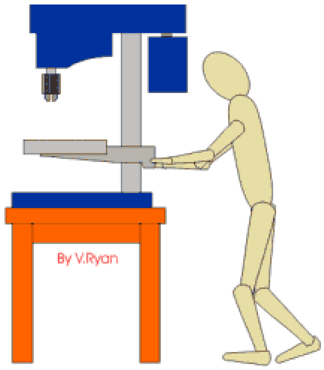
A ‘rack and pinion’ gears system looks quite unusual. However, it is still composed of two gears. The ‘pinion’ is the normal round gear and the ‘rack’ is straight or flat. The ‘rack’ has teeth cut in it and they mesh with the teeth of the pinion gear. *If gear ‘A’ rotates how would you describe the movement of the rack?*

The pinion rotates and moves the rack in a straight line – another way of describing this is to say ‘rotary motion’ changes to ‘linear motion’. A good example of a ‘rack and pinion’ gear system can be seen on trains that are designed to travel up steep inclines. The wheels on a train are steel and they have no way of griping the steel track. Usually the weight of the train is enough to allow the train to travel safely and at speed along the track. However, if a train has to go up a steep bank or hill it is likely to slip backwards. A ‘rack and pinion’ system is added to some trains to overcome this problem. A large gear wheel is added to the centre of the train and an extra track is, with teeth, called a ‘rack’ is added to the track. As the train approaches a steep hill or slope the gear is lowered to the track and it meshes with the ‘rack’. The train does not slip backwards but it is pulled up the steep slope



Another good example of a ‘rack and pinion’ train is seen in the Snowdonia National Park (North Wales). Mount Snowdon is the highest mountain in Wales and there are two ways to reach the top. The first is the walk and the second is to take the train. If you ever visit Mount Snowdon look at the train and the track, you will clearly see the ‘rack’. Below is another example of a ‘rack and pinion – drilling machine’ as seen in the school workshop and machine shops throughout the world.





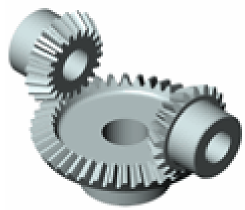
As the handle is turned, the table moves up and down the central pillar of the drill. This makes it easy to move the table and takes the minimum of effort. This is a simple but interesting application of a 'rack and pinion' mechanism. The less well designed machine drills do not have this and consequently brute force is needed to move the table up and down. Often this is difficult and requires some strength. The 'rack and pinion' reduces the force needed to move the table and most importantly protects the machine operator and his/her back from excessive strain. Above is one of the less well designed machine drills. The table on these machines can weigh a significant amount and if they are used often by the same operator damage to the back can occur. A well designed mechanism such as the 'rack and pinion' saves effort and time. Sometimes it is a good idea to invest in a slightly more expensive piece of machinery especially as health and safety is very important.

BEVEL GEARS

Bevel gears can be used to change the direction of drive in a gear system by 90 degrees. A good example is seen as the main mechanism for a hand drill. As the handle of the drill is turned in a vertical direction, the bevel gears change the rotation of the chuck to a horizontal rotation.

ENLARGED VIEW OF THE BEVEL GEARS OF A HAND DRILL MECHANISM

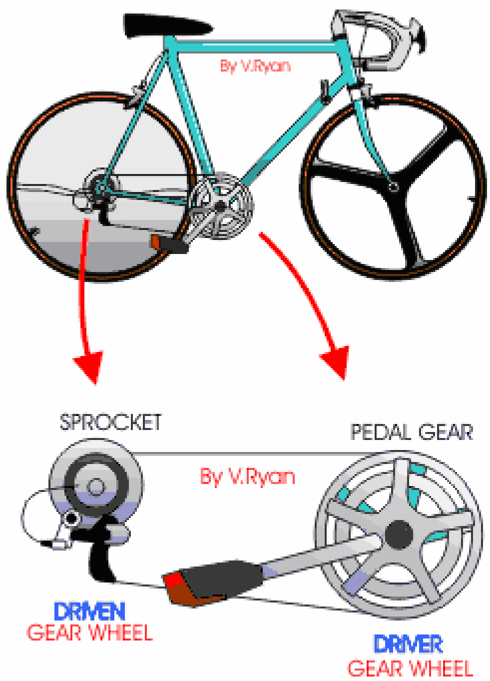
A TYPICAL HAND DRILL



The bevel gears in a hand drill have the added advantage of increasing the speed of rotation of the chuck and this makes it possible to drill a range of materials.

GEAR RATIO (VELOCITY RATIO)

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. Look at the gear wheel with the pedal attached and compare it in size to the gear wheels in the centre of the back wheel. *What do you notice about them?*



Most people have cycled a bicycle up a hill. The steeper the hill gets the more difficult it is to pedal and normally a cyclist will change gears to make it easier. When the cyclist changes gear, the chain moves from a small gear to a larger gear with more teeth, making it easier to push the pedals round. The more teeth the back gear has, the easier it is to cycle up hill although the bicycle moves forward more slowly. *What will happen if a cyclist going up a hill changes gear from a larger to a smaller gear wheel? Will it be easier or harder to pedal?*

The reason bicycles are easier to cycle up a hill when the gears are changed is due to what is called 'Gear Ratio' (velocity ratio). 'Gear ratio' can be worked out in the form of numbers. Basically, the ratio is determined by the number of teeth on each gear wheel, the chain is ignored and does no enter the equation.

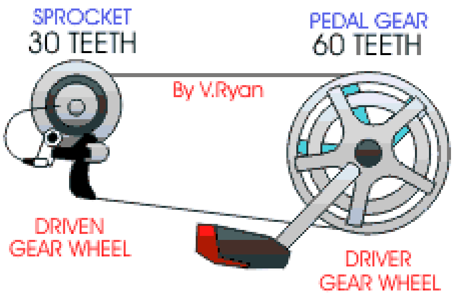
EXAMPLE: IF THE PEDAL GEAR REVOLVES ONCE, HOW MANY TIMES WILL THE SPROCKET GEAR REVOLVE?

$$\frac{\text{NUMBER OF TEETH ON PEDAL GEAR}}{\text{NUMBER OF TEETH ON SPROCKET}} = \frac{60 \text{ TEETH}}{30 \text{ TEETH}}$$

The gear ratio is

$= 2$ (THE SPROCKET GEAR REVOLVES TWICE)

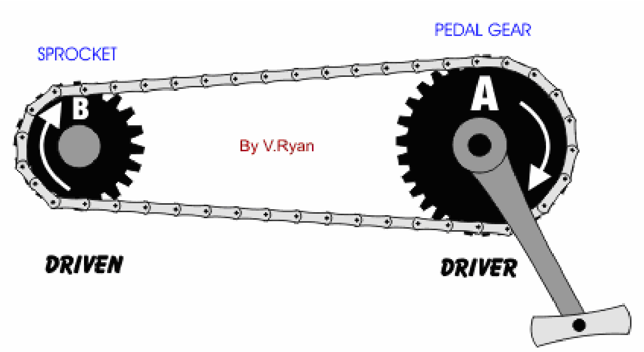
1	:	2
PEDAL GEAR		SPROCKET GEAR

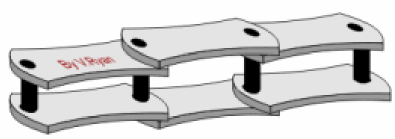


The example above shows that every time the pedal gear revolves once the sprocket gear on the back wheel revolves twice making it easier to cycle up hill.

GEAR WHEELS (SPROCKETS) AND CHAINS

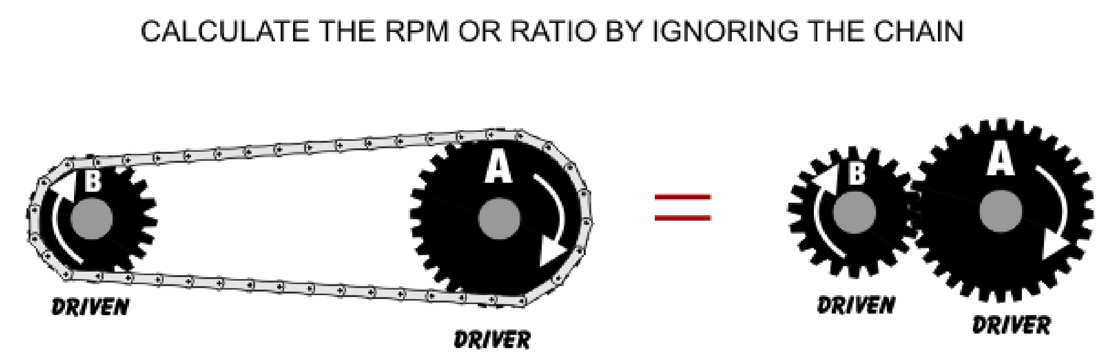
Everyone has seen a bicycle or used one and noticed that it is driven by a large driver gear wheel with pedals attached. Smaller gears at the back are driven round, in turn driving round the back wheel. As the back wheel turns the bicycle moves forwards. Gears driven by chains are used in machinery, motorcycles, car engines, and many more applications.





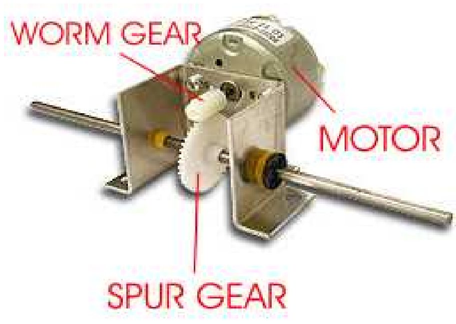
A chain is made up of a series of links with the links held together with steel pins. This arrange makes a chain a strong, long lasting way of transmitting rotary motion from one gear wheel to another. Chain drive has one main advantage over a traditional gear train. Only two gear wheels and a chain are needed to transmit rotary motion over a distance. With a traditional gear train, many gears must be arranged meshing with each other in order to transmit motion.

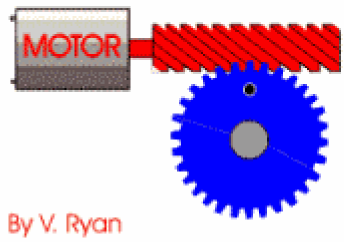
When working out gear/velocity ratio and the rpm of chain driven gears, it must be remembered that the chain is ignored. This means that you simply find out the teeth per gear wheel and the rpm and use the same method of calculating as you would with a normal, meshing gear system.



WORM GEARS

The arrangement of gears seen below is called a ‘worm’ and ‘worm wheel’. The worm, which in this example is brown in colour, only has one tooth but it is like a screw thread. The worm wheel, colored yellow, is like a normal gear wheel or spur gear. The worm always drives the worm wheel round, it is never the opposite way round as the system tends to lock and jam.





The gear ratio of a worm gear is worked out through the following formula:

$$\frac{\text{number of teeth on worm wheel}}{\text{number of teeth on worm}}$$

The worm acts as a single toothed gear so the ratio is;

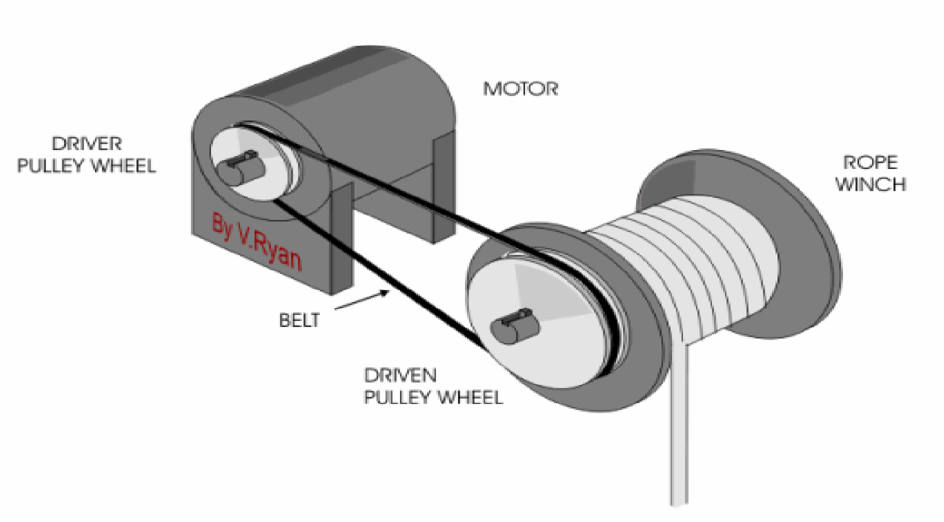
$$\frac{\text{number of teeth on wormwheel}}{1}$$

EXAMPLE: If the wormwheel has 60 teeth, then the Gear Ratio = 60:1 (Rotary velocity is also reduced by 60:1)

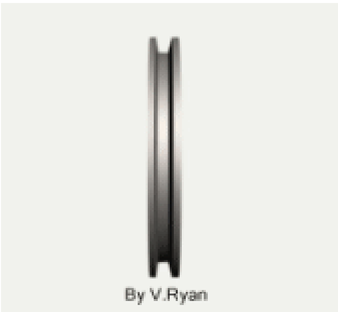
Quite simply, this means a worm gear reduces the speed of the spur gear by sixty times. If you need a gear system whereby the speed is reduced by a considerable amount - a worm and wormwheel are worth considering.

