Engineering

1. Fundamentals

Always write convention. $\circlearrowright +ve, \rightarrow +ve$

Mass – the amount of matter an object displaces, in kg
Force – a interaction between bodies, in a direction in N

Weight – attraction between mass and the Earth $F = mg$
Action – force applied to an object from outside $F = ma$
Reaction – force applied to balance another force
Friction – prevents motion between objects

Scalar – only magnitude (size)
Vector – magnitude, direction, Sense (motion of the line), point of application (start)

Simple machines

Inclined plane	Makes it easier to slide something up a plane.
Pulley	Reduces effort to lift something.
Lever	A force acting over distance, magnifies effort. 1. Fulcrum is in between effort and load. 2. Load is in between effort and fulcrum. 3. Effort is in between fulcrum and load.
Wheel & axle	Allows for a wheel to be turned by a motor.
Gears	Increases or decreases mechanical action.
Chain drive	Transfers rotational motion laterally.
Screw	An advanced inclined plane, which magnifies effort and friction.

Engineers select materials for a range of reasons:

- Functionality
- Availability
- Cost
- Special properties
- Environmental impact
- Aesthetics
- Workability

There are a range of materials:

Metals	A solid, malleable and ductile substance that can easily conduct heat and electricity.
Non-metals	A brittle material that insulates heat and electricity, which can form compounds.
Polymer	An organic substance that can be easily moulded and are a good insulator.
Natural	Produced from a life cycle of flora or fauna.

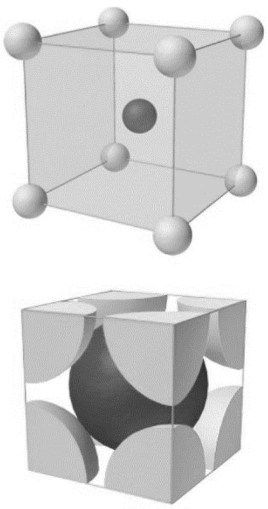
Materials bond into a range of different structures: (**primary**)

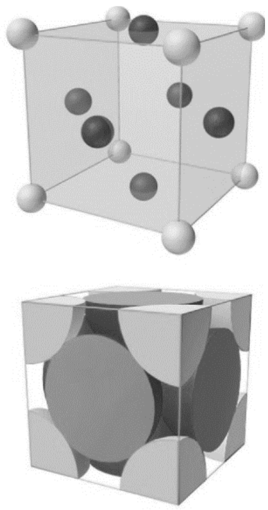
Metal + metal	**Metallic**	The free electrons form a sea, which attract the (naturally-repelling) nucleus together.
Non-metal + metal	**Ionic**	The metal gives the non-metal its free electrons.
Non-metal + non-metal	**Covalent**	The non-metals share electrons.

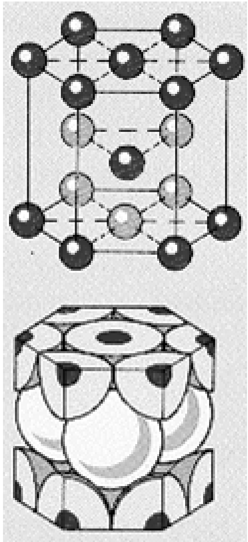
Secondary bonding, when small differences in charge between atoms (called diploes) help bind them together – van der Wall forces.

Polymorphs/Allotropes – materials that can have multiple crystalline structure.

Body Centred Cubic (BCC) Face Centred Cubic (FCC) Hexagon Close Packed (HCP)







Non-crystalline/Amorphous, materials that do not form a crystalline structure.

Ferrous materials are primarily iron. Steels are iron mixed with carbon and are classified by carbon content.

Austenite	**FCC** structure in steels, only exists when red hot.
Ferrite	**BCC** structure in steels/irons at room temperature.
Cementite	When austenite transforms, some is left as ferrite and the rest form cementite which is hard and brittle.
Pearlite	Pearlite is a compound of ferrite and cementite, layers of this structure.

