Physics Chapter 5: More on materials

Inter-atomic bonds

Bond type	*Energy required to break the bond / kJmol^{-1}*	*Details*
Ionic	500 → 3000	Electron(s) moves from one atom to another
Covalent	100 → 500	Electron(s) are shared between materials.
Metallic	60 → 600	Outer electrons are released and flow in a 'sea.' A lattice structure makes many metals tough.

Intermolecular bonds

Two types:

- Van der Walls: "uncharged" atoms have a continually changing charge that averages out over time (very short period), so we call neutral. The actual small fluctuations cause weak bonds.
- Hydrogen

Typically these take 1 → 50 kJmol^{-1} to break.

Further to the three states of matter (to solid, liquid and gas) there are three others:

- Plasma: high temperature ionised gas.
- Nuclear matter: breakdown of nucleus.
- *Unknown*: breakdown of protons and neutrons.

Viewing at a microscopic level

The wavelength of light is $\approx 4 * 10^{-7}$ m.

The diameter of an atom is $\approx 10^{-10}$ m.
The diameter of a nucleus is $\approx 10^{-14}$ m.

Therefore light is not suitable for viewing atoms and nuclei as it is not reflected from such small surfaces.

X-ray diffraction (*covered in more detail in Chapter 6*) can be used. A wave of a given wavelength similar to that of the gap it needs to go through it is used. If the wavelength of the same size as the gap a good image can be made.

This process can be used in reverse to find the size of the gap between atoms.

In the same way light can be viewed as both a wave and a particle electrons too can be viewed as both a wave or as particles.

Structures

Materials can be categorised as follows:

Crystalline

- Regular geometric arrangement of particles.
- Repeating small cells.
- Cleave easily along planes of atoms.
- Large scale symmetry reflects microscopic arrangement.
- Long range repeated structure (throughout entire sample).

Polycrystalline

- Individual crystals or grains arranged in a hap-hazard manner.
- Most metals are polycrystalline materials.
- A repeated pattern within a crystal or grain.

Amorphous

- Little or no long range order.
- No predictable arrangement of atoms and molecules.
- Glass and soot are examples of amorphous materials.

Semi crystalline

- Some crystalline regions in an amorphous structure.
- Polymers are examples of semi crystalline materials.

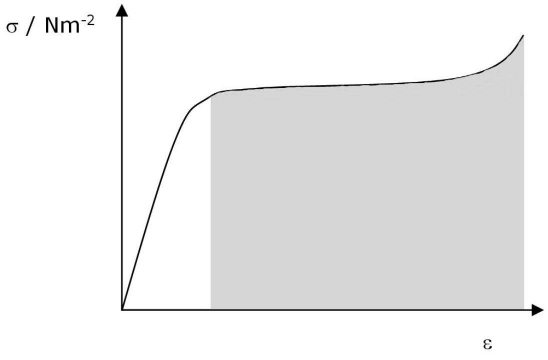
Materials can also be grouped into various groups including Ceramic and metallic structures.

Ceramics

- Covalently or ionically bonded oxides.
- Directional bonds, which makes the materials brittle.

Metallic Structures

- Non-directional, the packing of atoms can be modelled by spheres in three ways:
    1. Hexagonal close-packed.
        - Layers *a*, *b*, *a*, *b*, *a*, *b*….
        - Magnesium and Calcium are examples.
    2. Cubic close packed or face centred cube.
        - Layers *a*, *b*, *c*, *a*, *b*, *c*….
        - Copper, Aluminium, Silver and Lead are examples.
    3. Body centred cube.
        - Iron (at room temperature) and Sodium are examples.
        - At temperatures of 800°C+ Iron will become a face centred cube.
- This makes metals tough.

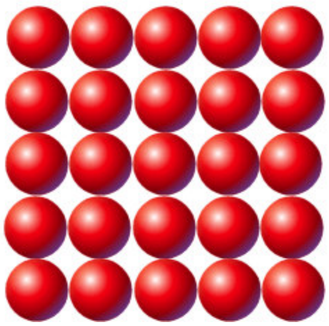


← A tough material has a large area under the graph, between the yield point and the ultimate tensile strength point (represented by shaded region on the graph) on a stress-strain plot. Brittle is the opposite of tough and so more brittle materials will have a smaller area under the graph. Tough materials are ductile and do not shatter like brittle materials.