PULLEY SYSTEMS

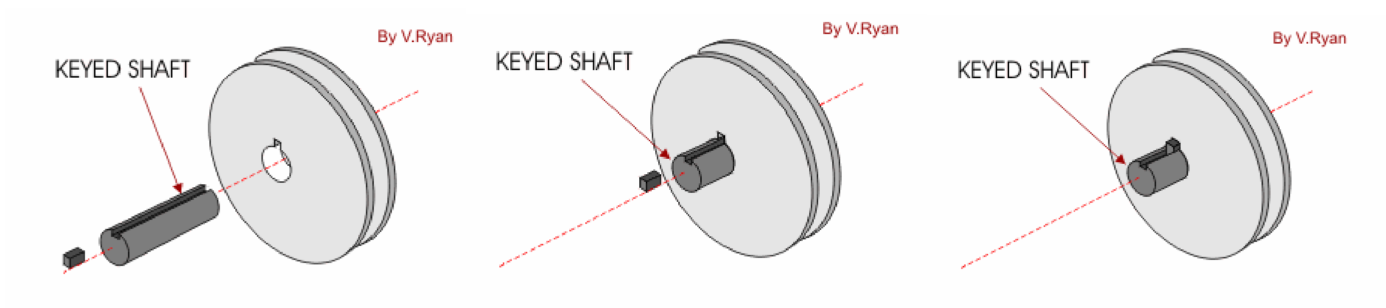
Pulley systems are used when there is a need to transmit rotary motion. The diagram below shows a simple system comprised of two pulley wheels and a belt. It is a simple mechanical device to winch up and down a rope. When the motor is turned on it revolves the driver pulley wheel. The belt causes the driven pulley wheel to rotate as well, winding out the rope.



Pulley wheels are grooved so that the belt cannot slip off. Also, the belt is pulled tight between the two pulley wheels (in tension). The friction caused by this means that when the driver rotates the driven follows.

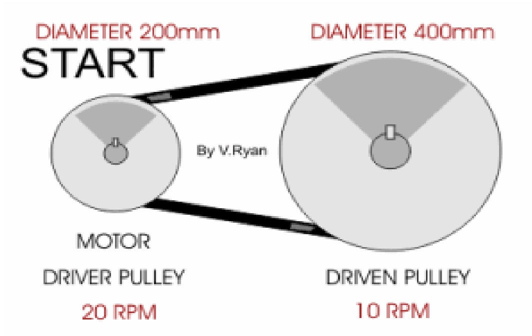


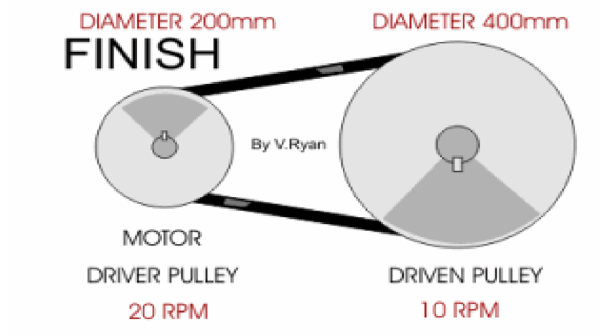
Most pulley wheels have a central shaft on which they rotate. To keep the wheel firmly attached to the shaft it is usual to use what is called a 'key'. The diagrams to the left shows a keyed shaft which is pushed through the centre of the pulley wheel. A small rectangular key is then 'tapped' into position, holding the shaft and the pulley wheel together. This fitting means that the pulley wheel cannot slip on the shaft.



VELOCITY RATIO

The diagram next page shows a small driver pulley pulling round a larger driven pulley. The rpm (revolutions per minute) of the larger driven pulley wheel will be less than the smaller driver pulley wheel. The same principle regarding speed of rotation regarding gears applies to pulley systems as well.





1. The system shown above has a driver pulley attached to a motor. When the motor is switched on the driver pulley revolves at 20 rpm. The diameter of the driver pulley wheel is 200mm and the driven pulley wheel is 400mm. This means for every single revolution of the larger driven pulley wheel, the smaller driver pulley wheel rotates twice. This is due to velocity ratio. The ratio can be worked out mathematically in different ways. The two most likely methods are shown below

METHOD ONE:

$$\frac{\text{DISTANCE MOVED BY DRIVER PULLEY}}{\text{DISTANCE MOVED BY DRIVEN PULLEY}} = \frac{400}{200} = \frac{400}{200} = 2 \quad \text{OR} \quad \underset{\text{DRIVEN : DRIVER}}{1:2}$$

METHOD TWO:

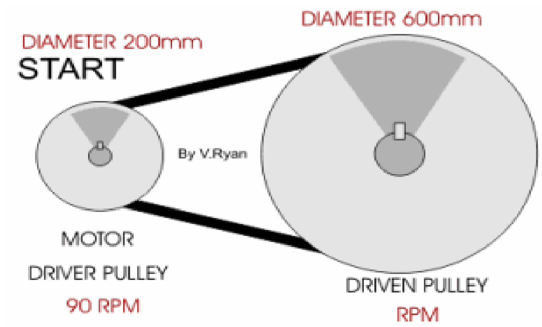
$$\text{VELOCITY RATIO} = \frac{\text{DISTANCE MOVED BY DRIVER PULLEY}}{\text{DISTANCE MOVED BY DRIVEN PULLEY}}$$

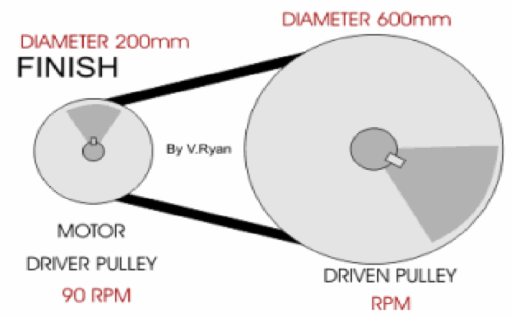
$$= \frac{\text{DRIVER PULLEY MOVES 2 REVOLUTIONS}}{\text{DRIVEN PULLEY MOVES 1 REVOLUTIONS}} = \frac{2}{1} \quad \text{OR} \quad \underset{\text{DRIVEN : DRIVER}}{1:2}$$

This means that the larger pulley wheel (the driven pulley wheel) revolves half as fast compared to the smaller driver pulley wheel. In effect the driven pulley wheel is slower and revolves half as many times as the driver. This means if the rpm of the driver pulley wheel is divided by 2, the output rpm of the driven pulley wheel will be found.

$$\text{VELOCITY / SPEED OF ROTATION OF DRIVEN PULLEY WHEEL} = \frac{\text{RPM OF DRIVER PULLEY}}{2} = \frac{20 \text{ rpm}}{2} = 20 \text{ rpm at Driven pulley wheel}$$

2. Now if the diameter of the driver pulley wheel is 200mm and the driven pulley wheel is 600mm. This means for every single revolution of the larger driven pulley wheel, the smaller driver pulley wheel rotates three times. This is due to velocity ratio. The ratio can be worked out mathematically in different ways. The two most likely methods are shown below





METHOD ONE:

$$\frac{\text{DISTANCE MOVED BY DRIVER PULLEY}}{\text{DISTANCE MOVED BY DRIVEN PULLEY}} = \frac{600}{200} = \frac{600}{200} = 3 \quad \text{OR} \quad \underset{\text{DRIVEN : DRIVER}}{1:3}$$

METHOD TWO:

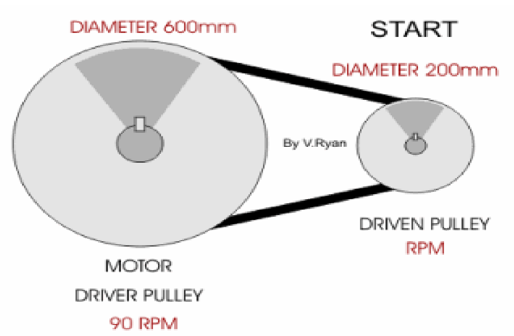
$$\text{VELOCITY RATIO} = \frac{\text{DISTANCE MOVED BY DRIVER PULLEY}}{\text{DISTANCE MOVED BY DRIVEN PULLEY}}$$

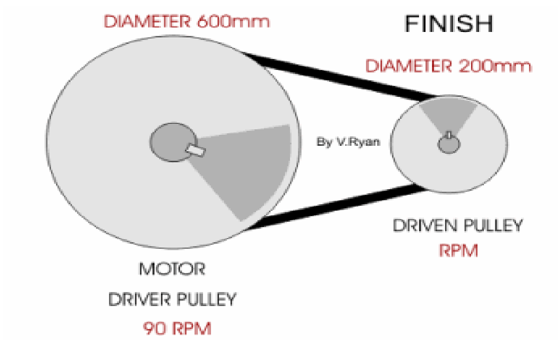
$$= \frac{\text{DRIVER PULLEY MOVES 2 REVOLUTIONS}}{\text{DRIVEN PULLEY MOVES 1 REVOLUTIONS}} = \frac{3}{1} \quad \text{OR} \quad \underset{\text{DRIVEN : DRIVER}}{1:3}$$

This means that the larger pulley wheel (the driven pulley wheel) revolves a third of the rpm compared to the smaller driver pulley wheel. In effect the driven pulley wheel is slower and revolves a third as many times as the driver. This means if the rpm of the driver pulley wheel is divided by 3, the output rpm of the driven pulley wheel will be found.

$$\begin{array}{c}\text{VELOCITY / SPEED OF ROTATION}\\ \text{OF DRIVEN PULLEY WHEEL}\end{array} = \frac{\text{RPM OF DRIVER PULLEY}}{3} = \frac{90\text{ rpm}}{3} = 30 \text{ rpm at Driven pulley wheel}$$

3. In the following example, the driver pulley wheel is the largest of the two. Because it is the largest it will automatically be the slowest and output less rpm's than the smaller driven pulley wheel.





The diameter of the driver pulley wheel is 600mm and the driven pulley wheel is 200mm. This means for every single revolution of the larger driver pulley wheel, the smaller driven pulley wheel rotates three times. This isdue to velocity ratio. The ratio can be worked out mathematically in different ways. The two most likely methods are shown below. Please note, the driven pulley wheel is placed on top of the equation as it is the larger number.

METHOD ONE:

$$\frac{\text{DISTANCE MOVED BY DRIVEN PULLEY}}{\text{DISTANCE MOVED BY DRIVER PULLEY}} = \frac{600}{200} = \frac{600}{200} = 3 \quad \text{OR} \quad \underset{\text{DRIVER : DRIVEN}}{1:3}$$

METHOD TWO:

$$\text{VELOCITY RATIO} = \frac{\text{DISTANCE MOVED BY DRIVEN PULLEY}}{\text{DISTANCE MOVED BY DRIVER PULLEY}}$$

$$= \frac{\text{DRIVEN PULLEY MOVES 3 REVOLUTIONS}}{\text{DRIVER PULLEY MOVES 1 REVOLUTIONS}} = \frac{3}{1} \quad \text{OR} \quad 1:3$$

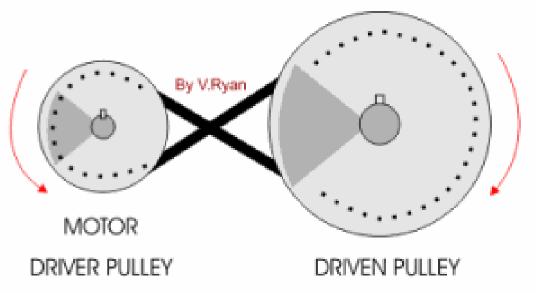
DRIVER : DRIVEN

This means that the larger pulley wheel (the driver pulley wheel) revolves a third of the rpm compared to the smaller driven pulley wheel. In effect the driver pulley wheel is slower and revolves a third as many times as the driven. This means if the rpm of the driver pulley wheel is MULTIPLIED by 3, the output rpm of the driven pulley wheel will be found.

