Trade of Sheet Metalwork	
Module 1:	**Sheetmetal Fundamentals**
Unit 5:	**Internal Cutting and Punching**
	Phase 2

Table of Contents

List of Figures

List of Tables

Document Release History

Date	Version	Comments
26/06/06	First draft	
31/03/14	2.0	SOLAS transfer

Module 1 – Sheetmetal Fundamentals

Unit 5 – Internal Cutting and Punching

Duration – 7 Hours

Learning Outcome:

By the end of this unit each apprentice will be able to:

- Describe the use and care of the flypress
- Mark out an internal and external circle using a dividers
- Cut an internal and external circle using a snips
- Notch a workpiece to given dimensions

Key Learning Points:

Sk Rk	Use and care of tools, machinery and equipment, especially the flypress and snips.
Rk Sk	Marking out patterns from a datum edge.
Rk Sk	Notching patterns.
Rk	Iron/steel production, manufacturing of sheets/sections.
Rk	Working properties of metals - iron and steel.
P Rk	Work planning, quality control, surface defects, problem solving.
P	Work independently.
M	Calculation of angular notching arrangements by Pythagoras Theorem.
M	Calculations of perimeter of squares and rectangles.
M	Calculations of surface area of square, rectangle, triangle and trapezoid.
Sc	Forces, weights, mass and momentum.

Training Resources:

- Toolkit
- Tools and machinery/equipment
- Samples
- 0.6 mm galvanised mild steel
- Safety equipment and protective clothing

Exercise:

Mark out and cut metal as per drawings – Exercises 2.1.4A and 2.1.4B using flypress, guillotine and snips.

Key Learning Points Code:

M = Maths D= Drawing RK = Related Knowledge Sc = Science

P = Personal Skills Sk = Skill H = Hazards

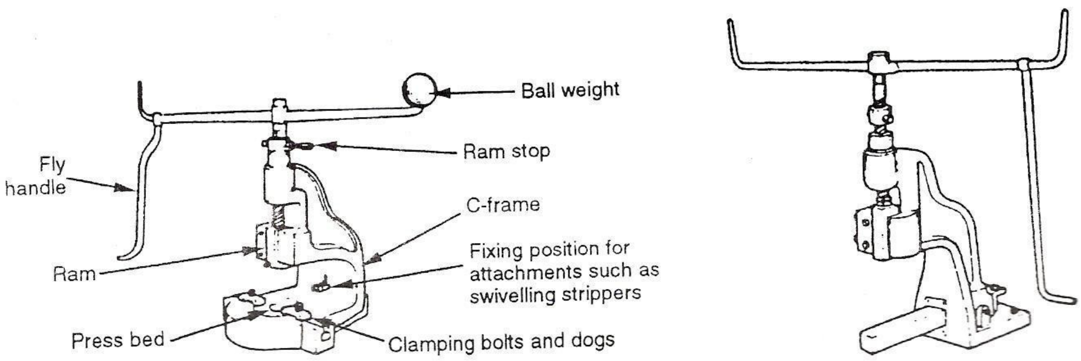
Fly Press Operations

A Fly Press is basically a hand press where the ram is worked in the flame by the operation of a screw which is rotated by the operator turning a handle or ‘fly’.

The types of fly press usually found in a fabrication shop are:

1. Standard or C-frame: the main dimensions are the bed to guides, centre to back and the screw diameter.
2. Tall type: These are available with a range of bed to guide dimensions – maximum about 360 mm.
3. Deep hack: These have a range of centre to back dimensions which are greater then the standard models – maximum about 360 mm.
4. Bar type: The solid bed is omitted and provision is made to fit a bar on which the work may be supported. Mainly for work on cylinders which pass over the bar.

The deep back type and the bar fly press are illustrated in Figure 1.



Deep Back Type Bar Press

Figure 1 - Types of Fly Press in Common Use

Hand Screw presses are generally selected dimensionally, but the pressure exerted is directly related to the screw diameter. As a general rough guide, the rating in tonnes* of a fly press is twice the screw diameter. The force can be increased by fitting ball weights to the fly arms.

**In the interest if safety, take care when operating a fly press because the fly arm and the weights can cause injury, not only to the operator but to those in close proximity.*

Notching, piercing and punching, light pressing, bending and riveting are all operations which can be performed on a fly press.

Sheetmetal work done in batches means that the fly press is set up for one specific operation and the batch is run through before resetting for the next operation. Alternatively more than one fly press may be set up to reduce waiting time due to resetting operations.

Typical Cutting Tools used on the Fly Press

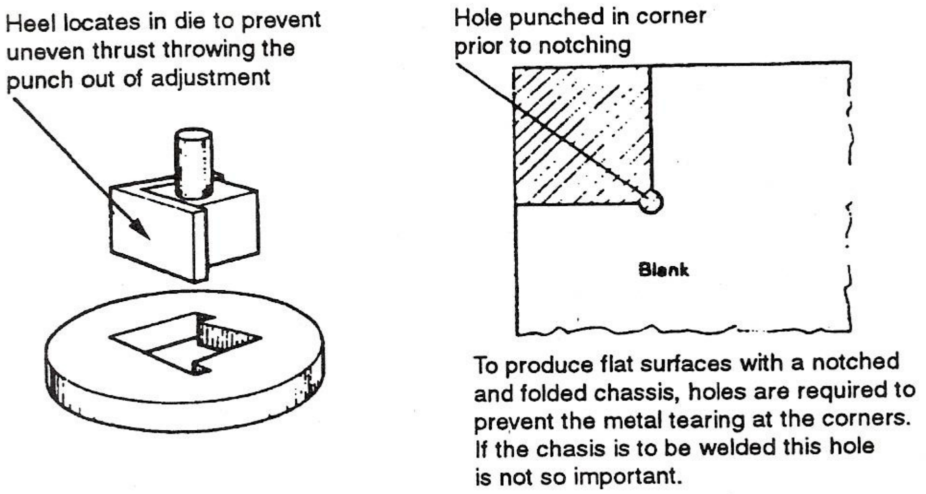


Figure 2 – Notching

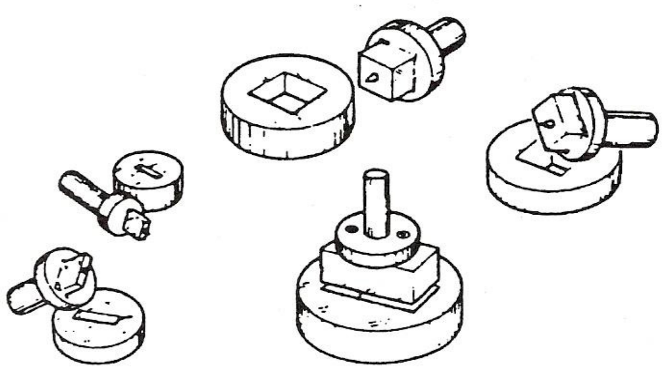


Figure 3 - Rectangular and Square Punches

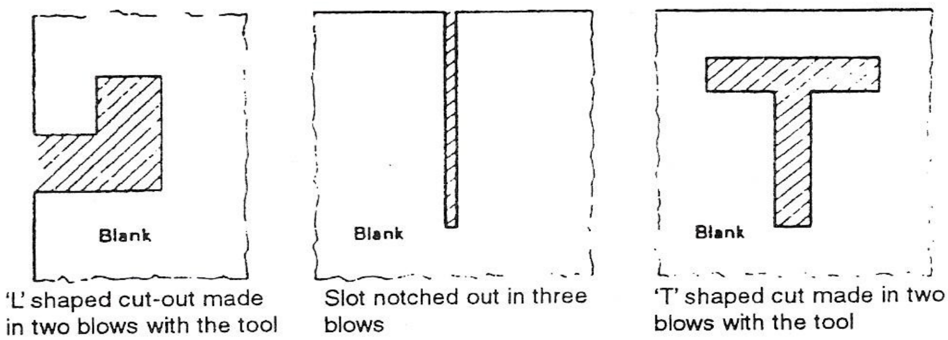


Figure 4 - Operations Performed

Dividers

Always make sure points are in good condition. If you adjust dividers and are inaccurate in your setting this mistake is doubled if marking out a circle e.g. radius 60, setting 61, Dia. = 122. Trammel points may be used when dividers is too small for the job.

Snips

The most commonly used types of snips in the sheet metal shop are the bulldog, combination and the left-hand and right-hand aviation snips.

Bulldog snips are heavy duty tools and are generally used for cutting metal that is 24-gauge or thicker.