Non-ferrous metals are those where iron is not a primary constituent. They metals do not rust as they have an oxide coating which prevents further corrosion and flaking.

Brass = $Cu + Zu$, Bronze = Cu + Tin.

Forming materials:

Casting	Pouring a molten metal/polymer into a mould.
Rolling	By using pressure applied by rollers, metals are compressing them – which changes their thickness and cross section.
Extruding	Molten metals are passed through a die – which creates a particular cross section.

Joining metals:

Welding	either using pressure, fusion or an alloy (added metal).
Soft soldering	tin alloy is used to join two metals together at 183°C.
Brazing/Silver soldering	using either bronze to fill small gap or silver at high temperatures to join dissimilar metals.

Polymers are a chain of carbon-based molecules:

Thermosetting	cannot be reshaped,	strong primary bonds between chains.
Thermosoftening	can be reshaped after heat,	weak secondary bonds between chains.

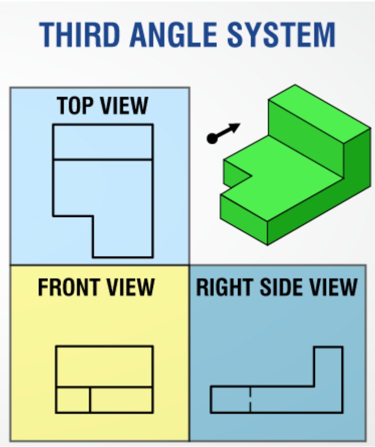
Ceramics are the products from the breakdown of rocks.

Ceramics are very resistant to heat (won't melt), non-conductive, corrosion resistant, highly porous and *brittle*.

To *permanently* fix their shape they need to be fired (heated to high temperatures).

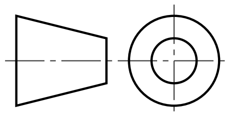
Sketching

Most of our orthogonal drawings are done in *3rd angle projection.*



2. Products

1. Clarify the need.
2. Conceptual design phase – ideas
3. Preliminary design phase – analysis of ideas
4. Detailed design phase – optimisation and evaluation



3rd angle projection

Don't just have to go into Uni, can go to TAFE/trade course.

Moments:
Clockwise is positive. $\circlearrowright +ve$

$$M_a = F \times \overset{\text{perpincidular distance from pivot to action}}{\overset{\frown}{d}}$$

All metals are made from crystals, when working hardening is performed (cold working) the metal becomes harder, but more brittle.

Dislocations are defects within the atomic structure of the metal crystals, these defects move to the edge of the crystal when force is applied causing deformation. When they end up on the edge, it causes plastic deformation as a new structure is now formed.
While though annealing (heating up to recrystallization temperature), new crystals are created though if it is heated to a too extreme degree, it can cause the crystals to grow too massive and cause irregularities.

Heat treatment can either **harden** (harder – more durable):
- Normalising: at critical temperature, air cooling, finer grains
- Quenching: above critical temperature, water cooling, finer grains - brittle

or **soften** (more ductile – easier to shape) the metal.
- Summary annealing: above critical temperature, slow cooling, new coarse grains
- Process annealing: below critical temperature, air cooling, finer grains, <u>restore</u> ductility
- Tempering: below critical temperature, air cooling to relieve stress – more ductile

Recycling is where materials are reprocessed to be used as new. It can reduce cost and waste for businesses.
Metals and plastics are sorted, then melted and recast into new materials.

Alloys is a combination of two metals, which leads to more rigidity as the new atoms block dislocations.

Composites is the combination of a matrix phase imbedded with a dispersed phase, it usually gives better properties of a new material.
A phase is a distinct form of an element characterised by shape, structure or properties.
- Particle reinforced: either large particles *or* dispersion strengthened [inter-molecular].
- Fibre reinforced: fibres strengthen a matrix.
- Structural composites: either laminated/layered *or* honeycomb.