VELOCITY / SPEED OF ROTATION OF DRIVEN PULLEY WHEEL = RPM OF DRIVER PULLEY X 3 = 90 rpm X 3

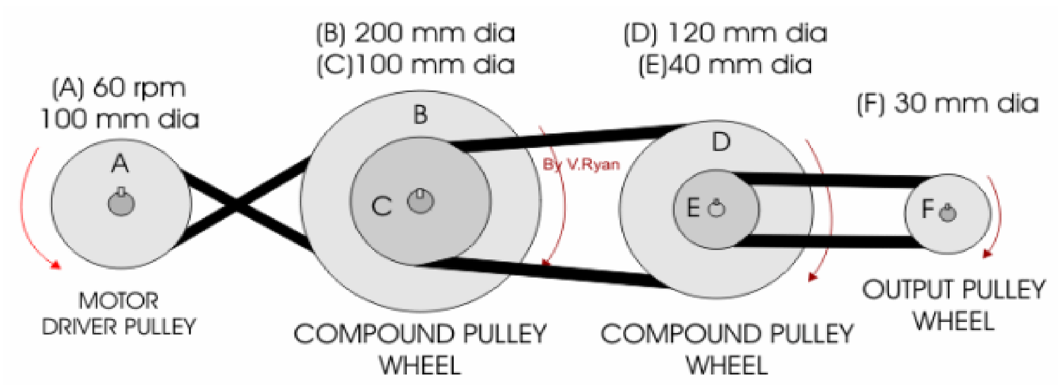
= 270 rpm at Driven pulley wheel

4. Sometimes it is necessary to reverse the rotation of the driven pulley wheel in relation to the driver pulley. If the driver is rotating in an anti-clockwise direction the driven pulley may be required to rotate in a clockwise direction.



This is achieved by twisting the belt as shown in the diagram above. Care must be taken when this is done as the belt can rub where it crosses and this may increase friction or damage it.

(i) If a system of four pulley wheels is set up as shown in the diagram below and the driver pulley rotates in an anti-clockwise direction, In what direction does the output pulley wheel revolve?



The final output of pulley F is a clockwise movement *(ii) If pulley ‘A’ (driver) rotates at 60 rpm, what is the output rpm at ‘F’?*

To answer the question spit the pulleys into pairs and work out the velocity ration of each pair. Treat the pairs of pulleys as separate questions. Use the diameters when dividing and place the largest number on the top of the division.

VELOCITY RATIO - PULLEYS A and B :

$$\frac{\text{DISTANCE MOVED BY PULLEY B}}{\text{DISTANCE MOVED BY PULLEY A}} = \frac{200}{100} = 2 \quad \text{OR} \quad \underset{A\,:\,B}{2:1}$$

VELOCITY RATIO - PULLEYS C and D :

$$\frac{\text{DISTANCE MOVED BY PULLEY D}}{\text{DISTANCE MOVED BY PULLEY C}} = \frac{120}{100} = 1.2 \quad \text{OR} \quad \underset{C\,:\,D}{1.2:1}$$

VELOCITY RATIO - PULLEYS E and F :

$$\frac{\text{DISTANCE MOVED BY PULLEY F}}{\text{DISTANCE MOVED BY PULLEY E}} = \frac{40}{30} = 1.3 \quad \text{OR} \quad \underset{E\,:\,F}{1:1.3}$$

Pulley wheel ‘A’ has an rpm of 60. Pulley ‘B’ is larger and so revolves at a lower rate than ‘A’. This means that the rpm of ‘A’ is divided by the ratio of 2.

$$\frac{\text{rpm of A}}{\text{ratio}} = \frac{60}{2} = 30 \text{ rpm at B}$$

Pulley wheel ‘C’ has the same rpm as pulley ‘B’ because they form a compound pulley. Pulley ‘D’ is larger and so revolves at a lower rate than ‘C’. This means that the rpm of ‘C’ is divided by the ratio of 1.2

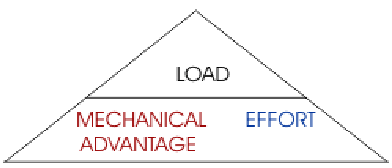
$$\frac{\text{rpm of C}}{\text{ratio}} = \frac{30}{1.2} = 25 \text{ rpm at D}$$

Pulley wheel ‘E’ has the same rpm as pulley ‘D’ because they form a compound pulley. Pulley ‘F’ is smaller and so revolves at a higher rate than ‘E’. This means that the rpm of ‘E’ is multiplied by the ratio of 1.3

$$\text{rpm of E} \times \text{ratio} = 25 \times 1.3 = \underline{\underline{32.5 \text{ rpm at F}}}$$

PULLEYS AND LIFTING - IMPORTANT FORMULAS

‘Mechanical advantage’ is defined as the ratio of load to effort. Pulley systems rely on this important relationship between load and effort. The formula seen below is best understood by writing it within a triangle. This helps when it is necessary to change the formula to find either; mechanical advantage or the load or the effort. In this way three formulas can be generated from the single formula inside the triangle.

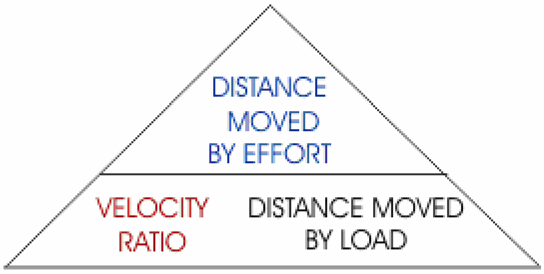


$$\text{MECHANICAL ADVANTAGE} = \frac{\text{LOAD}}{\text{EFFORT}}$$

$$\text{LOAD} = \text{MECHANICAL ADVANTAGE} \times \text{EFFORT}$$

$$\text{EFFORT} = \frac{\text{LOAD}}{\text{MECHANICAL ADVANTAGE}}$$

‘Velocity Ratio’ (sometimes called movement ratio) is defined as the ratio of the distance moved by the effort to the distance moved by the load. The formula seen below is best understood by writing it within a triangle. This helps when it is necessary to change the formula to find either; velocity ratio or the distance moved by the load or the distance moved by effort. In this way three formulas can be generated from the single formula inside the triangle.

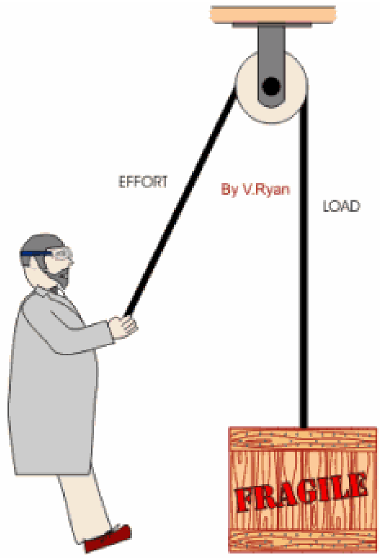


$$\text{DISTANCE MOVED BY LOAD} = \frac{\text{DISTANCE MOVED BY EFFORT}}{\text{VELOCITY RATIO}}$$

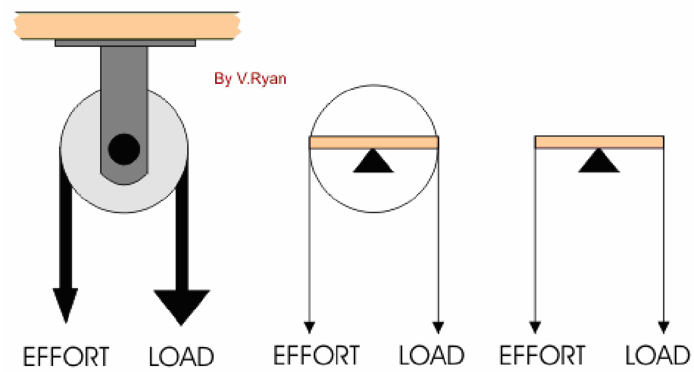
$$\text{VELOCITY RATIO} = \frac{\text{DISTANCE MOVED BY EFFORT}}{\text{DISTANCE MOVED BY LOAD}}$$

$$\text{DISTANCE MOVED BY EFFORT} = \text{DISTANCE MOVED BY LOAD} \times \text{VELOCITY RATIO}$$

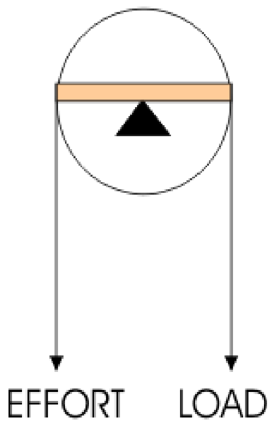
Pulley systems can be used to lift weights safely and effectively. The diagram below shows a pulley attached to a beam. The rope is ‘pulled’ on the effort side and the weight being lifted is on the right hand side, called the ‘load’. In general a single pulley is useful as it allows the laborer (shown right) to lift the weight without bending his back. This means it is much safer to lift the weight.



The diagrams below show how a pulley can be compared to a lever. First draw a fulcrum in the centre of the pulley wheel. Then draw a beam across the centre, balancing on the fulcrum. The comparison with a lever can now be seen clearly. Pulleys are a type of lever.

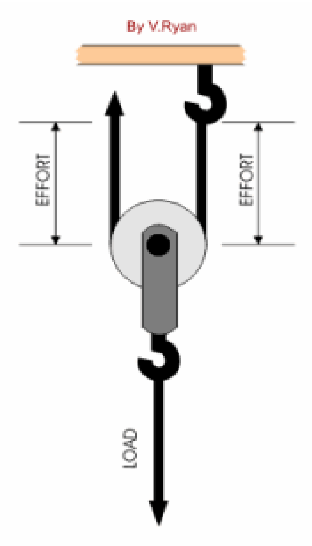


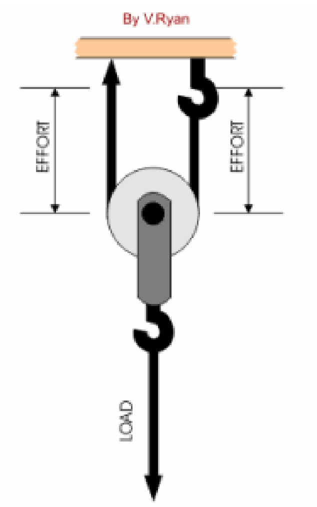
Again, ‘Mechanical advantage’ is defined as the ratio of load to effort. Pulley systems rely on this important relationship between load and effort. Pulleys like levers rely on mechanical advantage. The higher the mechanical advantage, the easier it is to lift a weight. In the example the LOAD and the EFFORT is equal and consequently there is no mechanical advantage with this single pulley.



$$\text{FORMULA FOR MECHANICAL ADVANTAGE} = \frac{\text{LOAD}}{\text{EFFORT}} = \frac{1}{1} = 1$$

With a single pulley, the pulley must be able to move so that mechanical advantage can be increased. Furthermore, the pulley is turned upside-down.





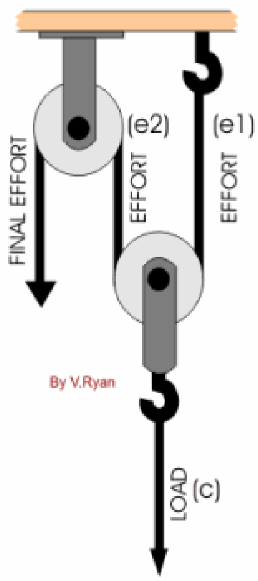
The pulley to the left is suspended and as a consequence the mechanical advantage is increased. This happens because the rope on the left and right of the pulley are both lifting the LOAD, they each lift half its weight. The load is split into 2. The calculation is shown below.

$$\text{MECHANICAL ADVANTAGE} = \frac{\text{LOAD}}{\text{EFFORT}} = \frac{2}{1} = 2$$

Again, ‘Velocity Ratio’ (sometimes called movement ratio) is defined as the ratio of the distance moved by the effort to the distance moved by the load. Using the example above, if the load is lifted 2 meters, above the pulley wheel - the rope on the right hand side must be shortened by one meter and this also applies to the left hand side. Therefore, the effort can be seen to move twice as far as the load.

$$\text{VELOCITY RATIO (MOVEMENT RATIO)} = \frac{\text{DISTANCE MOVED BY EFFORT}}{\text{DISTANCE MOVED BY LOAD}} = \frac{2}{1} = 2$$

A pulley system with the effort applied from above is very difficult to use. The most comfortable way to use a single moving pulley is combine it with a fixed pulley, seen right figure. This allows the effort to be applied downwards. Please note, as one of the pulleys is a fixed pulley the mechanical advantage and velocity ratio is still calculated as if only the moving pulley exists. The velocity ratio and the mechanical advantage remain 2. When dealing with a fixed pulley and a moving pulley, as shown in the diagram below, always work out which of the efforts move about the movable pulley. When the load is lifted two efforts (e1) and (e2) move. The strain of the load is divided into two whilst one final effort lifts the entire load.

