

A-Level Physics – Materials

A-Level Physics (Edexcel/AQA/OCR) · Total marks: 44 · Answers on the last page

This worksheet covers density, Hooke's law, the Young modulus and stress–strain behaviour of materials. A calculator is required; use $g = 9.81 \text{ m s}^{-2}$ where needed. Allow about 40 minutes.

Section A – Density and Hooke's law (skills)

1. A rectangular block has mass 0.540 kg and volume 200 cm^3 .
Calculate the density of the block, in kg m^{-3} , and suggest which common material it might be made from. [2]
2. (a) State Hooke's law.
(b) A spring extends by 2.4 cm when a force of 6.0 N is applied. Calculate the spring constant k . [3]
3. For the spring in Question 2, calculate the elastic potential energy stored when it is extended by 2.4 cm . [2]
4. Define, giving the SI unit of each:
(a) tensile stress
(b) tensile strain [3]

Section B – Young modulus (exam-style) (Calculator allowed)

5. A wire of original length $L_0 = 2.500 \text{ m}$ and diameter 0.56 mm is loaded with a force of 45.0 N , producing an extension of 2.18 mm .
(a) Calculate the cross-sectional area of the wire.
(b) Calculate the stress in the wire.
(c) Calculate the strain in the wire.
(d) Calculate the Young modulus of the wire material. [8]
6. For the experiment in Question 5 the measurements have uncertainties $\Delta F = 0.5 \text{ N}$, $\Delta d = 0.01 \text{ mm}$, $\Delta L_0 = 1 \text{ mm}$ and $\Delta(\Delta L) = 0.05 \text{ mm}$.
Calculate the percentage uncertainty in the Young modulus. [5]
7. Describe the shape of a stress–strain graph for a ductile metal wire loaded to fracture, identifying on it: the limit of proportionality, the elastic limit, the yield point, the ultimate tensile stress and the fracture point. [4]
8. For the wire in Question 5:
(a) Calculate the elastic strain energy stored per unit volume when the force is 45.0 N .
(b) Hence calculate the total elastic potential energy stored in the wire, and confirm your answer using $E_p = \frac{1}{2}F\Delta L$. [4]

Section C – Extended and challenge

9. Two springs, of spring constants $k_1 = 150 \text{ N m}^{-1}$ and $k_2 = 300 \text{ N m}^{-1}$, are combined. Calculate the effective spring constant when they are connected:

- (a) in series
- (b) in parallel [4]

10. The wire in Question 5 breaks when the load reaches 65.0 N. Calculate the breaking stress (ultimate tensile stress) of the wire material. [3]
11. The Young modulus found in Question 5 was 2.10×10^{11} Pa. A data book gives the Young modulus of steel as approximately 2.0×10^{11} Pa.
- (a) Suggest, with a reason, whether the wire is likely to be made of steel.
 - (b) Calculate the percentage difference between the experimental value and the data-book value. [3]
12. Explain the difference between elastic and plastic deformation of a material, and describe how each would appear if the wire were unloaded partway through the stress–strain test. [3]

Answers

Check your working against these. If an answer does not match, try the question again before looking for the method.

- $\rho = \frac{m}{V} = \frac{0.540}{2.0 \times 10^{-4}} = 2700 \text{ kg m}^{-3}$ – consistent with aluminium.
- (a) The extension of a spring is directly proportional to the applied force, provided the limit of proportionality is not exceeded ($F = kx$).
(b) $k = \frac{F}{x} = \frac{6.0}{0.024} = 250 \text{ N m}^{-1}$
- $E_p = \frac{1}{2}kx^2 = \frac{1}{2}(250)(0.024)^2 = 0.072 \text{ J}$
- (a) Stress = $\frac{F}{A}$, the force per unit cross-sectional area; unit Pa (or N m^{-2}).
(b) Strain = $\frac{\Delta L}{L_0}$, the extension per unit original length; strain has no unit (it is a ratio).
- (a) $A = \pi(d/2)^2 = 2.46 \times 10^{-7} \text{ m}^2$
(b) stress = $\frac{F}{A} = 1.83 \times 10^8 \text{ Pa}$
(c) strain = $\frac{\Delta L}{L_0} = \frac{2.18 \times 10^{-3}}{2.500} = 8.72 \times 10^{-4}$
(d) $E = \frac{\text{stress}}{\text{strain}} = 2.10 \times 10^{11} \text{ Pa}$
- $\frac{\Delta E}{E} = \frac{\Delta F}{F} + 2\frac{\Delta d}{d} + \frac{\Delta L_0}{L_0} + \frac{\Delta(\Delta L)}{\Delta L}$
 $= 1.11\% + 3.57\% + 0.04\% + 2.29\% = 7.0\%$ (to 2 s.f.)
- The graph starts as a straight line through the origin (stress $\propto$ strain) up to the limit of proportionality; shortly after this is the elastic limit, beyond which deformation becomes permanent. The curve then flattens sharply at the yield point, where strain increases with little extra stress (plastic deformation begins). Stress rises to a maximum – the ultimate tensile stress – then the curve falls as the wire narrows (necks) until it breaks at the fracture point.
- (a) energy density = $\frac{1}{2} \times \text{stress} \times \text{strain} = 7.97 \times 10^4 \text{ J m}^{-3}$
(b) volume = $AL_0 = 6.16 \times 10^{-7} \text{ m}^3$, so $E_p = 7.97 \times 10^4 \times 6.16 \times 10^{-7} = 0.049 \text{ J}$; check: $\frac{1}{2}F\Delta L = \frac{1}{2}(45.0)(2.18 \times 10^{-3}) = 0.049 \text{ J}$ – consistent.
- (a) $\frac{1}{k} = \frac{1}{k_1} + \frac{1}{k_2} \Rightarrow k = 100 \text{ N m}^{-1}$
(b) $k = k_1 + k_2 = 450 \text{ N m}^{-1}$
- breaking stress = $\frac{F_{\text{max}}}{A} = \frac{65.0}{2.46 \times 10^{-7}} = 2.64 \times 10^8 \text{ Pa}$ (264 MPa)
- (a) Yes – the experimental value is very close to the data-book value for steel, so the wire is likely to be steel (small differences could be due to the exact alloy or work-hardening).
(b) percentage difference = $\frac{|2.10 - 2.00|}{2.00} \times 100\% = 5\%$
- Elastic deformation is reversible: when the load is removed the material returns exactly along the same stress–strain line back to its original length, storing and then releasing the strain energy. Plastic deformation is permanent: beyond the elastic limit, unloading follows a line parallel to the original straight-line region but does not return to zero strain – the wire is left permanently longer, with the energy difference between loading and unloading dissipated as heat.

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