Combination snips are used for general cutting on 24-gauge metal or thinner. Since a great deal of the sheet metal used in the shop is 24-gauge or lighter, the combination snips are probably the most commonly used snips.

Aviation snips are very versatile tools with many applications in the sheet metal shop. The advantage of aviation snips is that they can cut very small and complex curves that would be difficult or impossible to cut with bulldog or combination snips. They are also the best snips to cut inside circles and inside corners as shown in Figure 5.

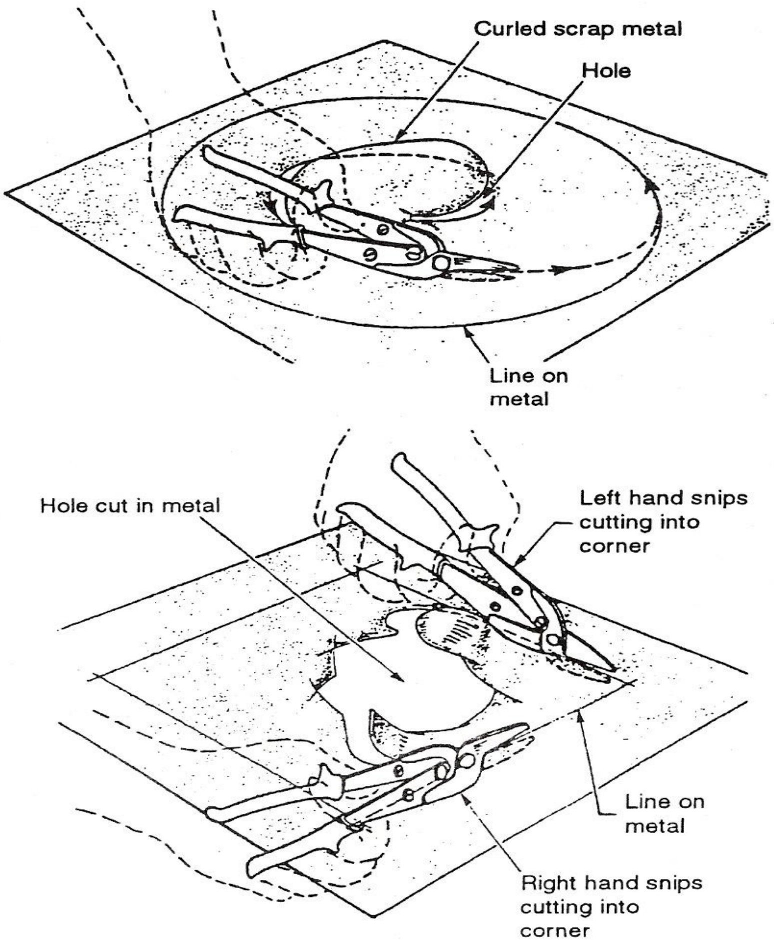


Figure 5 - Aviation Snips

There is more to using snips than merely working the handles. Both practice and knowledge are necessary to be able to make a clean cut on sheet metal in all sorts of circumstances. Too often the student of sheet metal work will at first cut very jagged and rough edges on the metal. Since these edges reflect upon the entire job and in many ways affect the quality of the finished job, it is essential that the student master the snips. It is impossible to do a workmanlike job in sheet metal until you first learn how to cut sheet metal skilfully. As in any other trade, successful sheet metal work depends upon accurate accomplishment of each individual operation for a complete, skilled job. If any given operation is done sloppily, the result will be evident throughout the rest of the operations.

Like any skill, the operation of snips depends upon practice. However, much of the mastery of snips also depends upon knowledge. If you study the following rules to learn the proper use and care of snips and practice them, then you will find that mastery of the actual hand processes is relatively simple.

1. Keep the small piece of metal over the bottom blade of the snips. In using snips, the greatest problem is not in making the actual cut, but in getting the snips into the end of the cut. This is because one piece of metal must slid over the bottom blade of the snips and up over the snip handle. If the metal sheet is large, it resists the bending necessary to accomplish that operation and makes it difficult to get the snips into the end of the cut. This in turn makes it difficult to control the snips after they are in the cut. However, if the piece of metal is narrow, it will naturally curl during the cutting operation itself and will curl up over the snips blade with no trouble. Even if the piece is too large to curl naturally, when it is the smaller of the two pieces it will still be easier to lift it up out of the way.
2. Trim off excess metal before making the cut on the line.
3. Whenever possible, rest the blade and handle of the snips on the workbench.
4. When notching, keep the end of the snips blades at the point where the notch will end. It is common for students to put the blades beyond the end of the notch. This results in having to make a very slow and careful cut to avoid cutting past the notch. And even with care, the cut will very often go slightly past the notch. Since bends are generally made to the corner of notches, this results in the metal breaking at the corners when the bend is made.
5. Keep oil from the blades of the snips. A drop of oil should occasionally be put on the swivel bolt of snips to keep them moving freely. However, do not allow it to run onto the blades, since this will cause the metal to slip out of the blades.
6. Cut only sheet metal with snips. The clearance on snips blades is for sheet metal thickness only. If you use them to cut wire, no matter how soft the metal, you are almost sure to nick the blades.
7. Don’t force snips. Extending the snips handles, placing all your weight on the handles, or pounding on the backs of the blades puts more pressure on the snips blades then they are designed for and will spring the blades making them useless. If snips blades are sprung there is too much clearance between the blades which means that when small edges of sheet metal are trimmed, the blades will bend the edge rather than cut it. Another common result of sprung blades is that the tips of the blades no longer meet, which means that notches cannot be made with the tip of the blade.

S.W.G	inch	mm*
24	0.022	0.56
22	0.028	0.71
20	0.036	0.90
18	0.048	1.25
16	0.064	1.60
14	0.080	2.00
12	0.104	2.50
10	0.128	3.15

Table 1 - Thickness of Sheet Metal in General Use

(*I.S.O. recommendations for basic thickness of sheet and wire diameters)

Craft Theory

The Production of Steel

There are two stages in the production of steel:

1. The extraction of IRON from the iron ore, which we have already considered.
2. The refining of the iron extracted.

Iron from the Blast Furnace contains around 4% carbon and sometimes 3-4% comprising – sulphur, phosphorus, manganese and silicon. Refining then, is basically a process that removes most of these unwanted elements. They are removed by heating and bringing them into contact with oxygen. The impurities combine with oxygen to form oxides which for the SLAG.

The three main processes used in the production of steel are, (in order of tonnes produced):

a) The Basic Oxygen Process
b) The Electric Arc Process
c) The Open Hearth Process

The Basic Oxygen Process

This is a modern development of the Bessemer convertor. The main difference is that, while the Bessemer process used compressed air, (blown up through the bottom of the vessel), the Basic Oxygen Process uses oxygen. The oxygen is brought onto the surface of the metal by a water-cooled lance.

The Electric Arc Process

Although scrap iron and steel make up the charge in the majority of cases, some 'hot metal' may also be used. Heat for this furnace is by an electric arc, similar to that used in electric arc welding.

In this furnace there are three electrodes. These are connected so that electric current flows from one electrode through the metal to the next electrode. The electric power required is very high. For example, a 90 tonne electric arc furnace might need 37 Megawatts (MW), (enough electricity to supply 15,000 houses). The furnace is a circular vessel which sits on a system of rollers, which allows it to tip over for slagging and tapping. To allow the furnace to be charged, a swivelling roof moves to one side complete with raised carbon electrodes. A 90 tonne electric arc furnace is around 6 metres in diameter, the carbon electrodes having a diameter of 560 millimetres.

The Open Hearth Process

This is an old process, having been used for about one hundred years. First, scrap is fed into the shallow basin-like hearth. A flame from either a gas or oil nozzle jet heats the space above the scrap and most of the scrap melts. Now, the molten iron part of the charge is added. In recent years, oxygen lancing has been used to remove unwanted carbon and other impurities. Another method of supplying oxygen is by enriching the combustion air with oxygen. These improvements have meant that the rate of output has been increased dramatically. However, it still takes 10 hours to convert 350 tonnes of steel by this method, making it very slow indeed compared to the Basic Oxygen Process. For this reason, it is likely that the use of the Open Hearth Process will fade out in the next decade.

Creep:

Slow collapse of metal under load. Often takes place at high temperatures though soft metals can suffer from creep at room temperatures. Lead sheet on roofs sometimes thickens towards the eaves.

Tension:

A stress due to a pulling force.