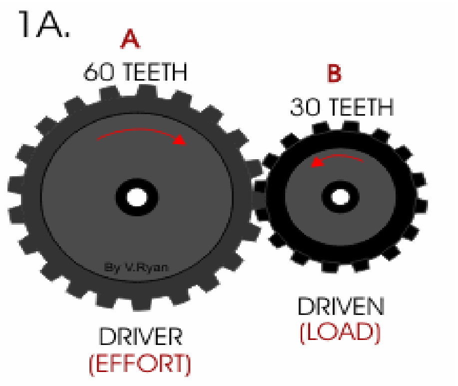


$$\text{MECHANICAL ADVANTAGE} = \frac{\text{LOAD}}{\text{EFFORT}} = \frac{2}{1} = 2$$

$$\text{VELOCITY RATIO (MOVEMENT RATIO)} = \frac{\text{DISTANCE MOVED BY EFFORT}}{\text{DISTANCE MOVED BY LOAD}} = \frac{2}{1} = 2$$

EXAMPLE QUESTIONS FOR GEARS (1)

In examinations, one of the first questions you will be probably asked is to work out the 'gear ratio' (sometimes called velocity ratio). As a guide – always assume that the larger gear revolves one revolution. The number of rotations of the second gear has then to be worked out. In the following examples work out the gear ratio (velocity ratio).

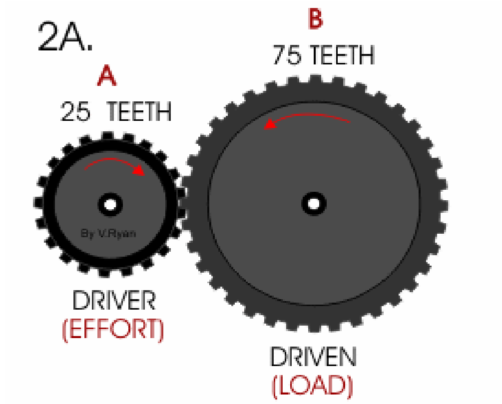


$$\frac{\text{Distance moved by Effort}}{\text{Distance moved by Load}} = \frac{\text{60T (GEAR A)}}{\text{30T (GEAR B)}}$$

$$= \frac{1}{2} = \frac{\text{Input movement}}{\text{Output movement}}$$

$$= \text{Driver : Driven}$$

1 : 2

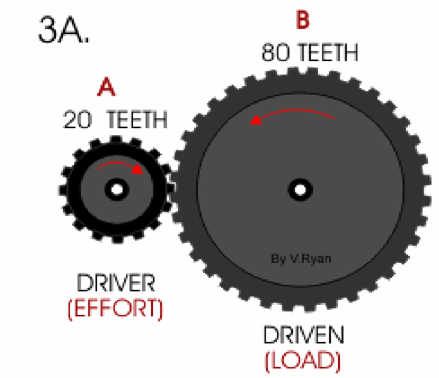


$$\frac{\text{Distance moved by Effort}}{\text{Distance moved by Load}} = \frac{\text{25T (GEAR A)}}{\text{75T (GEAR B)}}$$

$$= \frac{3}{1} = \frac{\text{Input movement}}{\text{Output movement}}$$

$$= \text{Driver : Driven}$$

3 : 1



$$\frac{\text{Distance moved by Effort}}{\text{Distance moved by Load}} = \frac{\text{20T (GEAR A)}}{\text{80T (GEAR B)}}$$

$$= \frac{4}{1} = \frac{\text{Input movement}}{\text{Output movement}}$$

$$= \text{Driver : Driven}$$

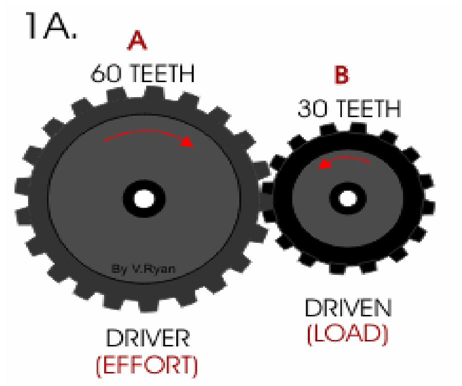
4 : 1

EXAMPLE QUESTIONS FOR GEARS (2)

Below are examples of the way to work out ‘revolutions per minute’ or ‘RPM’ as it is usually called. In the example below the DRIVER gear is large than the DRIVEN gear. The general rule is – large to small gear means ‘multiply’ the velocity ratio by the rpm of the first gear.

If ‘A’ revolves at 120 revs/min what is ‘B’? (Remember large gear to small gear increases revs)

Divide 60 teeth by 30 teeth to find the velocity ratio. Multiply this number (2) by the rpm (120). This gives an answer of 240rpm.



GEAR A	GEAR B
60 teeth	30 teeth
120 rpm	?

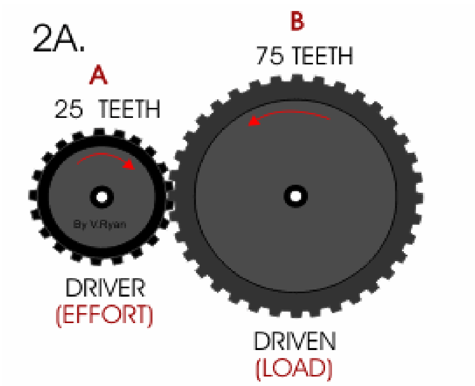
$$\frac{60}{30} = 2$$

$$= 120 \times 2 = 240 \text{ revs/min}$$

In the example below the DRIVER gear is smaller than the DRIVEN gear. The general rule is –- small to large gear means ‘divide’ the velocity ratio by the rpm of the first gear.

If ‘A’ revolves at 60 revs/min what is ‘B’? (Remember small gear to large gear decreases revs)

Divide 75 teeth by 25 teeth to find the velocity ratio. divide the 60rpm by the velocity ration (3). The answer is 20rpm.



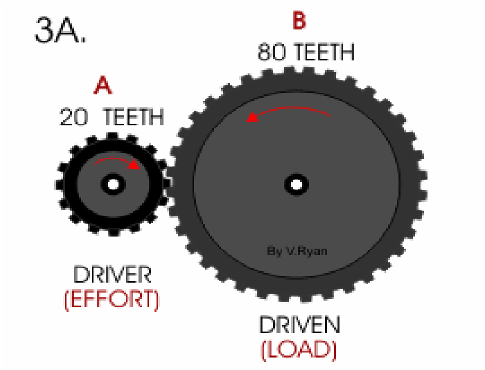
GEAR A	GEAR B
25 teeth	75 teeth
60 rpm	?

$$\frac{75}{25} = 3$$

$$= \frac{60}{3} = 20 \text{ revs/min}$$

If ‘A’ revolves at 100 revs/min what is ‘B’? (Remember small gear to large gear decreases revs)

Divide 80 teeth by 20 teeth to find the velocity ratio. divide the 100rpm by the velocity ration (4). The answer is 25rpm.



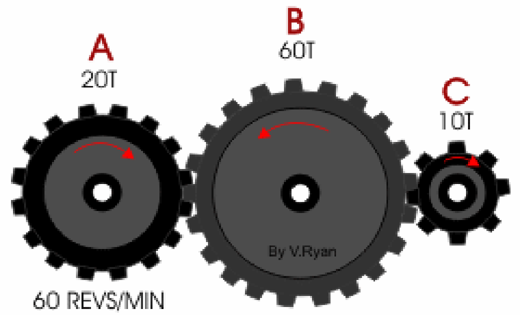
GEAR A	GEAR B
20 teeth	80 teeth
100 rpm	?

$$\frac{80}{20} = 4$$

$$= \frac{100}{4} = 25 \text{ revs/min}$$

EXAMPLE QUESTIONS FOR GEARS (3)

When faced with three gears, the question can be broken down into two parts. First work on Gears ‘A’ and ‘B’. When this has been solved work on gears ‘B’ and ‘C’. The diagram below shows a gear train composed of three gears. Gear ‘A’ revolves at 60 revs/min in a clockwise direction. *What is the output in revolutions per minute at Gear ‘C’? In what direction does Gear ‘C’ revolve?*



GEAR ‘A’	GEAR ‘B’	GEAR ‘C’
20 TEETH	60 TEETH	10 TEETH

First work out the speed at Gear ‘B’. Remember ‘B’ is larger than ‘A’ therefore, ‘B’ outputs less revs/min and is slower.

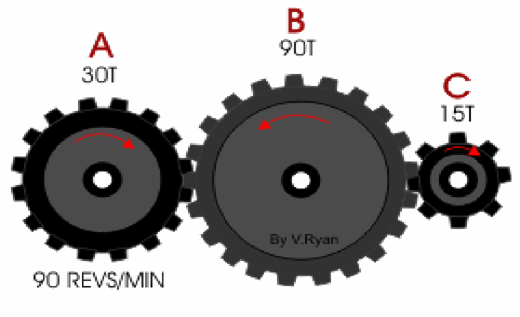
$$\frac{60}{20}\frac{B}{A} = 3 \longrightarrow \frac{60 \text{ REVS}}{3} = 20 \text{REVS AT B}$$

Next, take ‘B’ and ‘C’. ‘C’ is smaller, therefore, revs/minute will increase and rotation will be faster.

$$\frac{60}{10}\frac{B}{C} = 6 \longrightarrow 20 \text{ REVS X } 6 = 120 \text{ REVS AT C}$$

What direction does C revolve? ‘A’ is clockwise, ‘B’ consequently is anti-clockwise and ‘C’ is therefore clockwise.

Gear A revolves at 90revs/min. What is the output and direction at Gear C.



GEAR A	GEAR B	GEAR C
30 TEETH	90 TEETH	15 TEETH

First work out the speed at Gear ‘B’. Remember ‘B’ is larger than ‘A’ therefore, ‘B’ outputs less revs/min and is slower.

$$\frac{90}{30}\frac{B}{A} = 3 \longrightarrow \frac{90 \text{ REVS}}{3} = 30 \text{REVS AT B}$$

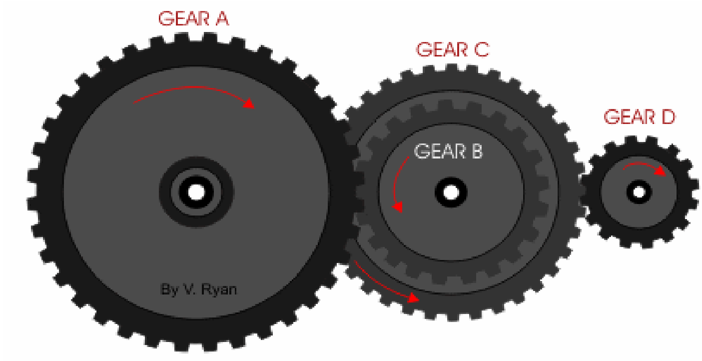
Next, take ‘B’ and ‘C’. ‘C’ is smaller, therefore, revs/minute will increase and rotation will be faster.

$$\frac{90}{15}\frac{B}{C} = 6 \longrightarrow 30 \text{ REVS X } 6 = 180 \text{ REVS AT C}$$

What direction does ‘C’ revolve? ‘A’ is clockwise, ‘B’ consequently is anti-clockwise and ‘C’ is therefore clockwise.

EXAMPLE QUESTIONS FOR GEARS (4)

Below is a question regarding ‘compound gears’. Gears ‘C’ and ‘B’ represent a compound gear as they appear ‘fixed’ together. When drawn with a compass they have the same center. Two gears ‘fixed’ together in this way rotate together and at the same RPM. When answering a question like this split it into two parts. Treat gears ‘A’ and ‘B’ as one question and ‘C’ and ‘D’ as the second part.



GEAR A	GEAR B	GEAR C	GEAR D
120 T	40 T	80 T	20 T

This is an example of a “compound gear train”. Gear A rotates in a clockwise direction at 30 revs/min. *What is the output in revs/min at D and what is the direction of rotation?*

First find revs/min at ‘B’;

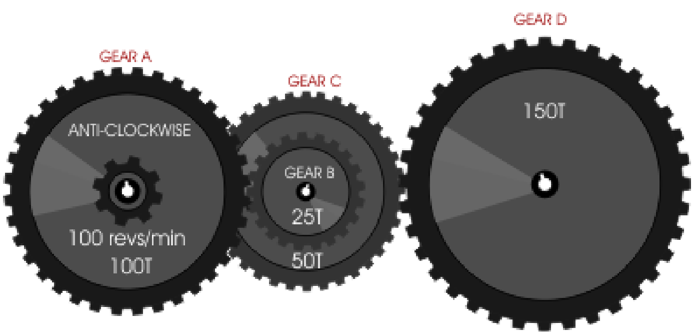
$$\frac{120\ A}{40\ B} = 3 \longrightarrow 30\ \text{REVS X } 3 = 90\ \text{REVS / MIN}$$

‘B’ is smaller, therefore it rotates faster and revs/min increase. ‘C’ is fixed to ‘B’ and therefore, rotates at the same speed; 90 REVS/MIN at ‘C’. Next find revs/min at ‘D’;

$$\frac{80\ C}{20\ D} = 4 \longrightarrow 90\ \text{REVS (AT C) X } 4 = 360\ \text{REVS / MIN}$$

‘D’ is smaller than ‘C’, therefore rotates faster (increased revs/min). ‘A’ revolves in a clockwise direction, ‘B’ is therefore anti-clockwise, ‘C’ is fixed to ‘B’ and is also anti-clockwise, which means ‘D’ revolves in a clockwise direction.

