A Level Physics Online

# OCR B Physics – H557

## Module 3: Physics in Action

| You should be able to demonstrate and show your understanding of: | Progress and understanding: 1 | 2 | 3 | 4 |
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| **3.2 Mechanical Properties of Materials** | | | | |
| Stiff: Resists deformation under an applied force, difficult to stretch/bend e.g. steel, ceramics | | | | |
| Strong: Resists breaking under an applied force e.g. steel | | | | |
| Tough: Resistance to propagation of cracks, does not snap cleanly when broken, absorbs a lot of energy before permanently deforming e.g. leather | | | | |
| Brittle: Snaps cleanly when broken, undergoes little/no plastic deformation before fracture e.g. glass/bones | | | | |
| Ductile: Can be easily drawn into a wire e.g. copper/lead. Metals are ductile as they have non-directional metallic bonds that allow ions to slide past one another | | | | |
| Hard: Difficult to dent e.g. many ceramics<br>Difficult to scratch e.g. diamond | | | | |
| Hooke's Law: For small extensions, applied force is proportional to extension, $F=kx$. The constant of proportionality, $k$ (units: $Nm^{-1}$), is the spring constant – it is a measure of the stiffness of a specimen. Large $k$ means the specimen is stiffer, more difficult to stretch | | | | |
| Stiffness depends on the type of material, the length, and the cross-sectional area. A short, thick wire is stiffer than a long, thin wire. All materials for small extensions/compressions show elastic behaviour (return to their original state after the applied force is removed) | | | | |
| <u>F-x Diagrams:</u><br><br><u>Elastic region:</u> Linear, Hooke's Law applies, gradient of this region is the spring constant. A steeper gradient means the specimen is stiffer, extends less for a greater applied force<br><u>Elastic limit:</u> Maximum stress at which an object returns to its original shape after the applied force is removed<br><u>Plastic region:</u> non-linear region, specimen does not return to original shape | | | | |

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| Fracture point: Where the graph ends the specimen breaks<br>Limit of proportionality: Where the material stops obeying Hooke's Law. If you need to extrapolate from a linear F-x graph, you are assuming the material obeys Hooke's Law | | | | |
| For the gradient of the linear region, if the length of the specimen doubles, the gradient halves (k halves). If the radius of the specimen doubles, the gradient quadruples (k quadruples) because the area has an $r^2$ term | | | | |
| Elastic deformation: The specimen returns to its original shape after deformation | | | | |
| Plastic deformation: The specimen undergoes permanent deformation, doesn't return to its original shape after the applied force is removed | | | | |
| Energy is the area on an F-x graph. When an elastic band is pulled back, work is done so energy is stored as elastic potential energy. The stored energy transfers to kinetic energy when released. W=Fx cannot be used to calculate the energy stored because F is not constant, it steadily increases the longer the elastic band is stretched. So, $E = \frac{1}{2}Fx = \frac{1}{2}kx^2$ | | | | |
| Stress, σ (units: $Nm^{-2}$ or Pa): Force per unit area. $\sigma = \frac{F}{A}$ | | | | |
| Strain, ε (no units): Change of length per unit length (ratio of extension to length) $\varepsilon = \frac{x}{L}$<br><br>[Note: Always convert % strain to a decimal before using!] | | | | |
| Young modulus, E (units: $Nm^{-2}$ or Pa): Ratio of stress to strain $E = \frac{\sigma}{\varepsilon} = \frac{FL}{Ax}$ | | | | |
| Stress-Strain Graphs: Brittle material is linear for all of its length. Shows little plastic deformation. The linearity shows stress and strain are proportional. The gradient is the Young modulus. High E is stiff, low E is flexible | | | | |
| Determine the Young modulus for copper, steel or other wire | | | | |
| Physical properties: Conductivity, resistivity, density, Young modulus, toughness, strength (Ductility not included as it is not a property when in use) | | | | |
| Non-physical properties: cost, abundance, environmental impact | | | | |
| Polymers: Natural – Leather, cotton, silk<br>S Synthetic - Polythene, nylon<br>G Glassy – Similar properties to glass, used as a replacement in s<br>pec spectacle lenses. Brittle<br>S Semi crystalline – Can sustain considerable deformation, can ab<br>so rb absorb more energy before breaking | | | | |