Compression:

The opposite to tension. A force applied to material which tends to crush the particles together.

Torsion:

A stress due to a twisting force.

Contraction:

Shrinkage from the size attained when hot, to that of the cold state.

Heat Treatment Processes

Annealing:

This softens and removes stresses in ferrous and non-ferrous metals. Ferrous metals are heated above the critical point and are held at this temperature for a short period. They are then allowed to cool in the hot ashes, which protects them from rapid cooling and oxidisation by the air. This leaves the material in a soft state and relieves the internal stresses caused by forging, bending or hammering. Non-ferrous metals which are subject to work-hardening have their crystalline structure altered and these are annealed in various ways, again to relieve internal stresses.

High Carbon Steel:

Heat to a bright cherry red and allow to cool very slowly in forge surroundings.

Copper:

Copper and copper alloys are annealed by heating to a dull red and quenching in water or allowing to cool slowly. Quenching in an acid bath removes any oxides formed in heating.

Brass:

Brass may be annealed by heating to a dull red and allowing to cool slowly as quenching causes cracks.

Aluminium:

Aluminium is annealed by rubbing soap over the surface, heating it until the soap turns black and cooling it in cold water.

Normalising:

This process refines the grain structure of ferrous materials. It enables the strains, which are set up by distortion and cold working, to be removed. The metal is heated above the critical temperature and allowed to cool in still air at room temperature.

Tempering:

Tempering takes some of the hardness and brittleness out of hardened steel and gives it the necessary toughness to make it suitable for tool making. Tempering should be done in daylight. Material which has been hardened should be polished with emery cloth to a bright finish. It is then heated slowly behind the hardness line until the appropriate colour (oxide film) appears on the polished surface and it is then quenched in oil or water. Different temperatures show different colour oxides but the appearance of the colours is affected by lighting. Table 2 gives the tempering colours for the various tools used in the work shop. The higher the tempering temperature rises, the softer the tool becomes. If the material is over-tempered it will be too soft and if under-tempered will be too brittle.

Tempering Colour	Temperature ºC	Uses
Pale Straw	230	Turning and boring tools, scrapers and scribers, hammer faces
Dark Straw	240	Drills, taps and dies, reamers, scissors and chisels
Brown	250	Shear blades, lathe centre drills and centre punch
Brownish Purple	260	Rivet Snaps
Purple	2π70	Axe heads
Dark Purple	280	Chisels
Blue	300	Springs and screwdrivers

Table 2 - Tempering Colours for Various Workshop Tools

Ferrous Metals

Ferrous metals contain iron as the main constituent. They are magnetic and they rust. Steel is a ferrous metal. The ferrous metals include carbon steels, tin plate and galvanised sheet. Carbon steels are classified according to the amount of carbon they contain:

Low carbon steel .... up to 0.3%

Medium carbon steel .... 0.5% to 0.7%

High carbon steel .... 0.8% to 1.2%

Low carbon steels do not contain enough carbon to be hardened. They are relatively soft and are often called Mild Steel. As they are easy to weld and form, they have many applications in sheet metal work. Mild steels are available as rods, bars, strips and sheets. Mild steel is very ductile.

Medium carbon steels have greater strength than mild steel, but are not as ductile or malleable. They can be hardened a certain amount by heat treatment, depending on its carbon content. High carbon steel is hard and wear resistant. It can be hardened and tempered. These steels are sometimes called tool steels and are used to make cutting tools (chisels, saws, files); dies, punches, springs and hammers.

Surface Treatment

All metals, more or less, oxidise or corrode when exposed to a damp atmosphere or corrosive fumes. If the oxide so formed is dissolvable in water or other liquid, or readily detaches itself from the metal, as in the case of iron, then rapid deterioration takes place. Although iron has many distinct advantages over other metals in the way of strength, working properties and cheapness, it is the worst of the ordinary metals in offering resistance to the action of air and moisture when exposed to the atmosphere without some protective coating. Copper, lead and zinc are all quickly acted upon by damp air, or if the atmosphere contains sulphur, carbonic acid or other fumes, the metals very soon tarnish. The thin film of oxide or scale so formed, however, in the case of these metals holds tenaciously to the metal, and consequently acts in a very effective manner as a protection skin for the metal underneath.

To protect the surfaces of metals from corrosive influences, many surface treatments are in vogue such as galvanizing, tinning, electro-plating, dipping, lacquering, enamelling, painting, oxidising and for special purposes, metals may be coloured by bronzing, bluing and gilding.

Galvanising is the most common process adopted for application of a protective coating to sheet iron/sheet work. Essentially the process consists in applying a thin film of zinc to the surface of the iron/steel.

The process of tinning sheets follows very much the same lines as galvanising, the molten metal in this case being tin, and the flux generally a solution of zinc chloride. The sheets are run through several pairs of rolls, and ultimately up and out through a "grease pot" filled with palm oil.

In summary, surfaces protection is required because of corrosion, abrasion, mishandling, oxidation and electrolytic action. These problems may be counteracted by the use of surface protections such as phosphating, painting, galvanising, tinplating, cadmium plating, chromium plating, anodising or plastic coating.

Ferrous Metals

The Latin name for iron is 'ferrum' and the word 'ferrous' means appertaining to iron. Thus 'ferrous' metals are those in which iron is the main consistuent. The word 'ferrite' is used to describe almost pure iron which outside the laboratory is rarely found in the pure state; it does in fact hold a minute quantity of carbon in solution.

Slight variations in the amount of carbon present can greatly influence the properties of the metal, and Table 3 shows how the addition of varying amounts of carbon, which is a 'non-metal' can produce a wide range of ferrous metals.

Pure Iron:

Commercially pure iron is a soft ductile material which has a very limited use. However, with the addition of silicon it has magnetic properties which make it a most suitable material for transformer cores.

Wrought Iron:

Wrought iron is produced from high quality pig iron. It has a characteristic fibrous structure as a result of entrapped slag having been rolled and forged into long fibres throughout the entire length of the material during the manufacturing process. These fibres strengthen and toughen an otherwise pure iron. It has considerable ductility and is easily welded.

Grey Cast Iron:

The carbon content of grey cast iron is far in excess of the upper limit of 1·7% carbon contained by plain carbon steels. Thus considerable uncombined or 'free' carbon exists distributed throughout the iron as fine flakes of GRAPHITE. The presence of graphite gives the material its characteristic grey appearance when fractured. It is also responsible for the dirty black dust experienced during drilling and machining operations. However, the graphite is important in that it not only acts as a self-lubricant when the material is drilled or machined, but also produces a cushioning effect between the iron grains which tends to dampen vibration. Cast iron has a high compressive strength but a low tensile strength; in compression it is about four times stronger than in tension. Because of its somewhat brittle structure it is not suitable for shaping by hot or cold working. However, it is extremely fluid when molten and is therefore suitable for making intricate castings. It can be both fusion and braze welded.

Dead Mild Steel:

Because the carbon content of dead mild steel is very low, it possesses high ductility and malleability enabling it to be deep drawn and pressed into complicated shapes by cold working.

Mild Steel:

This low carbon steel contains more iron carbide than dead mild steel making it much harder -but slightly less ductile and malleable. It is probably the most widely used fabrication material, being easily cold-worked or hot-worked.

Medium Carbon Steel:

These steels, when they are suitably heat-treated, provide the tough materials needed for components that require hardness combined with strength and ductility. Medium carbon steel is less malleable than the low carbon steels and cannot be cold-worked to any great extent without risk of fracture.

High Carbon Steel:

These steels combine hardness with high strength. They are less ductile and less tough than the medium carbon steels. Cold forming is not recommended, but they can be hot forged within a carefully controlled temperature range, and may be satisfactorily machined when heat-treated to a normalised condition. They can also be welded.

Typical applications of the above materials are listed in Table 3.