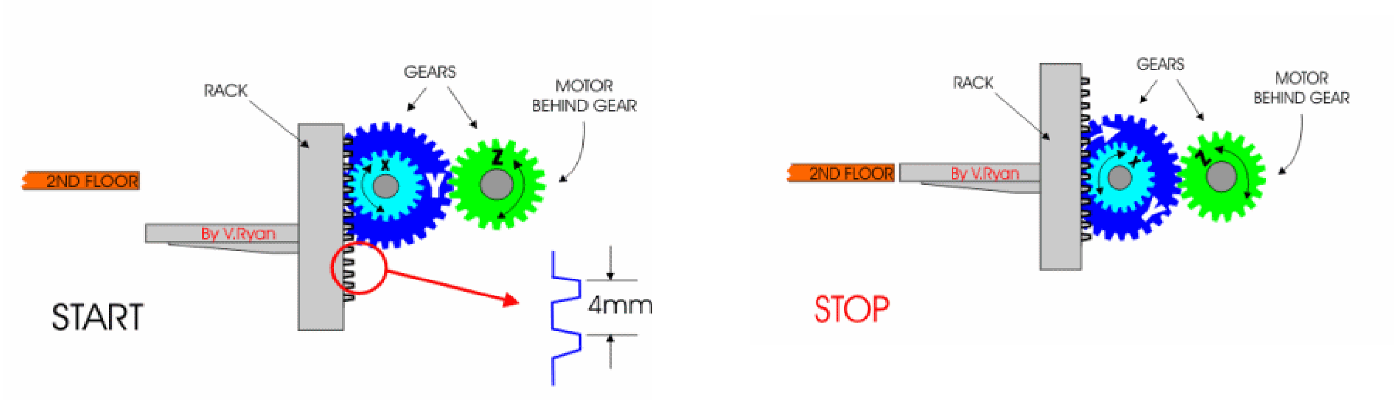
Try the following question:



What is the revs/min at gear D and what is its direction?

RACK AND PINION EXAMINATION QUESTION

The diagram below displays a platform that is used to lift boxes from one floor to another in a warehouse. The platform is fixed to a rack which operates through gears. As the gears turn the platform moves up or down depending on the direction of rotation. Gear ‘Z’ is the driver as it is connected directly to a motor.



Answer the following questions:

1. Name a suitable sensor that could be used to detect the platform as it reaches the desired floor.
2. On the drawing above, sketch the position of the sensor.
3. How is the sensor used?
4. If the motor is turned on, and rotates at 240 rev/min (rpm) and if Gear ‘Z’ = 13 teeth, Gear ‘Y’ = 39 teeth, and Gear ‘X’ = 13 teeth. Answer the followings:

(i) How many times will gear ‘X’ turn in one minute?

$$\text{VELOCITY RATIO} = \frac{\text{GEAR Y} = 39 \text{ teeth}}{\text{GEAR Z} = 13 \text{ teeth}} = 3$$

If gear ‘Z’ rotates once then gear ‘Y’ moves 3 times

$$\begin{array}{ccc} \text{GEAR Y} & & \text{GEAR Z} \\ 1 & : & 3 \end{array}$$

As gear ‘Y’ has more teeth than gear ‘Z’ then rpm is reduced

$$\text{Rpm of Y} = \frac{240\text{rpm}}{3} = 80 \text{ rpm}$$

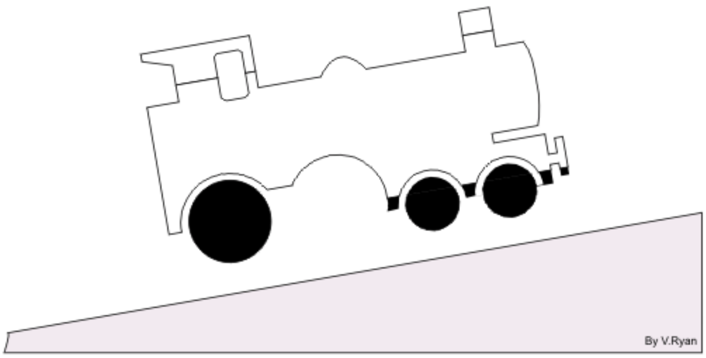
Since Gear ‘Y’ = 80 rpm and Gears ‘X’ and ‘Y’ are combined to form a compound gear, therefore, gear ‘X’ rotates at the same speed as ‘Y’, then Gear ‘X’ = 80 rpm

(ii) How far does the platform travel in one minute?

Gear ‘X’ has 13 teeth. This number is multiplied by the 80 rpm giving the distanced moved in terms of number of teeth, then 13 × 80 = 1040 teeth. The rack moves the same number of teeth as it meshes with gear ‘X’. To convert this distance into millimeters:

1040 (teeth) × 4mm (the pitch or distance between the teeth) = 4160mm

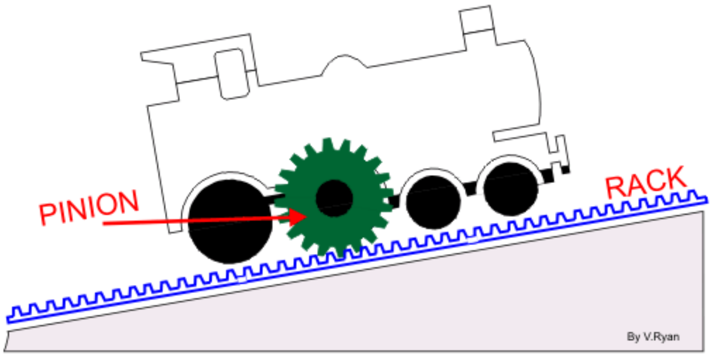
As another example, the train shown below cannot move up hill on a normal rail system as it will slide back down. A gear system must be added to allow the train to move up steep hills and mountain railway tracks.



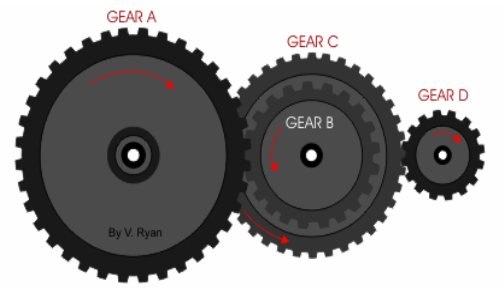
1. Name the gear system used on mountain railway tracks.

The gear system used for mountain railways is a Rack and Pinion.

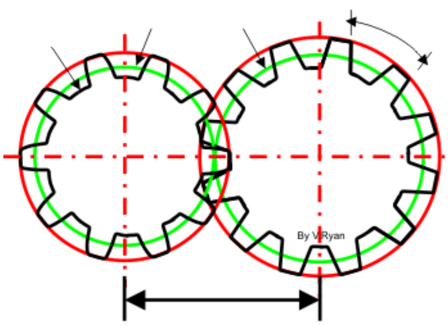
2. On the incomplete diagram shown above, add and label the gear system you have named.

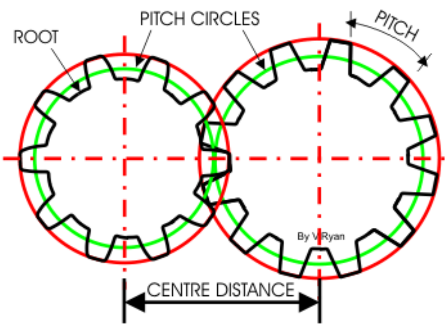


3. Name the gear system shown below.



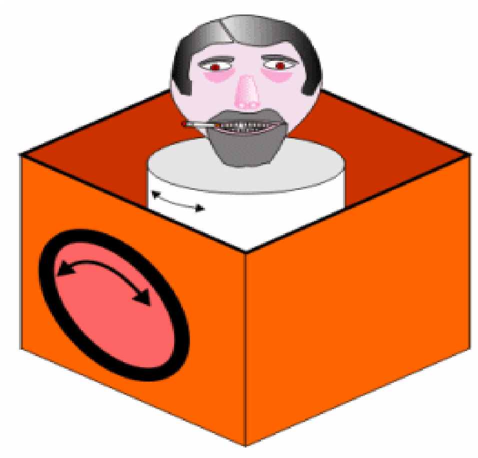
4. Add labels to the parts indicated on the gear system below.





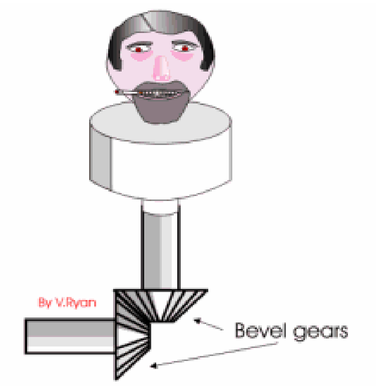
GEAR TRAIN QUESTION

A shop owner has approached your design company to make a mechanical toy based on a head turning. The owner would like your company to manufacture a shop display that is eye catching for passers-by. The figure below shows the intended idea. As the round handle turns the head also rotates.

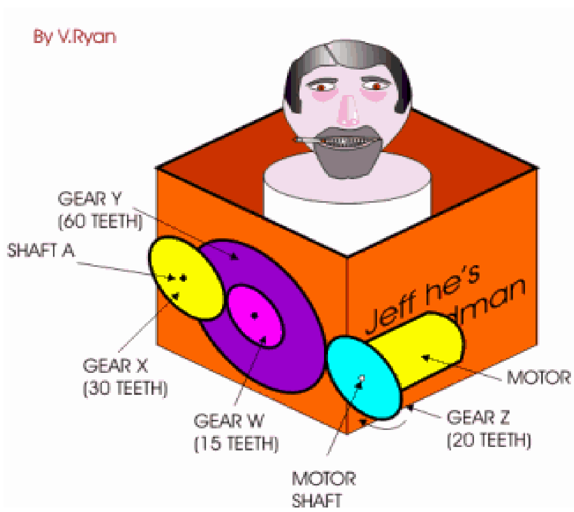


(a) *Using the incomplete diagram opposite, sketch a mechanism that would convert the rotary motion of the handle into rotary motion of the head.*

Bevel gears can be used to change the direction of drive in a gear system by 90 degrees. In the diagram, the head revolves clockwise and anticlockwise as the bevel gears are turn backwards and forwards.



(b) *The shop owner has decided that the model should be motorised and he has sketched the drawing opposite.*



(c) *If the motor turns in a clockwise direction, which direction will gear 'X' turn?*

CLOCKWISE

(d) *What is the name of the gear arrangement shown in the diagram above?*

COMPOUND

(e) *The motor turns at 180 rpm. How fast will gear 'Y' turn?*

Z= 20 teeth Y= 60 teeth

Work out the velocity ratio: $\frac{60 \text{ teeth}}{20 \text{ teeth}} = 3$

Gear Z rotates three times for every one rotation of Y (1:3)

As gear Y is larger than gear Z rpm is reduced:

$$\frac{180 \text{ rpm}}{3} = 60 \text{ rpm at Y}$$

(f) *How fast will gear X turn?*

Y=60 rpm - Because Y and W are compound gears, gear W has the same rpm (60rpm)

Know find the velocity ratio of gears W and X:

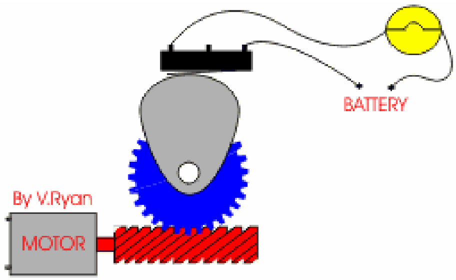
$$\frac{\text{Number of teeth - Gear X}}{\text{Number of teeth - Gear W}} = \frac{30}{15} = 2$$

Gear W rotates two times for every one rotation of X (1:2)

$$\frac{60 \text{ rpm}}{2} = 30 \text{ rpm at gear X}$$

WORM GEAR EXAMINATION QUESTION

The system opposite is used to control a set of traffic lights. The mechanism involved includes a motor which drives a worm gear round, turning a wormwheel and the attached cam. As the cam rotates it hits a micro switch which turns on a light



If the cam turns at one rev per minute (rpm) and the wormwheel has 110 teeth, how fast does the motor rotate?