Electronics

Electrical current is the flow of electric charge.

Voltage is electrical pressure, measures potential difference in circuit. Measured in Volts, V
Current is the measure of charge volume/movement in a circuit. Measured in Amps, A

Resistance is the opposition to current flow, this can be caused by collisions between electrons, between atoms of the material. Measured in Ohms, Ω

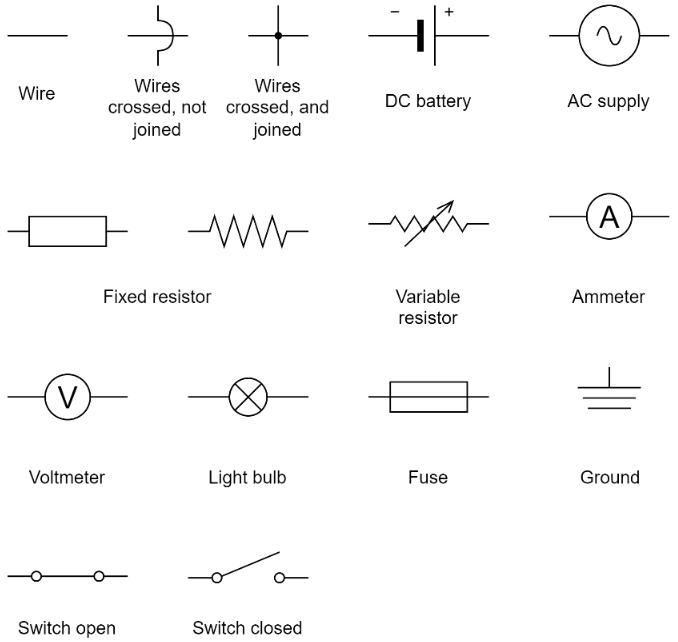
Ohms law: $I = \frac{V}{R}$

Electricity can severely disturb the body and can lead to fatalities; the body has a natural resistance of $\sim 10k\ \Omega$. Though ground wires, double insulation (with plastic) and circuit brakers still protect us.

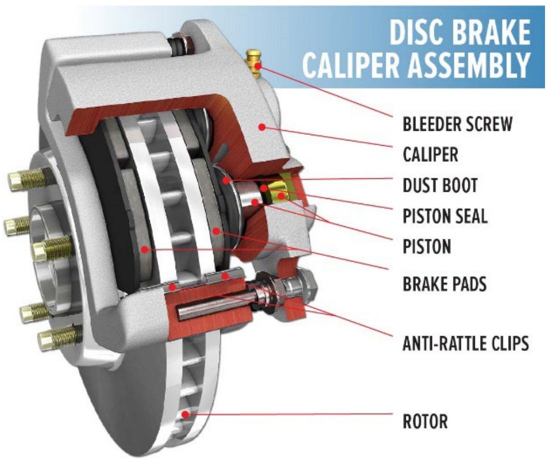
Series circuit: current is the <u>same</u> for all elements, voltage is <u>split</u> across components.
Parallel circuit: voltage is the <u>same</u> for all elements, current is <u>split</u> across components.

Electrical energy is generated through a conductor moving in a magnetic field.

Direct current (DC), electrical flow is one direction.
Alternating current (AC), electrical flow is in both directions, oscillating many times per second.



3. Braking Systems



External shoe brake: block of wood against the wheel, wears out quickly.
Band brake: band tightens around a hub, slowing it down, not weather resistant.
Drum brake: shoes pushed against the hub within a drum, tendency to heat up.
Disc brakes: brake pads (callipers) clamp a rotor, slowing it down, is weatherproof as self-cleaning due to airflow.

Hydraulic brakes: used hydraulic pressure to actuate the brakes, more reliable and has more force.
Brake booster: uses vacuum power (from the engine) to give extra force when actuating the brakes.

Regenerative brakes: turn rotational (motor) power back into electricity.