Carbon Content %		**Tensile Strength NM/m²**	**Some Applications**
Wrought Iron	Less than 0.05	330	Chains for lifting, tackle, crane hooks, ornamental architecture ironwork
Grey Cast Iron	3.2 to 3.5	225	General castings, machine beds, frames and sliding surfaces
Plain carbon steels are alloys of Iron and Carbon in which the iron and carbon are Chemically Combined at all times. The maximum solubility of carbon in iron is 1.7%, but the range of carbon content for carbon steel is from 0.1% to 1.2%.			
Dead Mild Steel	0.1 to 0.15	360	Sheets for deep-drawing and press forming of panels (aircraft and vehicle bodies), thin wire, rod and drawn tubing
Mild Steel	0.15 to 0.3	460 to 500	A general purpose material available in bars, plate, rods, sheet, wire and various structural sections
Medium Carbon Steel	0.3 to 0.5	700 to 800	High tensile tubing, crankshafts, forgings and axles, hammer heads, screwdrivers, spanners, wood saws, wire ropes. Cold chisels, high tensile tubing, leaf springs
High Carbon Steel	0.8 to 1.0	900	Coil springs, shear blades, wood chisels, high tensile wire (piano wire)
	1.0 to 1.2 1.2 to 1.4		Files, drills, taps and dies. Ball bearings, metal turning tools, fine-edged tools, knives etc.
Medium carbon steels respond to heat-treatment to further increase their toughness and hardness, and are used for highly stressed components. High carbon steels are mainly used where their properties – after suitable heat-treatment – of hardness and wear resistance can be exploited.			

Table 3 - Ferrous Metals

Properties of Metals

Metals possess the following properties to varying degrees:

Hardness:

This is the property of a metal to resist penetration or scratching.

Malleability:

This indicates the extent to which a metal can be extended in all directions by hammering or rolling without causing the material to crack. Metals are usually more malleable when hot than when cold, therefore it is usual to heat them when forging. Gold is the most malleable metal and may be beaten into very thin sheets.

Ductility:

The degree to which a metal may be expanded in the direction of its length. Ductile metals are easily hammered to shape and will yield to pressure. Ductile metals are used for wire drawing and tubes.

Conductivity:

Can be divided into two types: thermal and electrical.

Thermal Conductivity (k) is a measure of how well heat will flow though a material. Copper is an example of a material with good thermal conductivity and so is aluminium. These are used to make saucepans where we want heat to be conducted quickly. Materials which do not conduct heat well are called thermal insulators. Thermal insulation is used to slow down heat loss in homes (e.g. fibre glass in roof spaces, plastic foams in cavity walls). Heat always flows from hot to cold.

Electrical Conductivity is a measure of how well electricity will flow through the material. For a material to have good electrical conductivity it must have low resistance (e.g. copper). Some materials are poor conductors and so have a high resistance these are called insulators (e.g. polythene, rubber, and ceramics).

Fusibility:

All metals with the exception of mercury are solid at room temperature.

They are all capable of being melted by heating. Fusibility is the relative ease with which they may be melted.

Elasticity:

This property enables a metal to return to its original shape after external forces which cause distortion are removed. If the force causing distortion is increased without limit, a point is reached when the metal fails to regain its original shape and this point is called the 'elastic limit'.

Plasticity:

The ability of a metal to withstand 'permanent set' without cracking. This is a necessary property for forging. Steel is plastic at red heat.

Toughness:

Considerable effort is required to fracture tough material and it has the ability to withstand bending, twisting or sudden blows.

Impact Resistance:

Ability of a metal to withstand a severe impact without failure.

Tensile Strength:

The maximum pulling stress that a metal can withstand before breaking. The tensile strength of a piece of metal is called its tenacity.

Fatigue:

Metals can withstand heavy stresses of a constant nature indefinitely but a much lighter intermittent stress applied many times can cause total collapse.

Creep:

Slow collapse of metal under load. Often takes place at high temperatures though soft metals can suffer from creep at room temperatures. Lead sheet on roofs sometimes thickens towards the eaves.

Tension:

A stress due to a pulling force.

Compression:

The opposite to tension. A force applied to material which tends to crush the particles together.

Torsion:

A stress due to a twisting force.

Contraction:

Shrinkage from the size attained when hot, to that of the cold state.

Pythagoras Theorem

Pythagoras Theorem states that the square on the hypotenuse (the longest side) of a right angled triangle is equal to the sum of the squares of the other two sides. The right angle triangle shown in Figure 6 may be used to illustrate Pythagoras Theorem. The three sides are in the ratio 3:4:5. The square on the hypotenuse 5x5 (25) is equal to the sum of the squares on the other two sides:

3 x 3 (9) + 4 x 4 (16)

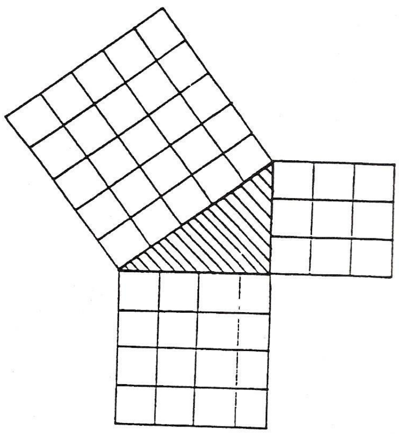


Figure 6 - Pythagoras Theorem

In general, for any right angled triangle as shown in Figure 7 the following rule applies,

$c^2 = a^2 + b^2$

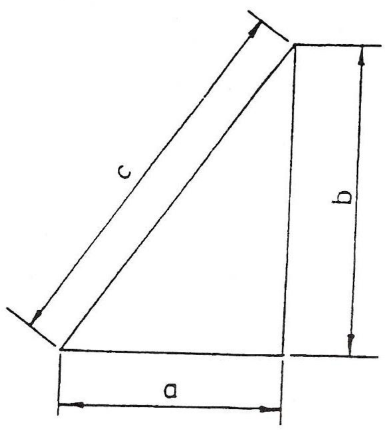


Figure 7 - Right Angled Triangle

There are a number of special right angled triangles where the lengths of the three sides have whole number values. The most widely known of these are the 3, 4, 5 triangle and the 5, 12, 13 triangle.

Force and Vector Representation

Force:

This may be defined simply as a push or a pull; the push or pull may result from the force of contact between bodies or from a force, such as magnetism or gravitation, in which no direct contact takes place.

Nature of Force:

- Acts in a straight line
- Produces or tends to produce motion
- Stops or tends to stop motion
- Changes speed or direction of motion
- Causes or tends to cause deformation of a body

The unit of force is the Newton (N).

9.91 Newtons	=	1Kilogram force
		(Gravity 9.81 N = 1 Kgf)
4.41 Newtons	=	1lb. force

Types of Force:

Tension: A stress due to a pulling force.

Compression: The opposite to tension. A force applied to material which tends to crush the particles together.

Shear: The action of two parallel forces acting in opposite directions (Example: Bench, Shears).

Torsion: A stress due to a twisting.

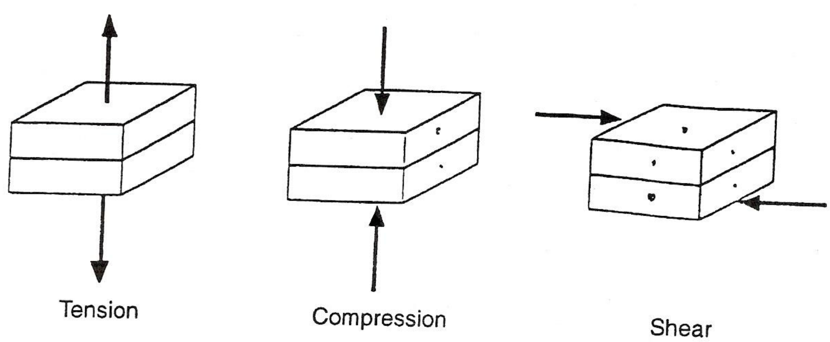


Figure 8 - Types of Force

Calculation of Blanks

Fractions:

$$4\tfrac{1}{3} + 1\tfrac{1}{5} = \tfrac{13}{3} + \tfrac{6}{5} = \frac{65+18}{15} = \tfrac{83}{15} = 5\tfrac{8}{15}$$

$$3\tfrac{1}{2} - 1\tfrac{2}{7} = \tfrac{7}{2} - \tfrac{9}{7} = \frac{49-18}{14} = \tfrac{31}{14} = 2\tfrac{3}{14}$$

$$\tfrac{2}{3} \times \tfrac{7}{8} = \frac{2\times 7}{3\times 8} = \tfrac{14}{24} = \tfrac{7}{12}$$

$$\tfrac{3}{4} \div \tfrac{5}{7} = \tfrac{3}{4} \times \tfrac{7}{5} = \tfrac{21}{20} = 1\tfrac{1}{20}$$