First work out the gear ratio:

$$\frac{\text{Number of teeth on wormwheel}}{\text{Number of teeth on worm}} = \frac{\text{Number of teeth on wormwheel}}{1}$$

It is always considered that a worm gear has just 1 tooth

$$= \frac{110}{1} \qquad \text{RATIO is } 110 : 1$$

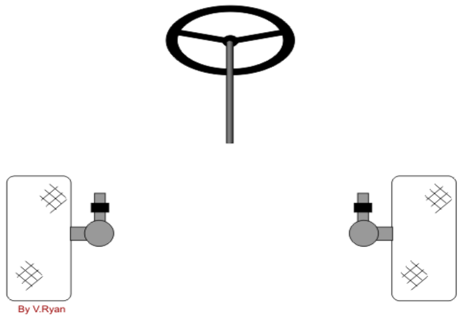
The worm gear always rotates at a faster rate than the wormwheel:

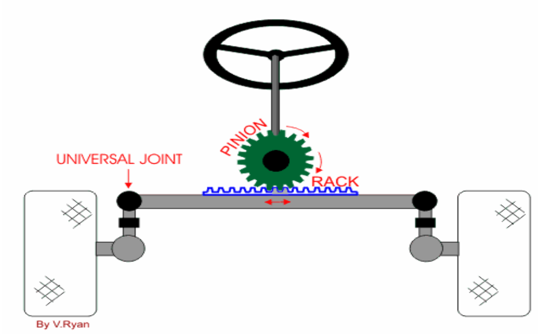
RPM is 110 × 1 = 110 rpm (motor rotates 110 times per minute)

The worm gear and motor rotates 110 times to every single rotation of the wormwheel.

RACK AND PINION EXAMINATION QUESTIONS

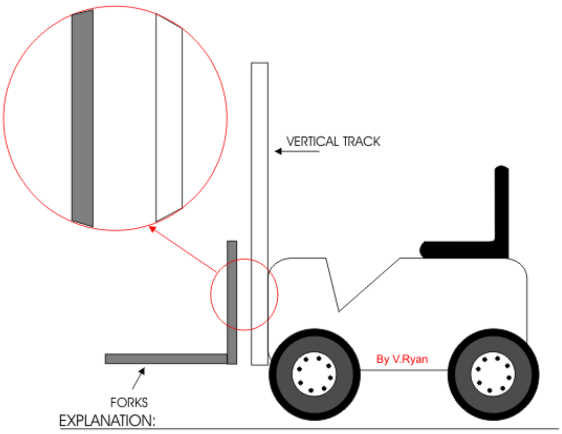
1. The diagram below shows a vehicle and its steering system. The most important part of the mechanisms is missing. This allows the steering wheel to turn the wheels left and right so that it can be steered.

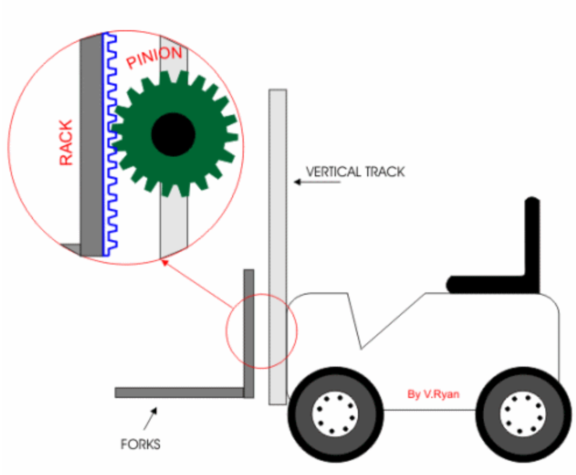




The rack and pinion gear system allows rotary motion of the steering wheel to be converted to linear motion. As the steering wheel is turned, the pinion gear also turns, driving the rack in the right or left direction, pointing the wheels in the desired direction.

2. The diagram below shows a fork lift truck. It is used to lift pallets, complete with their heavy loads. The forks on the front of the truck move up and down the vertical track. In the magnified area, draw the missing mechanism that allows movement of the forks.

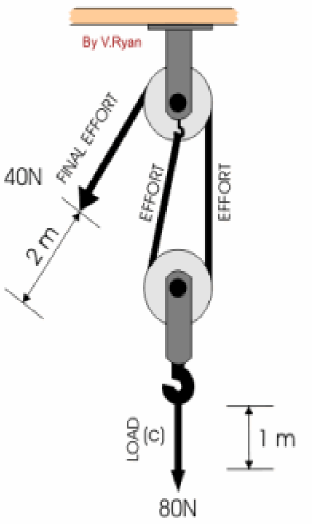




The driver controls the clockwise or anticlockwise motion of the pinion wheel. The pinion drives the rack either up or down. The rack is fixed to the forks and consequently they move in the same direction of the rack.

PULLEYS AND LIFTING QUESTIONS (1)

A simple pulley system is shown opposite. A 40N effort is used to move a 80N load. The final effort moves 2 meters and at the same time the load moves 1 meter.



$$\text{MECHANICAL ADVANTAGE} = \frac{\text{LOAD}}{\text{EFFORT}} = \frac{2}{1} = 2$$

$$\text{OR} \quad \frac{80N}{40N} = 2$$

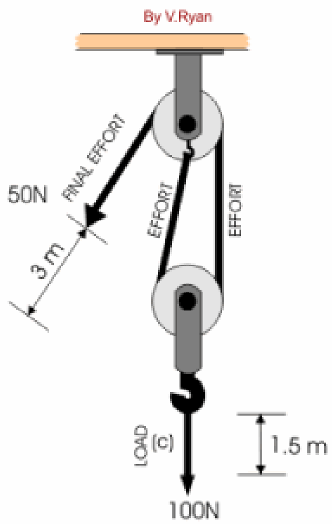
$$\text{VELOCITY RATIO} = \frac{\text{DISTANCE MOVED BY EFFORT}}{\text{DISTANCE MOVED BY LOAD}}$$

$$= \frac{2}{1} = 2$$

$$\text{EFFICIENCY} = \frac{\text{MECHANICAL ADVANTAGE}}{\text{VELOCITY RATIO}} \times 100\%$$

$$= \frac{2}{2} \times 100\% = 100\%$$

It is important to remember that NO pulley system is 100% efficient. This is due to friction of the ropes against the pulley wheels and the friction of the bearings of the pulley wheels as they rotate. 100% efficiency is only theoretical. The calculations for second example are seen below. This type of pulley arrangement will always have the same mechanical advantage and velocity ratio.



$$\text{MECHANICAL ADVANTAGE} = \frac{\text{LOAD}}{\text{EFFORT}} = \frac{2}{1} = 2$$

$$\text{OR} \quad \frac{100N}{50N} = 2$$

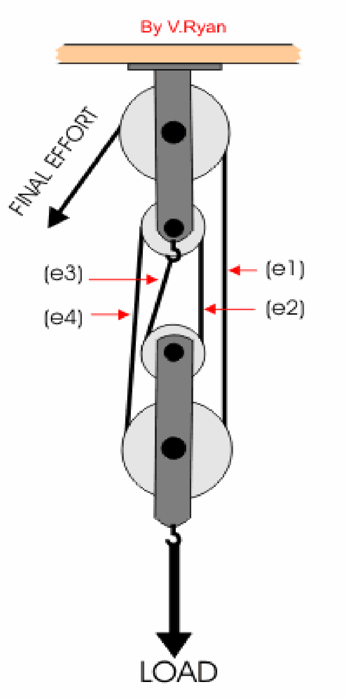
$$\text{VELOCITY RATIO} = \frac{\text{DISTANCE MOVED BY EFFORT}}{\text{DISTANCE MOVED BY LOAD}}$$

$$= \frac{3}{1.5} = 2$$

$$\text{EFFICIENCY} = \frac{\text{MECHANICAL ADVANTAGE}}{\text{VELOCITY RATIO}} \times 100\%$$

$$= \frac{2}{2} \times 100\% = 100\%$$

PULLEYS AND LIFTING QUESTIONS (2)

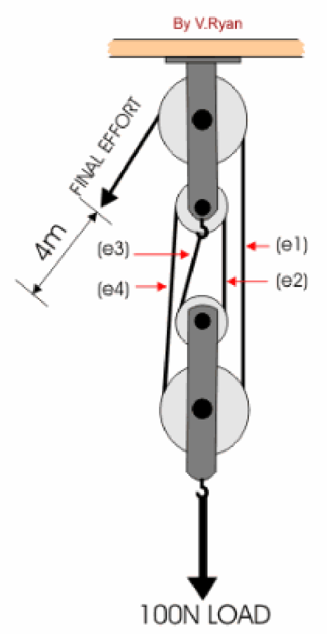


The pulley in the right figure has four pulleys which support the load by dividing it into four lengths. Each part of the rope equally supports the load. The mechanical advantage is 4. This means lifting a load with this arrangement of pulleys allows the lifting of 4 times a normal maximum load.

$$\text{MECHANICAL ADVANTAGE} = \frac{\text{LOAD}}{\text{EFFORT}} = \frac{4}{1} = 4$$

Each of the efforts (e1, e2, e3, e4) has to move in order for the load to move and calculating the velocity ration is seen below.

$$\text{VELOCITY RATIO} = \frac{\text{DISTANCE MOVED BY EFFORT}}{\text{DISTANCED MOVED BY LOAD}} = \frac{4}{1} = 4$$



The example in the right figure shows a pulley system used to lift a 100N load. Work out the mechanical advantage and velocity ratio.

$$\text{MECHANICAL ADVANTAGE} = \frac{\text{LOAD}}{\text{EFFORT}} = \frac{4}{1} = 4$$

$$\text{VELOCITY RATIO} = \frac{\text{DISTANCE MOVED BY EFFORT}}{\text{DISTANCED MOVED BY LOAD}} = \frac{4}{1} = 4$$

What effort is required to lift the 100N load?

$$\text{EFFORT} = \frac{\text{LOAD}}{\text{MECHANICAL ADVANTAGE}} = \frac{100N}{4} = 25N$$

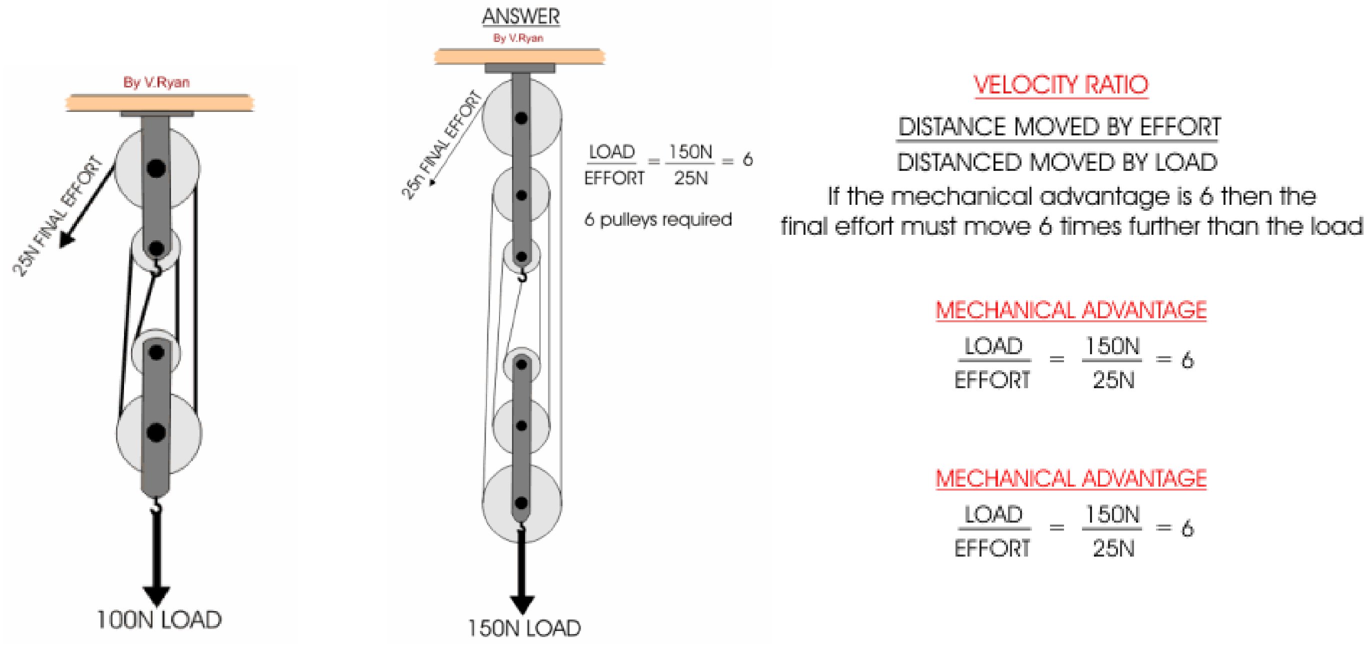
How far does the load move in compared to the 4m movement of the final effort?

$$\underline{\text{DISTANCED MOVED BY LOAD}}$$

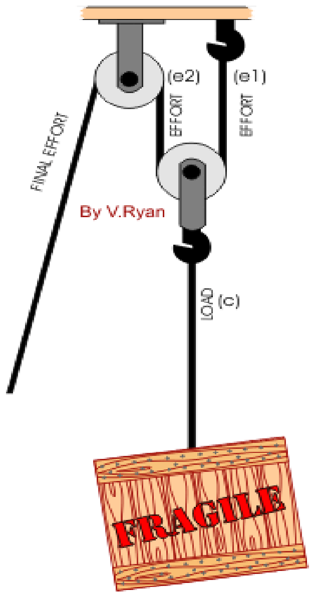
$$\frac{\text{DISTANCE MOVED BY EFFORT}}{\text{VELOCITY RATIO}} = \frac{4m}{4} = 1m$$

PULLEYS AND LIFTING QUESTIONS (3)

The pulley system shown below (left) has 1:4 ratio (effort: load) and an effort of 25N can lift a load of 100N. The other pulley system shown below (right) is capable of lifting 150N.