Pascal principle is that the pressure is that same at all points in a fluid.
$P = \frac{F}{A}$, F in Newtons, P in Pascals, A in m^2.

Angle of friction/inclination: $\tan\phi = \mu$, $\frac{\overset{\text{force down the plane}}{\widehat{P}}}{mg} = \mu$

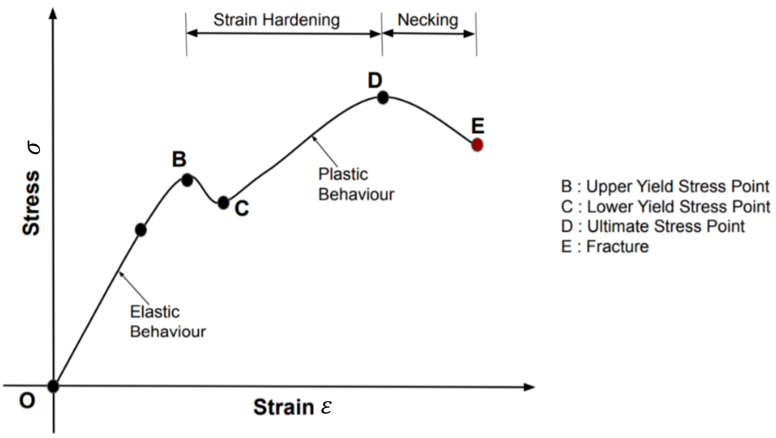
When body is at point of moving:

- Pulled **upwards** $F_R = \mu(mg - P\sin\theta)$

- Pushed **down** $F_R = \mu(mg + P\sin\theta)$

Stress equation: $\sigma = \frac{P}{A}$, with σ being stress in Pa, P force in N. With an object with multiple cross-sections, you choose the small cross-section to <u>maximise</u> stress, vice versa.

Stress is a limiting factor of a material, both stress and strain are **<u>not</u>** directly related to length of the material. Meaning that two blocks of the same material and cross-section with two different lengths would experience the same strain when subject to the same force.



When there is plastic deformation, $\varepsilon \propto \sigma$

Work is energy change due to a change in an object's attributes or location in Joules (J).

$$W = F\,\overset{displacement}{\overset{\frown}{s}}$$

Kinetic: energy due to motion

$$KE = \frac{1}{2}mv^2$$

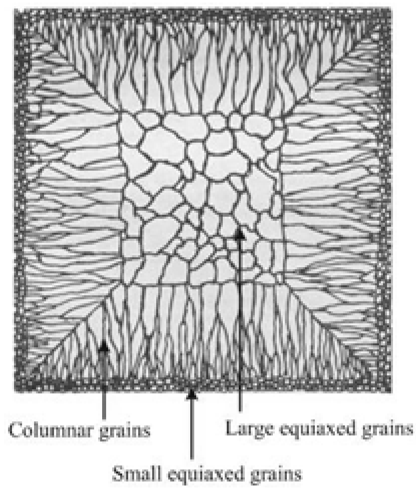
Potential: energy due to position

$$PE = mgh$$

Strain: energy due to deformation: $SE = \frac{1}{2}Fs$

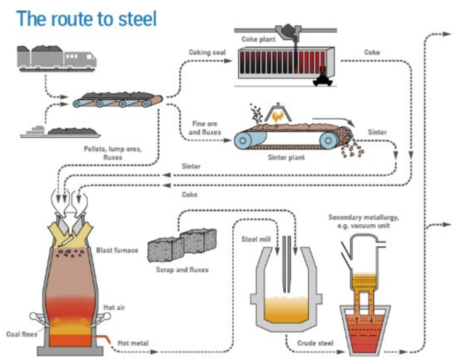
Power is rate to do work in Watts (W), $P = \frac{W}{t} = Fv$

Equiaxed grains: similar dimensions in 2 axes (square-like)
Equilibrium: atoms are allowed to arrange themselves into their optimal sturcture.