The area of one trapezium:

$$A = (\frac{b+c}{2})a$$

$$= \frac{4 + 1\tfrac{1}{2}}{2} \times 2\tfrac{1}{2}$$

$$= \frac{5.5}{8}\, sq\ ft$$

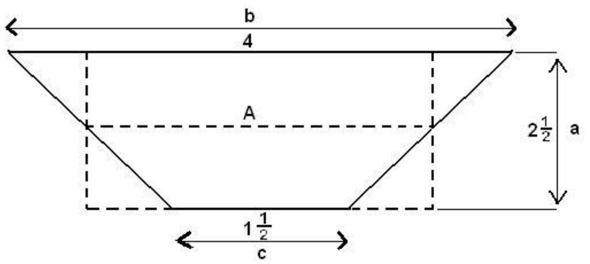


Figure 9 - Area of a Trapezium

Perimeter and Circumference

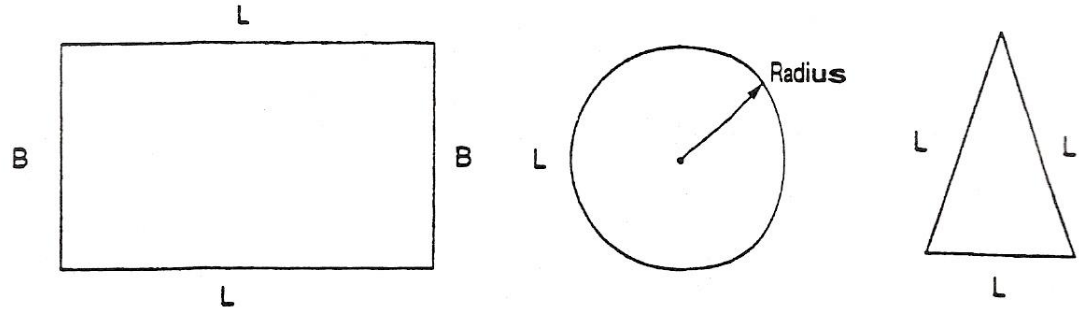


Figure 10 - Perimeter and Circumference

Perimeter of a Rectangle: = L + B + L + B

= 2L + 2B

= 2 (L + B)

= Sum of the four sides

Perimeter or Circumference is the outer length of an object.

Perimeter of a Triangle = Sum of all three sides

Perimeter of a Square = Sum of the four sides

Perimeter of a Parallelogram = Sum of the four sides

Perimeter or Circumference of a Circle = πD or $2\pi R$

Where D = Diameter of circle

R = Radius of circle

$\pi = 3.14$ or $^{22}/_{7}$

Note:

π, this symbol is the Greek letter "pi".

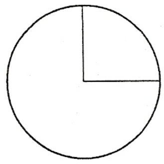
The exact length of a circle is 3.14 times the diameter of the circle.

$\pi = 3.14$, also $^{22}/_{7}$ (twenty two divided by seven) = 3.14.

Circumference (or Perimeter) of an Ellipse:

A = ½ major axis

B = ½ minor axis



Circumference $= \pi \sqrt{2(a^2 + b^2)}$

Note: a closer approximation is $= \pi \sqrt{2(a^2 + b^2) - \frac{(a - b)^2}{2.2}}$

Measuration: Areas and Volumes

Area of a circle	$= \pi R^2$
Area of a triangle	= ½ (base *x* vertical height)
Area of a square	= length *x* length
Area of a rectangle	= length *x* breadth
Area of a parallelogram	= base *x* perpendicular distance between parallels
Area of a rhombus	= base *x* perpendicular height
Area of a polygon	= sum of areas of triangles
Area of an annulus	$= \pi (R^2 - r^2)$
Area of an ellipse	= π (major axis *x* minor axis)

Volumes of Regular Solids

a) Prisms – Solids with same cross section along the whole length.
Volumes = area of cross section *x* length
Surface area = sum of the areas of faces

b) Cylinder – Circular sectioned prism.
Volume = area of circular section *x* length = πr^2 *x* L (H)
Surface area = 2π R *x* L

c) Sphere = volume = $4/3 \pi r^3$
surface area = $4 \pi r^2$

d) Cone/Pyramid – Volumes are 1/3 of the volume of the enclosing prism.
Volume of cone = $1/3 \pi r^2 h$
Curved area of cone = $\pi r l$, where l = slant height
Volume of pyramid = 1/3 A h, where A = base area
Surface area of pyramid = sum of areas of triangular sloping faces

Moment of a Force

Figure 11 shows the turning effect of a force. This is called the moment of a force or torque. It can be increased by increasing the force, the leverage distance or both. The turning effect of a force has many applications in the workshop.

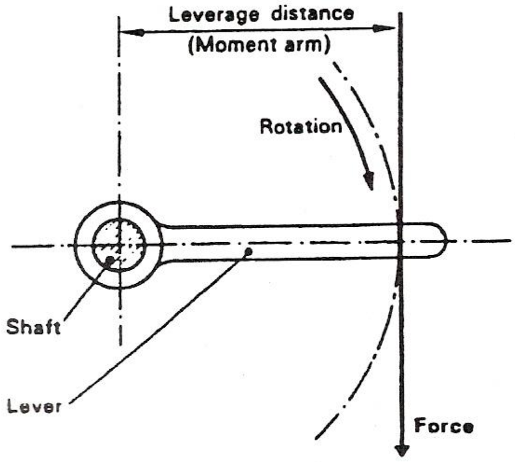


Figure 11 - Turning Effect of a Force

The moment of a force can be calculated quite easily as follows:

moment = force *x* leverage distance.

Example: Figure 12 shows a spanner and nut. The force acting on the spanner is 30 N and the leverage distance (moment arm) is 200m.

Calculate the moment of the force.

Solution:

Moment = force *x* leverage distance (moment arm)

= 30 *x* 200

= 6000Nmm (Newton millimetres)

$= \frac{6000}{1000}$ Nm

= 6Nm (Newton metres - the unit of torque)

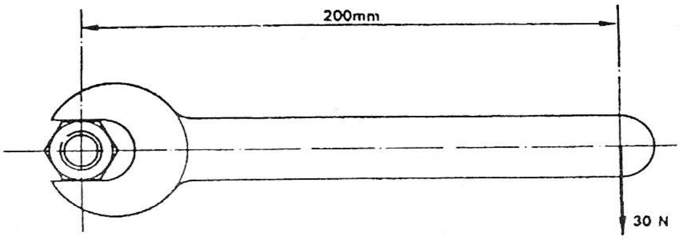


Figure 12 - Calculation of Torque

Principle of Moments

A lever is a device by which an effort can overcome a load. Whether the effort is greater or smaller than the load will depend upon the position of the pivot (fulcrum). Some examples of levers are shown in Figure 13.

It will be seen from Figure 13 that for the lever to remain stationary (in a state of balance) the load and the effort must be acting upon it in opposite directions. This observation is used in working out the forces acting on a lever.

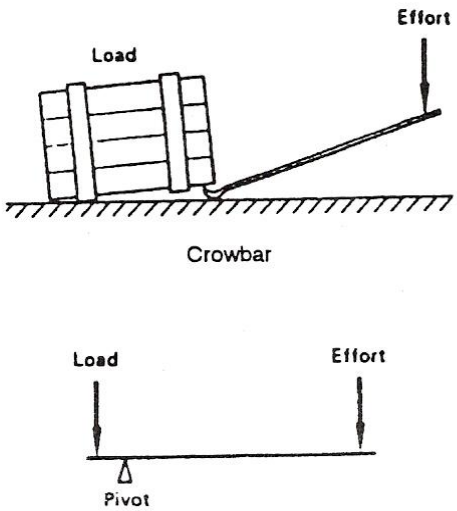


Figure 13 - Levers

For a state of equilibrium (balance) to exist:

the total = the total

clockwise = anti-clockwise

moments = moments

This is called the principle of moments. Figure 14 shows how the principle of moments is applied to a machine clamp.

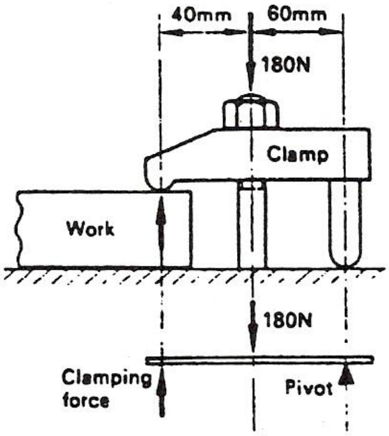


Figure 14 - Clamping Force

Example:

Calculate the clamping force on the work when the nut is tightened until it exerts a force of 180N on the clamp.