PULLEYS AND LIFTING EXAM QUESTION



The pulley system shown in the right figure is used to lift small loads from a ground floor to an upper floor. The load being lifted is 200N.

(i) what is the mechanical advantage of this pulley system?

$$\text{MECHANICAL ADVANTAGE} = \frac{\text{LOAD}}{\text{EFFORT}} = \frac{2}{1} = 2$$

(ii) what is the velocity ratio of the system?

$$\text{VELOCITY RATIO} = \frac{\text{DISTANCE MOVED BY EFFORT}}{\text{DISTANCE MOVED BY LOAD}} = \frac{2}{1} = 2$$

(iii)What effort is required to lift the load?

$$\text{EFFORT} = \frac{\text{LOAD}}{\text{MECHANICAL ADVANTAGE}} = \frac{200\text{N}}{2} = 100\text{N}$$

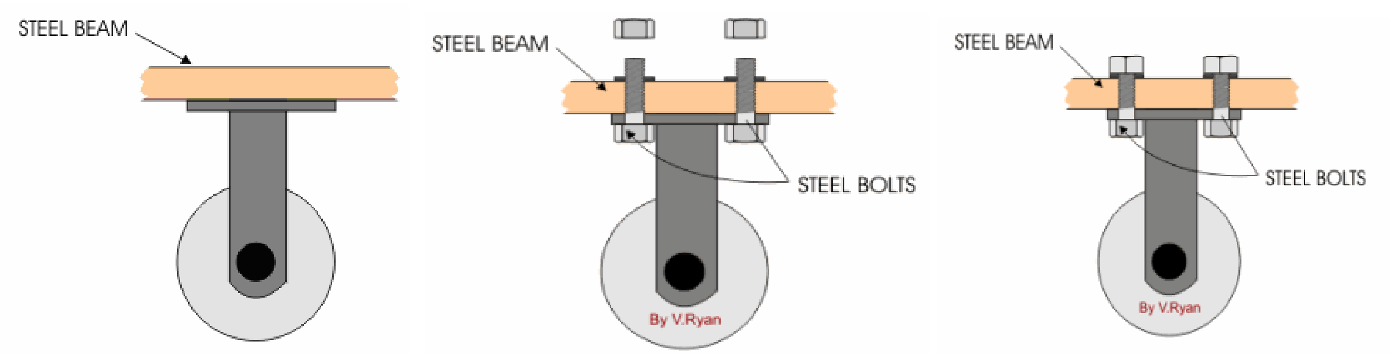
(iv) if the system moves the load 5metes upwards, how far must the effort move?

$$\text{VELOCITY RATIO} = \frac{\text{DISTANCED MOVED BY EFFORT}}{\text{DISTANCE MOVED BY LOAD}}$$

$$\text{DISTANCED MOVED BY EFFORT} = \text{VELOCITY RATIO} \times \text{DISTANCE MOVED BY LOAD}$$

$$= 2 \times 5 = 10\text{M} \quad \text{(DISTANCE MOVED BY EFFORT)}$$

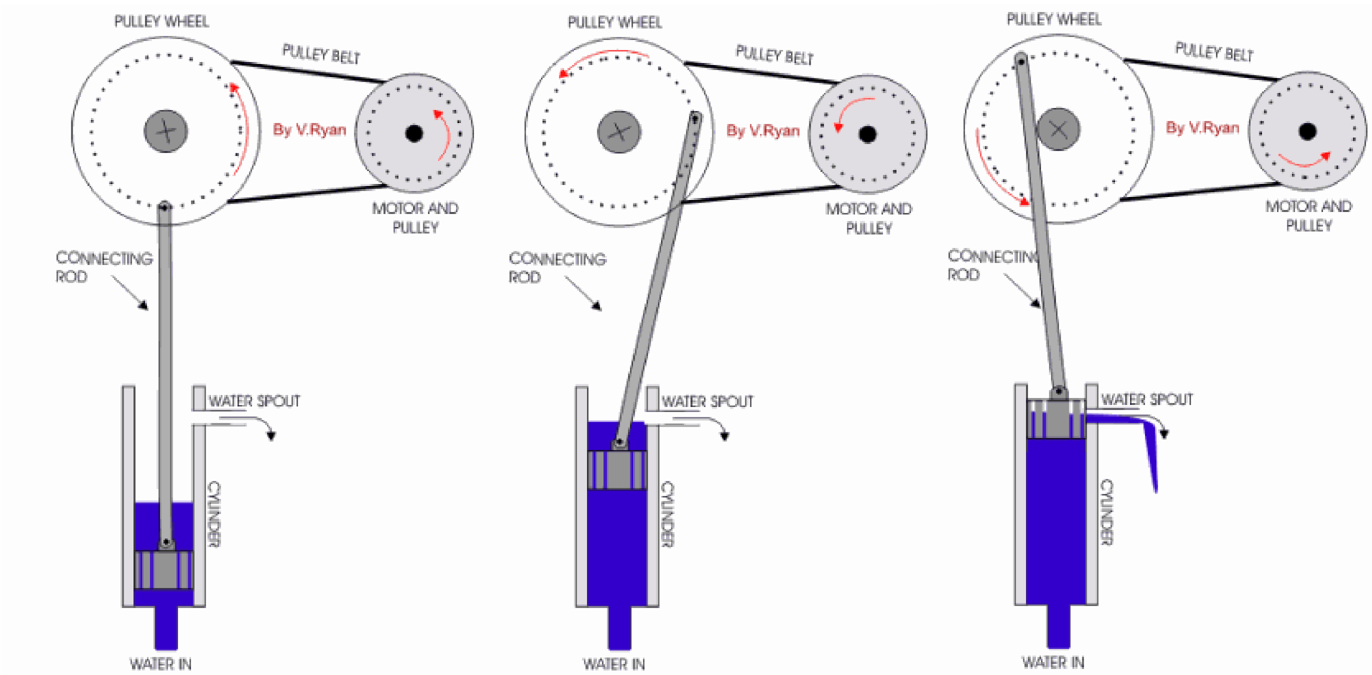
(v) with the aid of a diagram, describe how the pulley wheel at the top of the pulley system could be fixed in position, with enough strength to hold heavy weights.



Steel bolts could be used to hold the weight of the pulley system. One advantage of using bolts is that they can be removed easily so that the pulley system can be dismantled.

MECHANISMS EXAMINATION QUESTION (1)

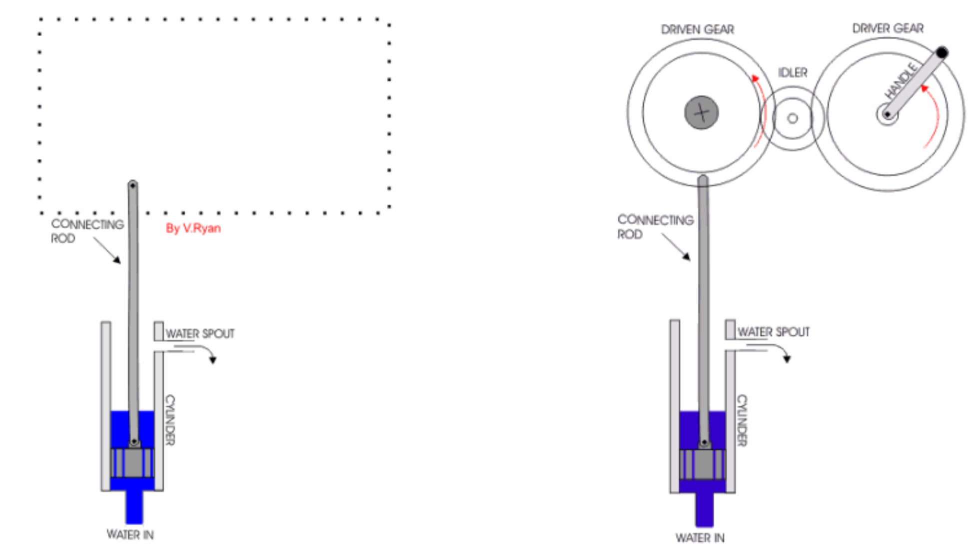
A small hillside village has discovered a fresh water spring and wishes to pump the water up to the surface, into a bottling plant. A local engineer has developed a simple pump. As the motor spins, a pulley belt rotates a pulley wheel. A connecting rod then pushes a plunger downwards. Water rises through holes in the plunger and as the plunger rises water is lifted to the water spout, where it pours out. This cycle of events continues until the motor is turned off.



1. List three possible safety improvements that could be applied to this design of pump.

   A. The mechanism at the top of the system needs to be guarded. A wire mesh or a sheet steel guard would protect the operator
   B. A low voltage motor to replace a 240 volts powered motor would remove the possibility of electrocution.
   C. Adding emergency stop buttons so that the operator could stop the motorized pump immediately in case of an accident.

2. The motor has broken down and the pulley mechanism has been removed. Draw in the box an alternative mechanism, powered by hand, that could be used as a short term alternative to the motorized system.



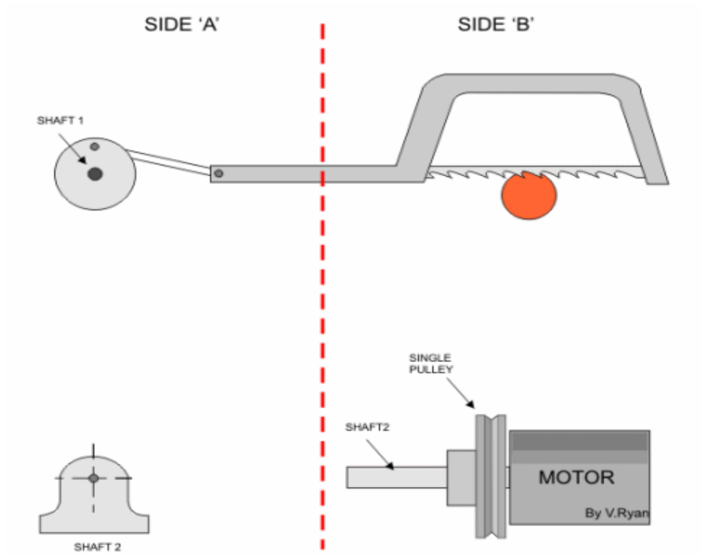
3. List four advantages / disadvantages of your design.

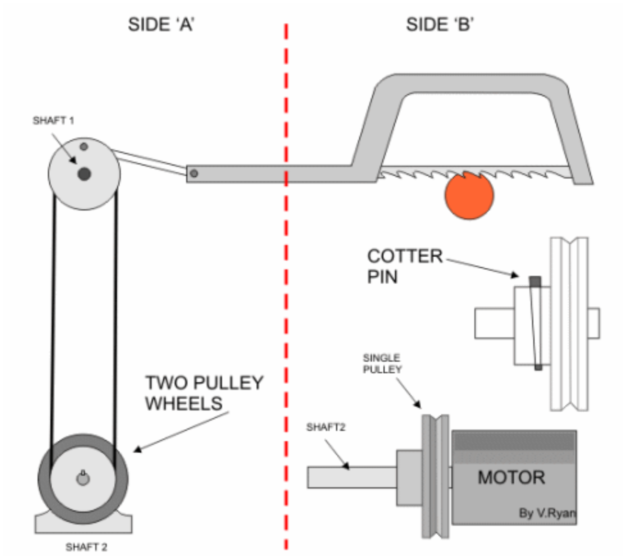
A. The mechanism is hand powered and as such it does not need electrical power.
B. The gears can be changed so that the ratio is improved and the handle is easier to turn or the driven gear is driven round faster or slower
C. The system is simple and easy to maintain
D. Two handles could be added so that the mechanism can be driven round by two people or the handle can be lengthened so that the mechanical advantage is increased.