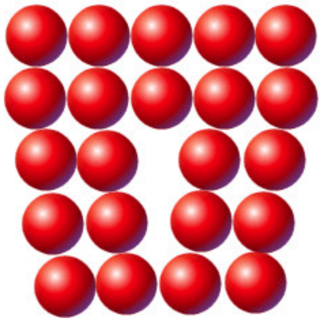
Dislocations

A macroscopic property of metals, toughness, ductility and malleability can be explained using their microscopic structure.

- To model the microscopic movement of atoms within a metal as planes sliding over each other overestimates the toughness of a metal.
- A much better model is dislocations. Dislocations in metals are caused by vacancies (missing atoms) or interstitial atoms (atoms out of place).
- Dislocations occur within individual grains, which make up crystals within a polycrystalline structure.



Perfect Crystalline structure



Missing atoms cause dislocations

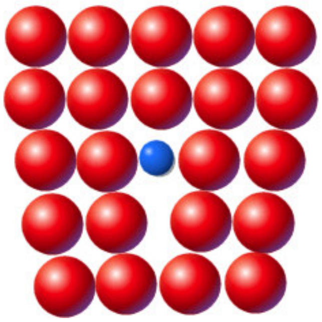
- Dislocations in a metal make it ductile.
- Metals with small grains will not deform as readily as those with larger grains.

Controlling metal properties

- Grain size can be controlled by heat treatment.
- <u>Work hardening, or "cold working"</u>
    - Metal is hammered, beaten and bent to form more dislocations.
    - This makes the material harder, stiffer and more brittle. The dislocations become entangled, making the metal brittle. This means cracks can propagate more easily.
    - Work hardening increases the Young Modulus of a material.
- <u>Annealing</u>
    - The metal is heated until it is red hot and cooled slowly.
    - Grains grow larger making the material softer, more ductile and malleable.
- <u>Tempering</u>
    - The metal is heated until it is red hot and then cooled very quickly.
    - This is called "quenching," and is usually done by submerging the hot metal in cold water.
    - Small grains are formed, which makes the metal hard and brittle.

Alloys and Impurities

- In an alloy atoms "pin" the dislocation making it harder the slip, and so the metal stronger.



Missing atoms cause dislocations

- In metals stretching pulls bonds apart. Elastic extensibility ~0.1%.
- In polythene stretching rotates the bonds. Elastic extensibility ~1%.

Colours and reflected light

- Electrons orbit in allowed energy levels.
- A change in the energy level of an electron moves the electron nearer to or further away from the nucleus of the atom.
- Energy inputted into the atom is absorbed by the electrons. These, having a higher energy level move further away from the nucleus of the atom.
- This can result in ionisation where the atom looses the electron and becomes positively charged.
- This can also result in (for example) metals giving off coloured light as the electron drops down the energy levels.
- Sodium, *Na* gives a yellow/orange light.
- The drops in energy levels are discrete and unique amounts.
- When light is reflected the energy is reflected immediately. This is because electrons cannot sustain high energy levels.
- This change in *E*, energy gives rise to the following equation (where *f* is the frequency and *h* the wavelength):

$$E = hf$$

Electron Microscopes

Given our understanding of the wavelength of light ($\lambda \approx 10^{-7} \rightarrow 10^{-11}$ m) and the size of an atom (Mass of proton $\approx 1.67*10^{-27}$ kg = 1 amu, mass of electron $\approx 10^{-30}$ kg = 1/1820 amu) it is not possible to see an atom in the same way that we view objects by the reflection of light (meaning we do not "see" the object, only a representation of it).

- Negatively charged particles are (comparatively) easy to accelerate and focus.
- Electrons are used instead of electromagnetic waves.
- The electron has a wavelength associated with it.

$$\lambda = \frac{\text{Planck constant } (\sim 6.6 * 10^{-34}),\ h}{\text{Momentum } (mv),\ p}$$

(See "Electron Microscopes" on the *Advancing Physics AS* CD-ROM)

- An electron gun creates a thermionic emission. Supplying heat energy causes ionic emissions from atoms, in a similar manner to evaporation. A metal cathode is used as the electrons are released easily from metallic materials.
- There are two ways to control the direction of this electron stream, either a magnetic field or electric plates.

There are various types of electron microscope:

- <u>Scanning Electron Microscope:</u>
    - ~*100,000 magnification.
    - 3D images are created by scanning across the surface and those reflected and emitted are recorded.
    - Each electron reflection or emission creates a pixel in an image.