Clockwise	= Anti-clockwise
Moments	= Moments

Force *x* distance	= Force *x* distance
Clamp force *x* (40+60)	= 180 *x* 60
Clamp force *x* 100	= 180 *x* 60
Clamp force	$= \dfrac{180 \times 60}{100}$
	= 108N

Note:

1. The balance of the force exerted by the nut (180-108=72N) is exerted on the paching and is wasted.
2. By working this example again for different positions of the nut and bolt it will be found that the nearer the bolt is to the work, the greater will be the proportion of the force exerted on the work.

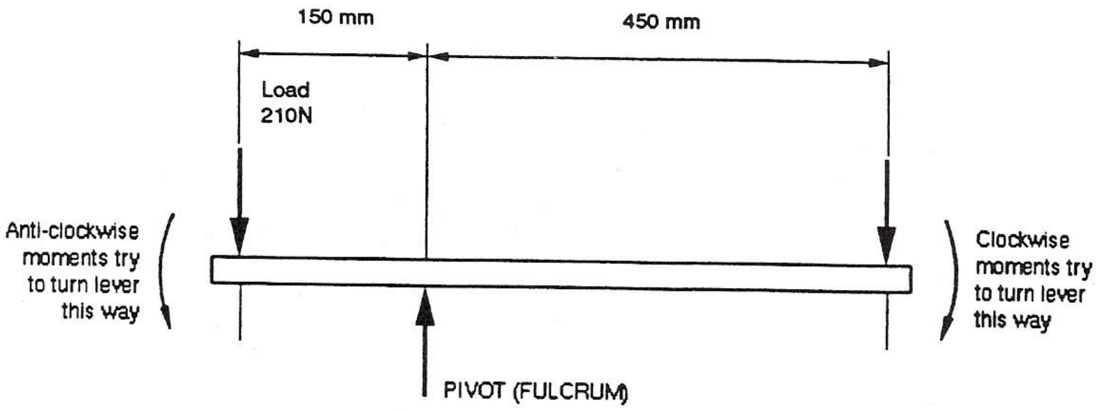


Figure 15 - Principle of Moments

Example:

To calculate the required effort to balance a load of 210N

Clockwise moments	= Anti-clockwise moments
Effort *x* Distance	= Load *x* Distance
Effort *x* 450	= 210 *x* 150
Effort	$= \dfrac{210 \times 150}{450}$
Effort	= 70N

Note:

If the effort is less than 70N the level will rotate in an anti-clockwise direction.

If the effort is greater than 70N the lever will rotate in a clockwise direction.

Definition of Mass

A property of matter equal to the measure of an object's resistance to changes in either the speed or direction of its motion. The mass of an object is not dependent on gravity and therefore is different from but proportional to its weight.

Newton's second law enables us to underline the difference between mass and weight. On earth a man has a mass of 60kg. His weight is the force pulling him towards the centre of the earth.

By Newton's second law

force = mass *x* acceleration

weight = mass *x* acceleration due to gravity

weight = mass *x* 'g'

Therefore, the man's weight is

60 *x* 9.8 = 588N.

Generally **weight = mass *x* 'g'**

The acceleration due to gravity on the moon is only about 1/6 of its value on earth, so that if this man were to go to the moon his mass would still be 60Kg, but his weight would only be 98N as opposed to a weight of 588N on earth.

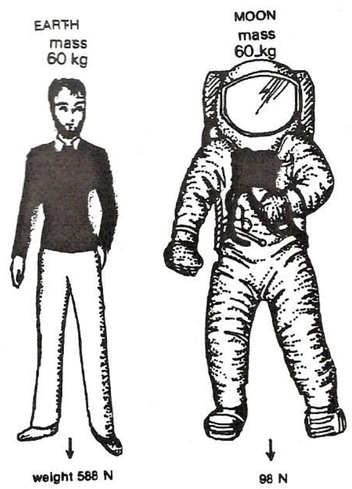


Figure 16 - Weight of Man on Earth and Moon

Note:

The point at which the whole weight of a body appears to act is called its centre of gravity.

Craft & Engineering Science

Force and Vector Representation

Force:

This may be defined simply as a push or a pull; the push or pull may result from the force of contact between bodies or from a force, such as magnetism or gravitation, in which no direct contact takes place.

Nature of Force:

a) Acts in a straight line
b) Produces or tends to produce motion
c) Stops or tends to stop motion
d) Changes speed or direction of motion
e) Causes or tends to cause deformation of a body

The unit of force is the Newton (N).

9.81 Newtons = 1 Kilogram force (9.81N = 1Kgf)

4.43 Newtons = 1lb. force

Types of Force:

Tension: A stress due to a pulling force.

Compression: The opposite to tension. A force applied to material which tends to crush the particles together.

Shear: The action of two parallel forces acting in opposite directions (Example: Bench, Shears).

Torsion: A stress due to a twisting force.

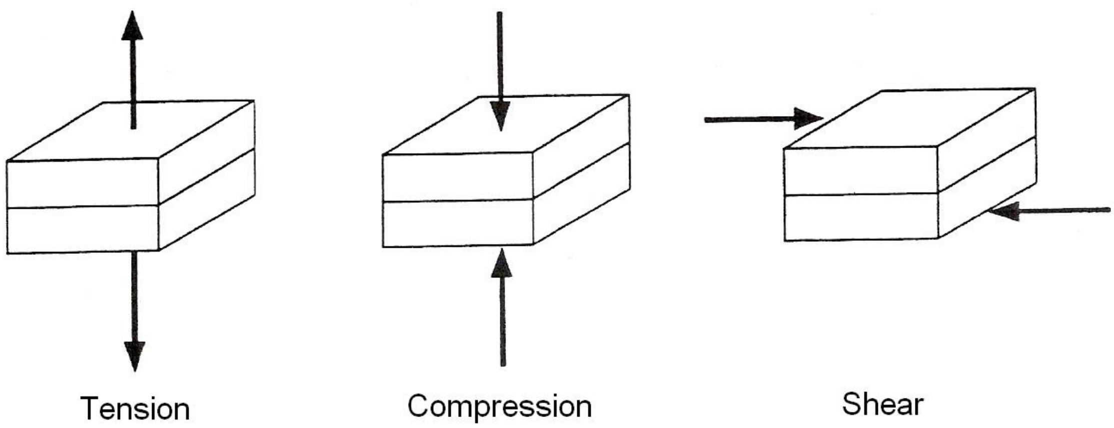


Figure 17 - Types of Force

Scalar and Vector Quantities

The quantities dealt with in mechanics are of two kinds according to whether magnitude alone or direction as well as magnitude must be known in order to completely specify them. Quantities such as time, volume and density are completely specified when their magnitude is known. Such quantities are called **scalar** quantities. Quantities such as force, velocity, acceleration, moment and displacement which must, in order to be specified completely, have a specific direction as well as magnitude, are called **vector** quantities.

Graphical Representation of Forces

A force has three characteristics which, when known, determine it. They are direction, point of application, and magnitude. The direction of a force is the direction in which it tends to move the body upon which it acts. The point of application is the place on the line of action where the force is applied. Forces may conveniently be represented by straight lines and arrow heads. The arrow head indicates the direction of the force, and the length of the line, its magnitude to any suitable scale. The point of application may be at any point on the line, but it is generally convenient to assume it to be at one end. In the accompanying illustration, a force is supposed to act along line *AB* in a direction from left to right. The length of line *AB* shows the magnitude of the force. If point *A* is the point of application, the force is exerted as a pull, but if point *B* be assumed to be the point of application, it would indicate that the force is exerted as a push.

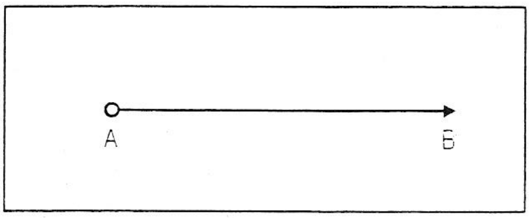


Figure 18 - Graphical Representation of Forces

Velocities, moments, displacements, etc. may similarly be represented and manipulated graphically because they are all of the same class of quantities called vectors.

Force Diagram

Two forces F1 and F2 of 50N each act on a body causing it to move.

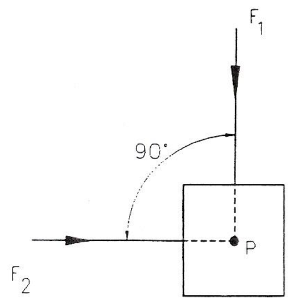


Figure 19 - Force Diagram

Vector Diagram

If the body "P" is to remain at rest, a force equal and opposite (Newton's Law), to the Resultant must be applied. This is termed the Equilibriant. This is shown in Figure 20 and Figure 21 in vector representation.