MECHANISMS EXAMINATION QUESTION (2)

Pulley systems are used widely in industry and on production lines. The power hacksaw shown below moves backwards and forwards continuously, cutting metal. A basic drawing of this machine is shown below.

PROBLEM **POSSIBLE ANSWER**





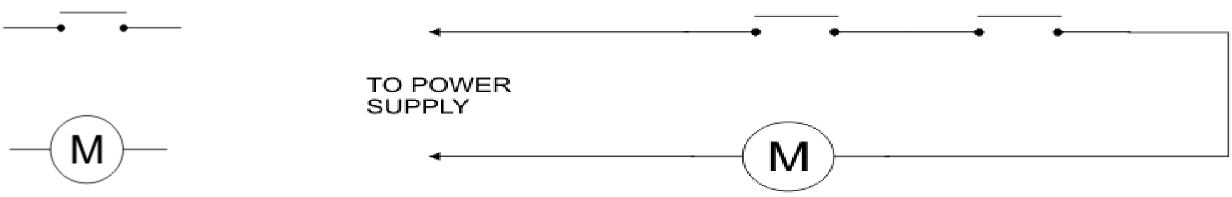
1. *The diagram above (left) has been divided into two sides; A and B. On side 'A' adds a pulley system that connects shaft 1 and 2 so that two different speeds can be selected. On side 'B' show how a single pulley is held securely on to the shaft.*

   Two pulley wheels are added to shaft 2. They have different diameters. Changing to the large pulley slows down movement of the hacksaw. Changing to the small pulley speeds up movement. A cotter pin can be used. It is tapped through a hole that runs through the pulley and the shaft, holding it firmly together.

2. *Why are different speeds needed for the power hacksaw needed?*

   Each type of metal has a particular speed at which it can be cut efficiently. Choosing the wrong speed may damage the blade and it may take longer to cut through the metal.

3. *To make the power hacksaw safe to use to 'push to make' (PTM) switches have been added. The incomplete circuit below shows one of the switches in position. Complete the circuit be adding the second switch.*



4. *What is the color of the ON button of any machine?*

   GREEN IS NORMALLY THE 'ON' BUTTON

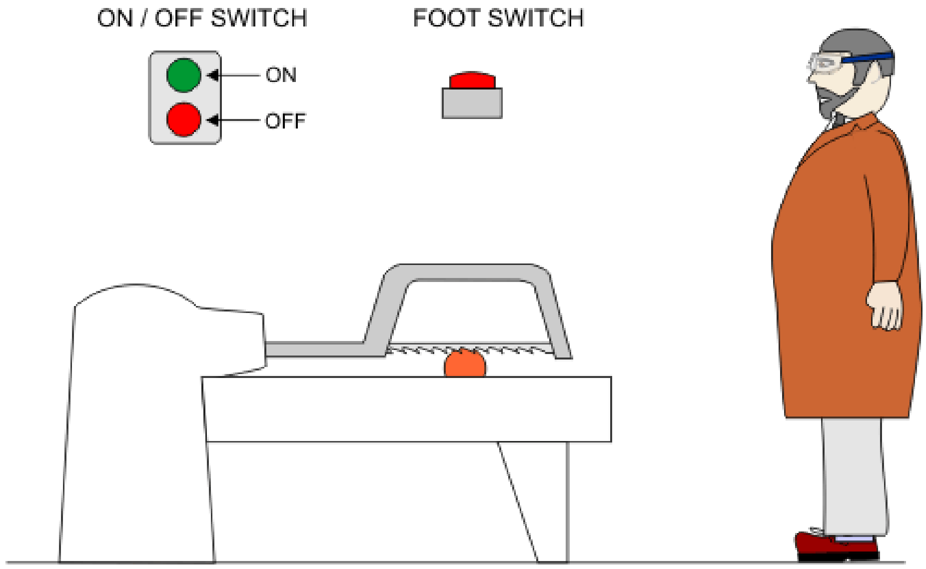
5. *What is the color of the OFF button of any machine?*

   RED IS NORMALLY THE 'OFF' BUTTON

6. *Why should the switches be placed at least 500mm apart?*

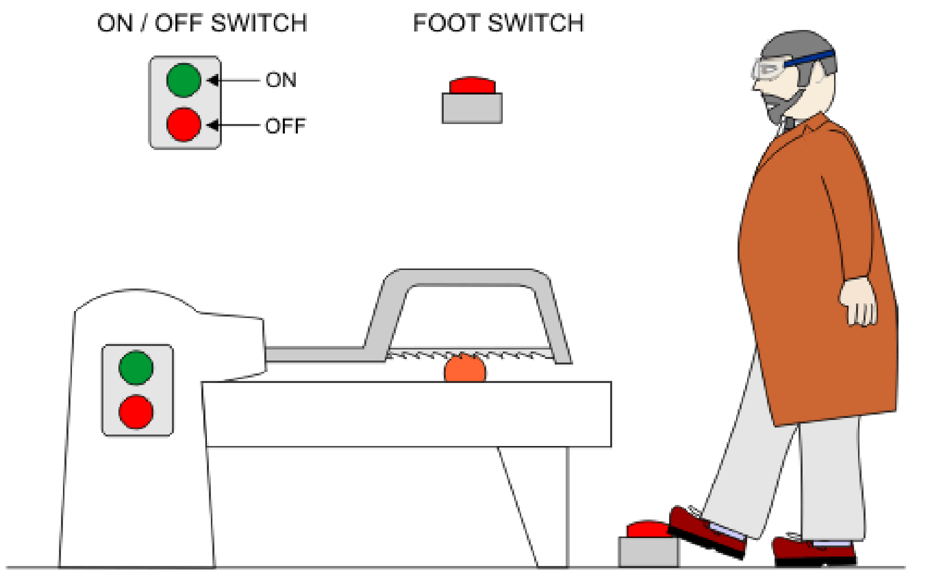
   Placing the buttons 500mm apart means that both hands of the operator must be used to turn the machine on. This means that the operator's hands cannot be near the saw blade.

7. *The drawing of a new style of power hacksaw needs two types of switches; a foot switch and a normal ON/OFF switch. Draw each switch in its best position on the diagram and explain your reasoning with notes.*



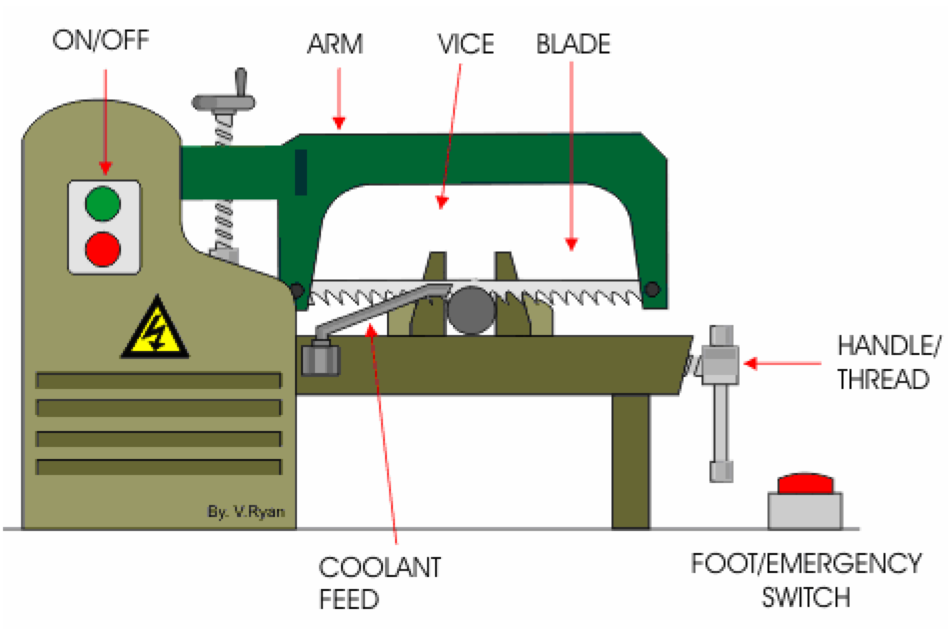
POSITION OF FOOT SWITCH - EXPLANATION: The operator can stand at the front and watch the machine working. He/she can turn it off using the foot switch without getting close to the moving blade.

POSITION OF NORMAL SWITCH - EXPLANATION: The operator can stand at the side of the machine and switch it on, then move to a more suitable position to watch it cut.



MECHANISMS EXAMINATION QUESTION (3)

The machine seen below is a power hacksaw used for cutting large section metals. It is powered by a motor. However, some motors tend to rotate at very high speeds making the power hacksaw cut far too quickly, over heating the blade. This will eventually snap and damage the material being cut.

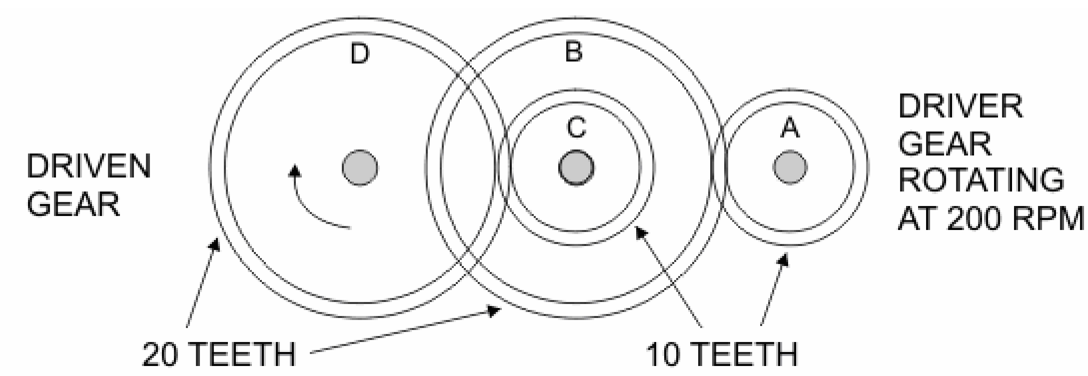


1. *List two advantages of controlling the speed of a motor on any machine.*

ADVANTAGE 1: If the speed of the motor can be controlled the final output speed of the machine can be controlled.

ADVANTAGE 2: Different materials are cut and shaped at different speeds. Controlling the speed of the motor means that a range of materials can be cut/shaped by the machine.

2. *The gear system shown below is to be added to the motor so that the speed of the power hacksaw can be controlled. Calculate the velocity ratio of gears 'A' and 'B'.*



FORMULA
VELOCITY RATIO

$$\frac{\text{number of teeth on DRIVEN gear}}{\text{number of teeth on DRIVER gear}} = \frac{20T \text{ (GEAR B)}}{10T \text{ (GEAR A)}}$$

$$= \frac{1}{2} = \frac{\text{Output movement}}{\text{Input movement}}$$

$=$ Driver : Driven
1 : 2

3. *Calculate the RPM (revolutions per minute) of gear 'B'.*

GEAR A	GEAR B
10 teeth	20 teeth
200 rpm	?

$$\frac{20}{10} = 2$$

$$= \frac{200}{2} = 100 \text{ revs/min (AT GEAR B)}$$

4. *What is the speed (RPM) of gear 'C'?*

   The speed of gear C is the same as gear B because they are fixed together and rotate together.

5. *Calculate the velocity ratio of gear 'D'.*

<u>FORMULA</u>
<u>VELOCITY RATIO</u>

$$\frac{\text{number of teeth on DRIVEN gear}}{\text{number of teeth on DRIVER gear}} = \frac{20T \text{ (GEAR D)}}{10T \text{ (GEAR C)}}$$

$$= \frac{1}{2} = \frac{\text{Output movement}}{\text{Input movement}}$$

= Driver : Driven
1 : 2

6. *Calculate the RPM (revolutions per minute) of gear 'D'.*

GEAR C	GEAR D
10 teeth	20 teeth
100 rpm	?

$$\frac{20}{10} = 2$$

$$= \frac{100}{2} = 50 \text{ revs/min (AT GEAR D)}$$