Ferrite: very soft, ductile BCC iron with every low carbon content
Cementite: very hard, brittle BCC iron with 6.67% carbon content and is a compound = Fe_3C

	Type of steel	*Carbon content*	*Uses*
Harder/brittle ↔ Malleable/Ductile	Dead mild – equiaxed ferrite and pearlite	0.05-0.15	Chain, rivets
	Mild – e. ferrite and pearlite	0.15-0.30	Structural steels, gears, screws & nuts
	Medium carbon – pearlite and e. ferrite	0.30-0.60	Axles, springs, shafts
	High carbon – pearlite and cementite Eutectoid steel – pearlite	0.60-0.90 0.80	Dies, brake cable wire Brake cable wire,
	Tool steel – pearlite and cementite	0.90-1.40	Cutting tools, ball bearings
	White cast iron – pearlite in cementite matrix	1.3-3.6	Dies and wearing plates
	Grey cast iron – pearlite/ferrite with graphite flakes	2.4-3.6	Brake master cylinders



	Spheroidal graphite cast iron – pearlite/ferrite with graphite nodules	3.0-4.0	Brake discs

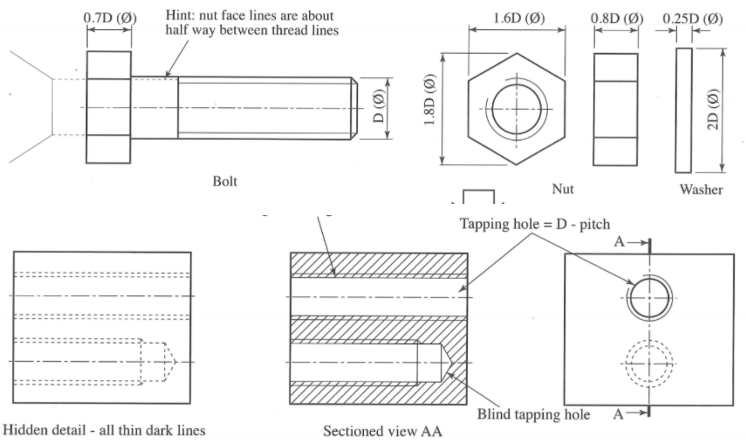
Mechanical properties:
Benefits of CAD:

Brittleness	Lack of plastic deformation, will fracture when affected by a load.
Ductility	A material's ability to be plastically deformed by elongation (tensile load).
Hardness	A material's ability to resist changes to shape from external loads.
Malleability	The ease at which a material is deformed under compression load.
Stiffness	The resistance to deformation by an external force.
Strength	The ability to oppose deformation from external loads.
Toughness	The ability to absorb external stresses and plastically deform instead of fracturing.

Faster, more precise and easier to access than drawings. It is in 3D, can be transformed easily and printed out easily.

Sectioning is used to expose detail of an object, by 'removing' material shown through a cutting plane on a 3d view. Material cut through is shown with cross hatching. (*Section _ view)*
Nuts, bolts, rivets, washers, pins are not sectioned.

Nuts & bolts:



4. Biomedical

Biomedical is using engineering to help design methods for diagnosis and treatment of injuries and diseases.

Bio-engineering fields:

- Bio-mechanics: mechanical functioning of body parts
- Bio-materials: study of materials compatible with living tissue
- Bio-instrumentation: design of instruments to monitor and measure bio-engineered devices
- Bio-computing: simulating biology (biophysics)
- Rehabilitation engineering: design of rehabilitation equipment (e.g., wheelchairs)
- Systems physiology: observation and measurement of biology/physiological events

All bio-engineered products have health and safety concerns as they can be incompatible because of <u>construction</u> of implant and/or <u>nature</u> of surgery.

Engineers can sometimes manage to initiate design and coordinate experts.