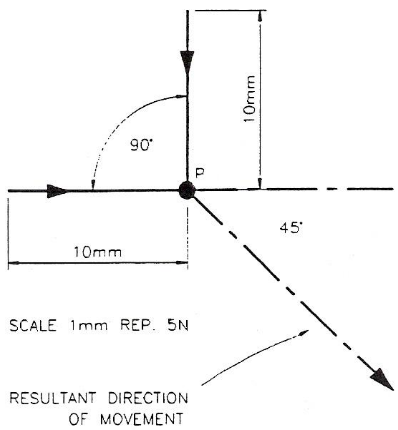


Figure 20 - Resultant Direction of Movement

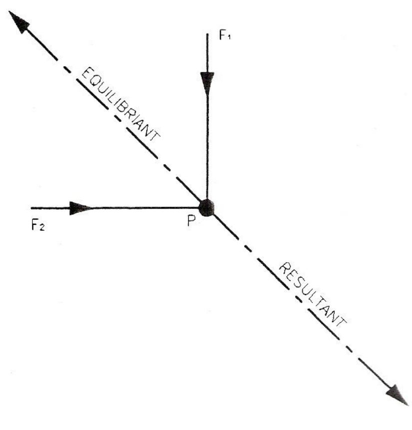


Figure 21 - Vector Representation

Composition of Forces: Parallelogram Law

Parallelogram Law of Vectors: If two vectors are represented by the two adjacent sides; *ab* and *ad* of a parallelogram *abcd,* then the diagonal ac represents their resultant.

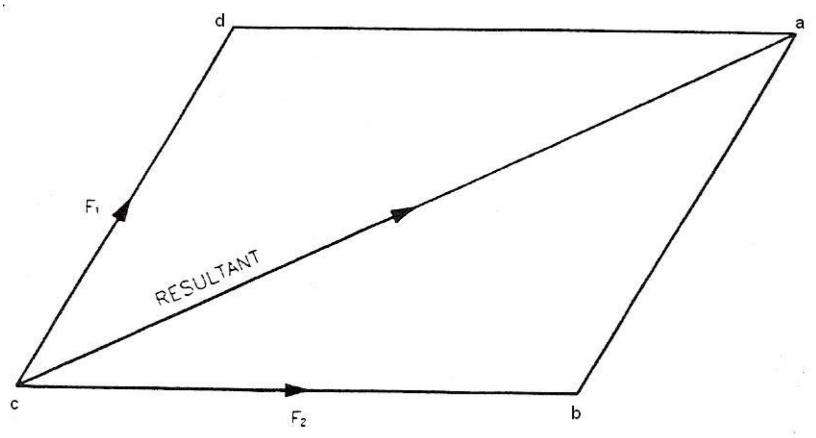
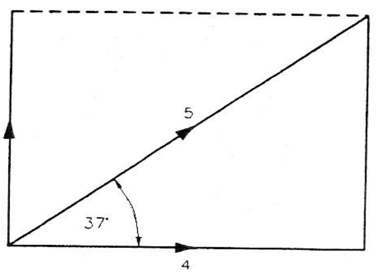


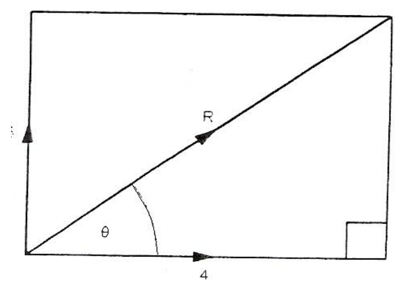
Figure 22 - Parallelogram Law

Example:

Find the resultant of a force of 3 units due north and a force of 4 units due east.



1. **By drawing**
   Answer: A force of 5 units 37º north of east.



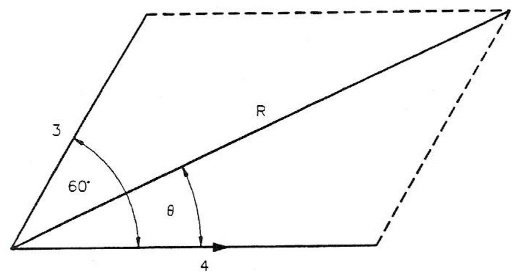
2. **By calculation – (Pythagoras)**
   $R^2 = 3^2 + 4^2$
   $R^2 = 25$
   $R = 5$
   $\tan \theta = \frac{3}{4} = 0.75$
   $\theta = 36^\circ\ 52'$

Answer: A force of 5 units at an angle of 36º 52'.

If the vectors are not perpendicular the calculators are somewhat more complicated.

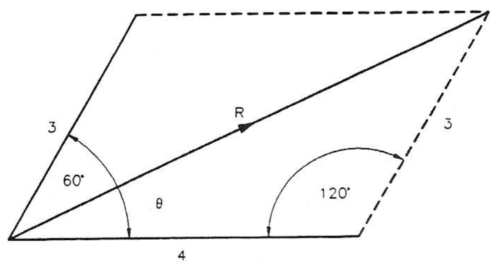
As one can see from the above example, the method of calculation is more precise. Pythagoras Theorem is used in this case because the angles are at 90º to each other. In the next example the angles differ, and thus complicate the problem.

Find the resultant force of 4 units due east and a force of 3 units 60º north of east.



1. **By drawing**
   Answer: A force of 6 units 25º north of east.

2. **By calculation**
   By the cosine rule
   $R^2 = 3^2 + 4^2 - 2 \times 3 \times 4 \cos 120^\circ$
   $R^2 = 9 + 16 – 24 (-½)$
   $R^2 = 25 + 12$
   $R^2 = 37$
   $R = \sqrt{37} = 6.082$



By the sine rule

$$\frac{\sin\theta}{3} = \frac{\sin 120^\circ}{6.082}$$

$$\sin\theta = \frac{3\sin 120^\circ}{6.082}$$

$$= \frac{3(0.8660)}{6.082}$$

$$= 0.4272$$

$$\theta = 25^\circ\ 15'$$

Answer: 6.082 units at an angle of 25º 15'.

Triangle Law:

When two vectors form two sides of a triangle, the third side is their resultant.

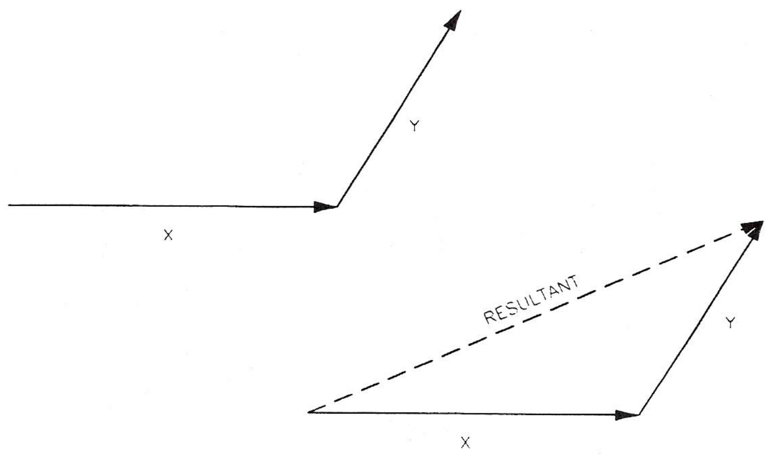


Figure 23 - Triangle Law

Tuning Effects of a Force

Couples

If the forces AB and CD are equal and parallel but act in opposite directions, then the resultant equals 0, or, in other words, the two forces have no resultant and are called a couple. A couple tends to produce **rotation**. The measure of this tendency is called the moment of the couple and is the product of one of the forces multiplied by the distance between the two. As a couple has no resultant, no single force can balance or counteract the tendency of the couple to produce rotation. To prevent the rotation of a body acted upon by a couple, two other forces are therefore required, forming a second couple. In Figure 24, E and F form one couple and G and H are the balancing couple. The body on which they act is in equilibrium if the moments of the two couples are equal and tend to rotate the body in opposite directions. A couple may also be represented by a vector in the direction of the axis about which the couple acts. The length of the vector, to some scale, represents the magnitude of the couple, and the direction of the vector is that in which a right-hand screw would advance if it were to be rotated by the couple.