  - Some materials require preparation for this method, which can take the form of a metallic coating.
- Transmission Electron Microscope:
  - ~*1,000,000 magnification.
  - Electrons pass through the specimen, and are recorded on a screen. The pattern created a 2D image.
  - This technique samples ~100 atoms.
- Scanning Tunnelling Electron Microscope:
  - Quantum tunnelling energy (energy required for an electron to escape an atom) is measured.
  - The tip is held close to the surface and a potential difference applied.
  - As the current increases the distance decreases. Generates 3D images.
- Atomic Force Microscope:
  - Sharp tip scans the surface following like the relief on a map.
  - Repulsion between electrons on the surface and on the probe.
  - Force applied is constant as the tip moves across the sample.

Polarisation

The concept can be analysed by a letter box and letter. The orientation of the polarised filter and the light must be the same for the light to pass through. Glare from water and shiny surfaces is polarised. Sunglasses can reduce this glare by using polarised filters.

Long chain molecules in transparent plastics (for example Perspex and Polythene) can rotate the plane of polarisation of the light. If two polaroids (polarised filters) are arranged with perpendicular polarisation planes the intensity of the light is reduced. When the polaroids are parallel the intensity is increased.

When passing through a layer of plastic the polarisation of the plastic causes some rotation of the plane of the transmitted light (varies for different plastics). Controlling factors:

- λ, the wavelength of the light.
- Strain, caused by an applied photo elastic stress in the sample.

As the wavelength effects polarisation it may be that, for example, only the red light is at the same polarisation as the second filter so only red light will be transmitted (all other wavelengths are blocked).

$$\text{Fracture energy} = \frac{\text{Total energy used to fracture (UTS)}}{\text{Specimen cross-section area}}$$

Fracture energy demonstrates toughness.

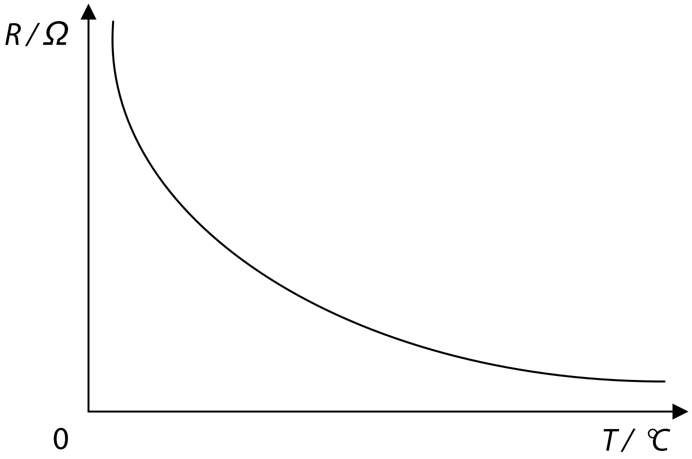
$$\text{Tensile strength} = \frac{\text{Breaking force}}{\text{Specimen cross-section area}}$$

Tensile strength demonstrates strength.

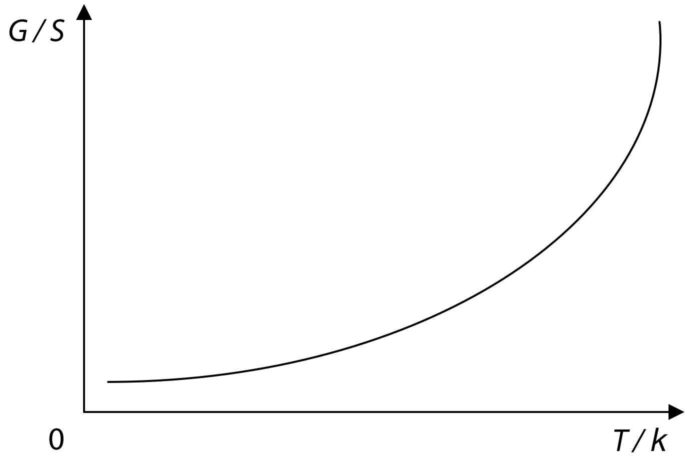
Semiconductors

Resistance is related to temperature. Temperature is generally measured in Kelvin, the increments of °C are the same as those in Kelvin, but the scale starts at “absolute zero,” where 0k = -273°C, a temperature which it is impossible to achieve. Kelvin is referred to as a “thermodynamic” temperature scale.

This graph shows the resistance of a thermistor bead:



This graph shows the conductance of a thermistor bead:



These graphs are called calibration curves, where the resistance of the component (here, the thermistor) is plotted against another physical quantity. Using versions of this graph with values when we know the resistance of a component we could determine the temperature.

If an experiment were performed to create a calibration curve it is likely results would be scattered about a curve, and a smooth curve drawn between them. If generally the results were very close to this line the experiment could be described as precise.