Bio-engineers have to develop mechanisms to imitate the function of a human organ and be compatible with a living tissue e.g., glasses, braces, fillings

Can use moments to calculate the balance of levers, with *effort* being the force being put into a system and *load* being the work done because of the system.

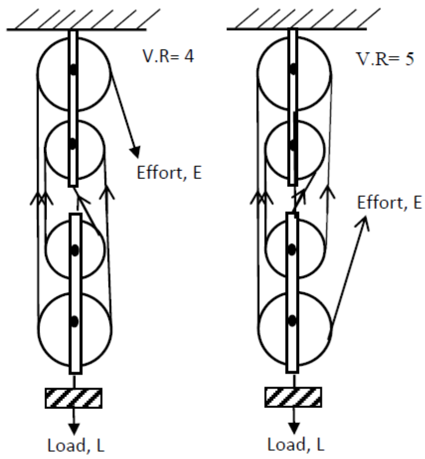
Mechanical advantage: is the load out of a lever proportional to effort.
Mechanical advantage: $\mathrm{MA} = \frac{\text{load}}{\text{effort}} = \frac{L}{E}$,

Velocity ratio: $VR = \frac{\text{velocity of effort}}{\text{velocity of load}} = \frac{\text{displacement of effort}}{\text{displacement of load}} = \frac{\underset{\text{radius of effort arm}}{\overset{\frown}{r_E}}}{\underset{\text{radius of load arm}}{\overset{\frown}{r_L}}}$

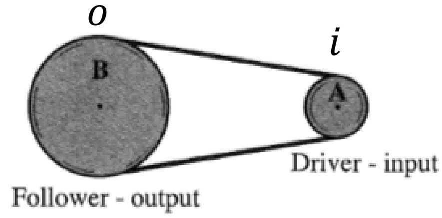
For 2nd order lever: $MA \,\&\, VR > 1$
For 3rd order lever: $MA \,\&\, VR < 1$

Efficiency (as a percentage): $\eta = \frac{MA}{VR} \times 100 = \frac{\text{output work}}{\text{input work}}$, a machine is almost never 100% efficient.
VR is ***never*** effected by efficiency.

Inclined plane: $VR = \frac{1}{\sin\theta}$
Block and tackle: $VR = \sum \text{ropes}_{\max}$, determined by the number of ropes **supporting** the load.

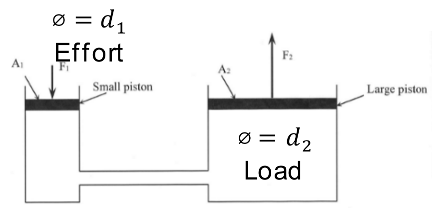


Belts: $VR = \frac{v\text{ of input pulley}}{v\text{ of output pulley}} = \frac{r_o}{r_i} = \frac{d_o}{d_i} = \frac{c_o}{c_i}$
Revolutions: $1\,rev = \frac{\#\text{ of my gear teeth}}{\#\text{ of other gear teeth}}$



Belts and pulleys

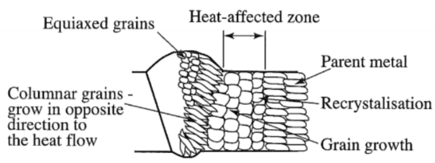
For an 100% efficient hydraulic system:
$MA = \frac{d_2^2}{d_1^2}$, $VR = \frac{d_2^2}{d_1^2}$, which d being diameter, d_2 is diameter of <u>load</u> piston



Material fabrication:

Welding:	Fusing together two similar metals.
Brazing:	Joining together steel with brass (which flows around the steel pieces – filling gaps), good in shear not in tension or compression
Soldering:	Joining together metals (particularly electronics) with a lead-tin alloy, less strong then brazing
Bolting:	Using fasteners to join to materials through an extra component.
Adhesives:	Using glues to fabricate polymers or woods (not metals).