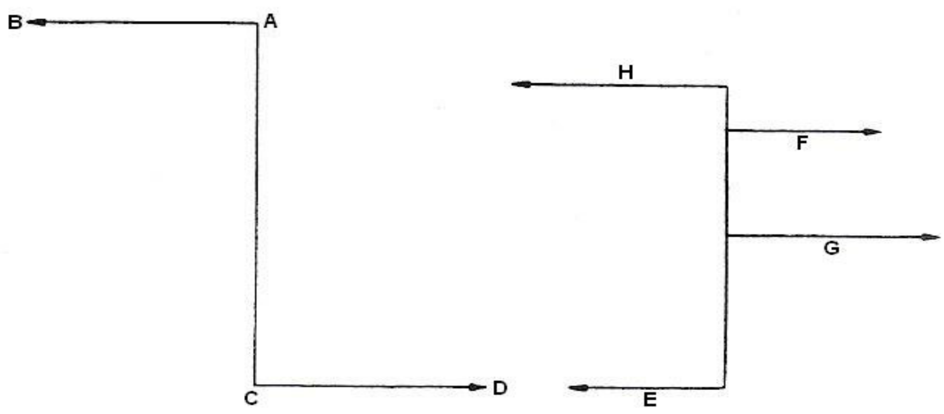


Figure 24 - Couples

Moment of a Force

The moment of a force with respect to a point is the product of the force multiplied by the perpendicular distance from the given point to the direction of the force. In the illustration, the moment of the force *P* with relation to point *A* is *P x AB.* The perpendicular distance *AB* is called the lever-arm of the force. The moment is the measure of the tendency of the force to produce rotation about the given point, which is termed the centre of moments. If the force is measured in pounds and the distance in inches, the moment is expressed in inch-pounds. In metric SI units, the moment is expressed in newton-metres (Nm), or newton millimeters (Nmm). The moment of the resultant of any number of forces acting together in the same plane is equal to the algebraic sum of the moments of the separate forces.

The turning effect of a force is known as its moment. The moment of a force about any point is the force *x* perpendicular distance from the point, to the line of action of the force.

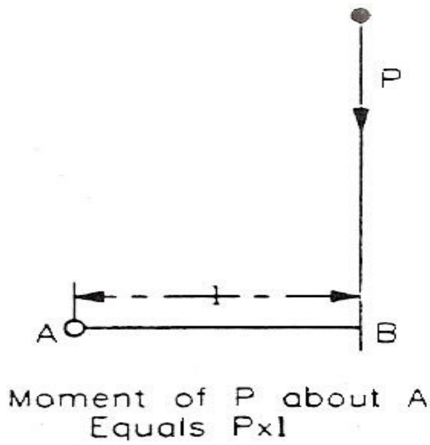


Figure 25 - Moments of a Force

Example: To achieve balance/equilibrium

Moments to the left = Moments to the right

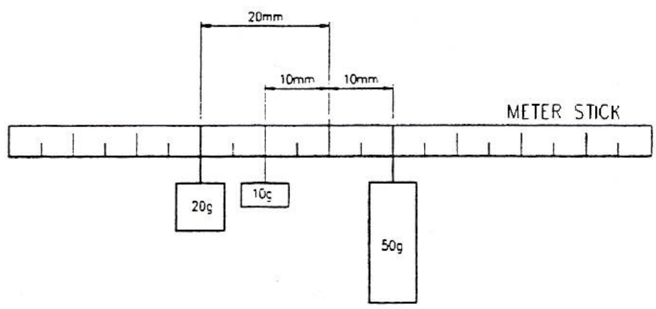


Figure 26 - Metre Stick

This metre stick is a lever. We know it is balanced because:

Moments to the left	= Moments to the right
Sum of anti-clockwise moments	= Sum of clockwise moments
(20mm *x* 20g) + (10mm *x* 10g)	= (10mm *x* 50g)
400 + 100	= 500
500	= 500 = Balance

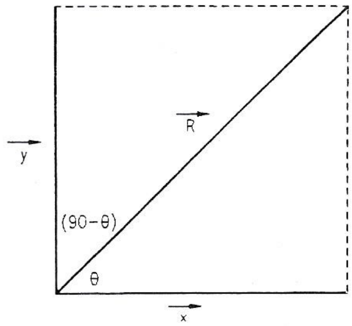
The principle of moments can be used to find the centre of gravity of a compound body. In the case of regular bodies the centre of gravity is at the geometric centre. For example, the centre of gravity of a disc is at its centre, and the centre of gravity of a ring is at its centre. In the case of a compound body, the position of the centre of gravity can be calculated by taking moments. It may be used in the bracketry of ducting and supports for air handling units.

Resolution of Forces

If two vectors can be replaced by a single vector, called their resultant, it stands to reason that the reverse is also true. So a vector can be resolved into two components. The most convenient components of vectors are those at right angles to each other.

$$\frac{\vec{x}}{\vec{R}} = \cos\theta \Rightarrow \vec{x} = \vec{R}\cos\theta$$

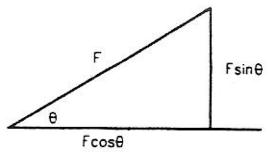
$$\frac{\vec{y}}{\vec{R}} = \cos(90-\theta) = \sin \Rightarrow \vec{y} = \vec{R}\sin\theta$$



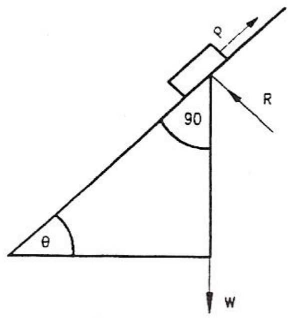
Vector R can be resolved into two components ⊥ to each other:

R cos θ and R sin θ.

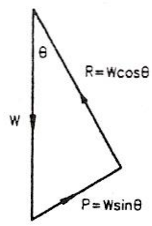
1. For a force F which makes an angle θ with the horizontal
   Horizontal Component – F cos θ
   Vertical Component = F sin θ



2.
   a) A body is kept in equilibrium on the plane by the action of three forces VIZ:
      i. the weight W of the body acting vertically downwards
      ii. the reaction R of the plane to the weight of the body (R is called the normal reaction or normal)
      iii. the holding force P acting in some suitable direction required to prevent the body sliding down the plane
   b) For P parallel to the inclined plane,
      then R = W cos θ
      P = W sin θ



3.
   a) Resolve forces into their horizontal and vertical components
   b) Find resultant horizontal force and resultant vertical force
   c) Compose resultant horizontal force with resultant vertical force.



Example:

A force of 5 units acts in a direction 60º north of east. Its component due east is:

$$5 \cos 60\,^{\circ} = 5\,(1½) = 2½$$

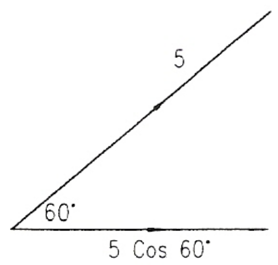


Figure 27 - Resolution of Forces

Note: If we consider a force of 10 units acting due east its component due north is:

$$10 \cos 90^{\circ} = 10\,(0) = 0$$

Self Assessment

Questions on Background Notes – Module 1.Unit 5

1. When would you drill a Pilot Hole?

2. List three of the five grades of files.

3. What are the pitches of the above files and what material would you use them on?

4. Name three types of file.

5. Name the three types of saw teeth on a hack saw blade.

Answers to Questions 1-5. Module 1.Unit 5

1.

Pilot Holes:

For large holes 9mm or more it is good practice to drill a pilot hole. It is especially useful on hard materials such as stainless steel.

2.

Grades of File:

- Rough
- Bastard
- Second Cut
- Smooth
- Dead Smooth

3.

a. **Rough:**
Pitch 1.8 – 1.3mm.
Soft metals and plastics.

b. **Bastard:**
Pitch of 1.6 – 0.65mm.
General roughing out.

c. **Second Cut:**
Pitch of 1.4 – 0.60mm.
For roughing out tough materials and finishing soft materials.

Continued.

d. **Smooth**:
Pitch 0.8 – 0.45mm.
For general finishing and draw filing.

e. **Dead Smooth:**
Pitch 0.5 – 0.25mm.
Not often used except on tough steels where high accuracy and finish is required.

4.

Flat File:
Used for large flat surfaces.

Hand File:
Has one safe edge (or uncut edge) and is used to file up to a shoulder without marking it.

Other Files include:
Pillar, Ward, Half Round, Round, Square, Three Quarter and Knife File.

5.

Coarse Pitch:	**1.8 – 2.2mm**
Medium Pitch	**1.4 – 1.6mm**
Fine Pitch	**0.8 – 1.3mm**

Index