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| Rayleigh's Oil Drop Experiment:<br><br>1) Measure diameter, d, of oil drop<br>2) Find radius, r of oil drop<br>3) Place oil drop on water<br>4) Measure diameter, D, and hence radius, R, of oil patch<br>5) Volume of drop = volume of patch (assuming no oil lost)<br>$\frac{4}{3}\pi r^3 = \pi R^2 h$ where h is the thickness of the drop<br>6) We assume the drop has spread to its maximum extent on the water so h is the diameter of one oil molecule<br>$h = \frac{4r^3}{3R^2}$ | | | | |
| Finding Order of Magnitude of an Atom:<br><br>1) Mass = Density x volume (using ρ given in question and V = $1m^3$). To find mass of $1m^3$<br>2) $n_{atoms} = \frac{total\ mass\ of\ 1m^3}{mass\ of\ one\ atom}$<br>3) $n_{atoms}$ has a volume of $1m^3$ so one atom has a volume of $1/n_{atoms}$<br>4) $\sqrt[3]{V_{atom}} = l\ of\ side\ of\ atom\ (estimate\ for\ d)$<br>5) Order of magnitude is standard form of final answer<br>(This is all assuming atoms are cubes) | | | | |
| To measure individual atoms, atomic force microscopes (AFMs) or scanning tunnelling microscopes (STMs) are used. To measure larger structures, scanning electron microscopes (SEMs) are used | | | | |
| AFMs:<br><br>1) A fine point is mounted on a cantilever arm<br>2) The point moves over a sample's surface<br>3) Forces between the surface and tip make the arm bend<br>4) A laser beam from the laser emitter reflects off the arm and detects the bending<br>5) The specimen can be moved under the tip (using an actuator) to keep the force on the tip constant<br>6) The vertical movement of the specimen as it is scanned corresponds to the surface profile<br>Advantage: Does not require a specially prepared surface. Doesn't need to conduct electricity or a vacuum so is suitable for biological work | | | | |
| SEMs:<br><br>1) Fine beam of electrons scans a tiny specimen (coated in metal)<br>2) From the place where the beam contacts the specimen, the electrons are scattered or emitted and picked up by the detector<br>3) The signal from the detector controls the brightness of the dot on the monitor in time with the beam scanning the specimen<br>4) A picture of the specimen is built up point by point on the monitor | | | | |

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| $$Magnification = \frac{scan\ line\ spacing\ on\ monitor}{scan\ line\ spacing\ on\ specimen}$$ Advantage: Good depth of focus, shows relief very well<br>Disadvantage: Specimen must be in a vacuum and coated with metal so isn't suitable for biological work | | | | |
| Vacancy: Where an atom is removed from the lattice | | | | |
| Interstitial: A small atom that fits within the metal structure | | | | |
| Dislocation: An atom is removed; the remaining atoms slip into an irregular arrangement | | | | |
| Grain boundary: The line where the angle of alignment of atoms changes direction | | | | |
| Crystalline: Atoms arranged in a uniform, regular pattern over many times the spacing between the atoms. A result of controlled cooling e.g. high purity silicon in microchips, metals | | | | |
| Amorphous: A random, disordered arrangement of atoms caused by rapid cooling. Atoms don't have time to arrange themselves. No dislocations e.g. glass, concrete | | | | |
| Polycrystalline: Consists of a number of grains all arranged differently; but with an ordered regular atom structure within individual grains. Produces a patchwork of crystals/grains e.g. brass | | | | |
| Strength: Has a large breaking stress (glass has a similar breaking stress to steel, but steel is much tougher). It is affected by internal structures cracks, flaws, impurities | | | | |
| Alloying: Different sized atoms pin the dislocation, so slip between atoms is limited. Makes it harder and generally less ductile | | | | |
| Metals:<br><br>-Each cation is attracted to each electron. The electrons are free to move between ions. Ionic lattice is strong. Bonds are non directional.<br>-Stiff due to electrostatic forces of attraction between electrons and cations<br>-Ductile and malleable due to mobile dislocation moving through the structure<br>-Non directional bonds | | | | |
| Fracture in Metals:<br><br>1) Metals contain mobile dislocations<br>2) The movement of dislocations stops cracks propagating<br>3) Crack becomes broader and more blunt<br>4) Force can be spread over a larger cross-sectional area, so stress is reduced | | | | |

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| Crack propagation: If a material is cracked, stress is concentrated around the crack. This leads to cracks propagating through the specimen until it fractures.<br><br>1) At tip of the crack, two neighbouring atoms are pulled apart<br>2) Work is done in breaking the bond between two atoms. The energy required to do this is the fracture energy<br>3) Moves on to next pair of atoms like a zip<br>Tough – Cracks can't propagate easily<br>Brittle – Cracks propagate easily, fragments are small, sharp and jagged | | | | |
| Cross Links: Chemical bonds that link together chains of some polymers. They lock polymer molecules into a regular arrangement so they can't move without cross links breaking, makes material harder, stronger and less flexible. Melting point is increased. | | | | |
| Vulcanisation:<br><br>1) Natural rubber is a runny, white liquid with limited uses<br>2) Heated with sulphur<br>3) Sulphur atoms form crosslinks between the chains<br>4) More sulphur added, makes rubber stiffer (e.g. for tyres) | | | | |
| Polymers:<br><br>-Weak forces between chains<br>-Chains slide over each other so they are flexible<br>-Bonds between atoms are strong, they don't break easily under an applied force so they are strong<br>-Polymers are flexible as they have rotational bonds<br>-To increase stiffness, add cross links between chains | | | | |
| Elastic and Plastic Extensibility: Rubber has an elastic extensibility of more than 100%, this is because when stretched the bonds rotate, the chains are extended. When the applied force is removed, it contracts back to its' original shape<br>Polythene has a plastic extensibility of more than 100%, this is because it is semi crystalline so when stretched plastically, the chains line up and slip past each other. So, for a greater force it is more crystalline, after a certain point it necks (plastically deforms) and extends greatly. This is because the forces between the chains are broken | | | | |