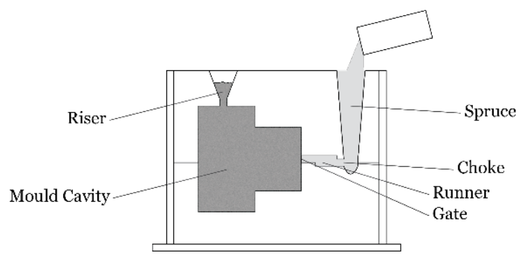
With welding: the heat affected zone is where the material has been affected by weld, it is weaker than the parent material and the grains become equiaxed.



Weld microstructure

Casting: pouring molten metal into hollow cavity, allowing it to solidify into a desired shape. It is cheap, efficient, fast and flexible.

Sand casting is where pattern (shape of final product) is used to create a sand mould (negative), then molten metal is poured in and that cools into the final form.
Choke: controls flow rate; spruce: main feed line



Shell casting: an extra resin-based sand mould is used leading to finer detail and greater dimensional accuracy.

Investment casting: wax mould is made which is made from a core and the final product is snapped off the core.

Centrifugal casting: continual centrifugal force creates hollow objects (i.e., pipes)
Die casting: a permanent metal mould is created of which molten metal is poured into.

Forging: metal is plastically deformed to achieve a desired shape.
Hot working is done above the metal's recrystallisation temperature, which means the grains reform into more stable structures.
Cooling working, grains become compressed/stretch when worked, leading to higher strength across the stretch direction yet increased brittleness and lower durability.

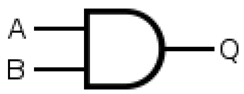
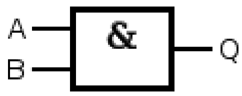
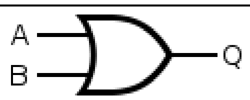
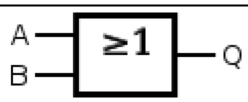
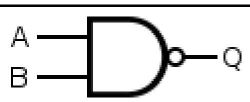
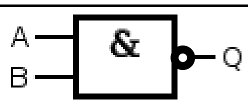
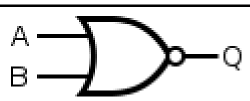
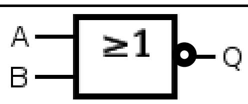
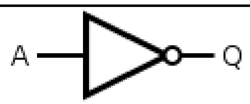
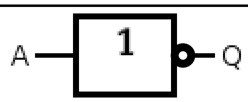
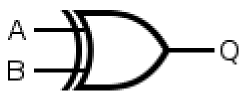
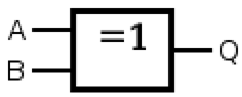
Secondary recrystallisation the metal is held above recrystallisation temperature means that the small equiaxed grains become enlarged.

Blacksmithing: repeated hammering by hand.
Drop forging: repeated hammering by machine.
Press forging: forged through a minimal amount of actions.
Upsetting: increases cross-sectional area of a piece.
Swaging: changes diameter of a tube.

Materials for use in bio-engineered products must be inert (not chemically react):
- **Stainless steel**: has a thin oxide layer protects from corrosion, hard, strong and used as surgical pins, bionic ears and artificial hearts.
- **Titanium**: excellent strength to weight ratio, high yield strength and corrosion resistance. Used in hip joints, bone screws, dental implants and pacemakers.
- **Polymers**: stable, inert and impact resistance. Used as prosthesis, cochlear implants.
- **Ceramics**: less ductile, compressive strength and high wear resistance. Used in dental implants and hip replacements.

Power: $P = VI = EI$

Integrated circuits are miniaturised circuits manufactured onto a single chip of silicon made up of many resistors, capacitors, transistors and diodes.

			Maths equation true if: a & b are logical inputs
AND Gate			$2 = a + b$
OR Gate			$1 \geq a + b$
NAND Gate			$2 > a + b$
NOR Gate			$0 = a + b$
NOT Gate:			$1 - a$
XOR Gate:			$1 = a + b$