OCR A A Level Physics | Material behaviour solutions

Matching solutions and teaching prompts for the class review | 44 marks

Specification points covered

- 3.4.2(c) Define and use stress, strain and ultimate tensile strength.
- 3.4.2(d)(ii) Use techniques and procedures to determine the Young modulus for a metal.
- 3.4.2(e) Interpret stress-strain graphs for typical ductile, brittle and polymeric materials.
- 3.4.2(f) Describe elastic and plastic deformation of materials.

Class review
Keep three comparisons separate: initial gradient gives stiffness, maximum stress gives UTS, and the strain or plastic region before fracture describes deformation behaviour.

1. Precision language [4 marks]

Use definitions that would be accepted in an examination answer.

(a) Define tensile stress. **[1 mark]**

(b) Define tensile strain. **[1 mark]**

(c) Define ultimate tensile strength (UTS). **[1 mark]**

(d) Explain why the word brittle does not necessarily mean weak. **[1 mark]**

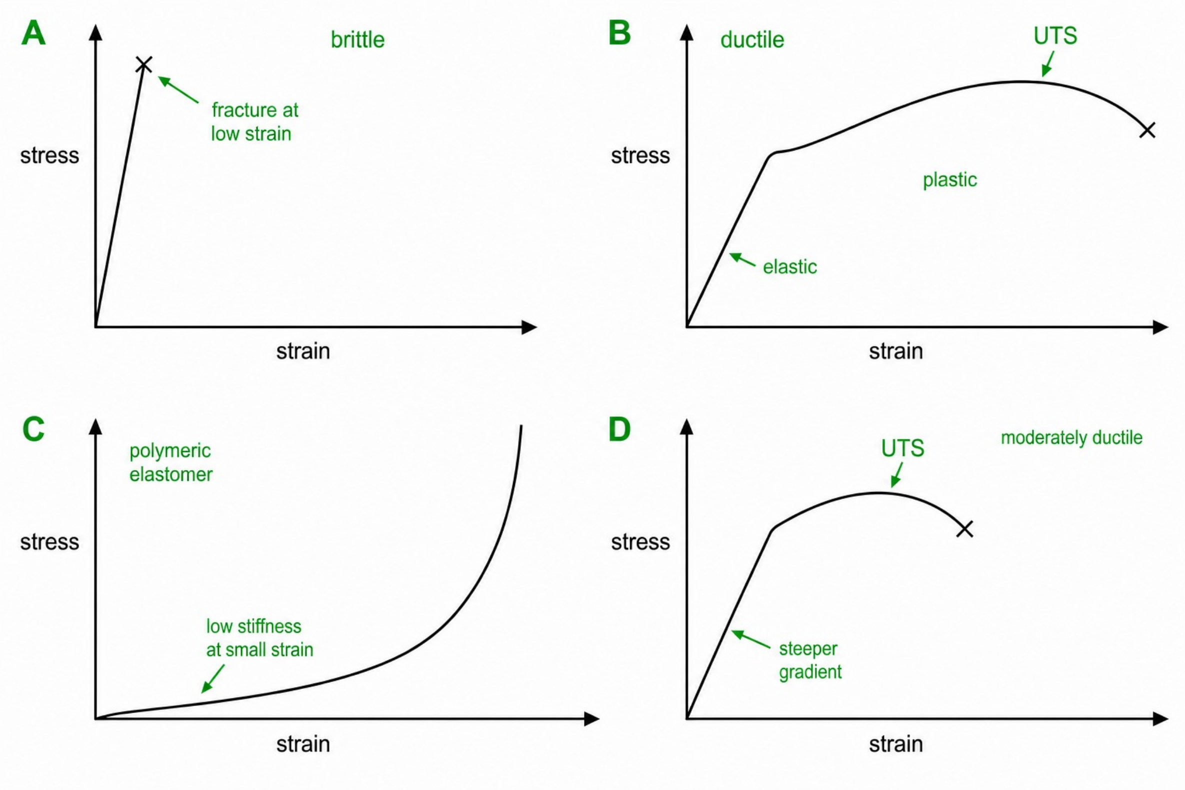
Answer / mark points: (a) Tensile stress is tensile force divided by cross-sectional area: $\sigma = F/A$. [1]
(b) Tensile strain is extension divided by original length: $\varepsilon = \Delta L/L$. It is dimensionless. [1]
(c) UTS is the maximum tensile stress that a material can withstand. [1]
(d) Brittle describes fracture after little or no plastic deformation; a brittle material can still withstand a large stress before fracture. [1]

Teacher prompt / common error: Stiffness, strength and brittleness are different ideas. A steep graph concerns stiffness; its maximum stress concerns strength; the strain/plastic region before fracture concerns brittleness or ductility.

Scenario: the Aster automated warehouse robot
Use the green annotations to model how a graph feature supports a conclusion about material behaviour.

2. Reading stress-strain behaviour [8 marks]

The four panels use the same stress and strain scales. Crosses show fracture points. Curve C is shown only over its working range.



(a) Identify the brittle curve, the most ductile curve and the polymeric-elastomer curve. **[3 marks]**

(b) State one feature of curve A that shows brittle behaviour. **[1 mark]**

(c) Which curve has the greatest initial gradient? State the material property represented by this gradient. **[1 mark]**

(d) Mark the UTS on curve B with the letter U. **[1 mark]**

(e) Explain how curve B shows that the specimen is ductile rather than brittle. **[2 marks]**

Answer / mark points: (a) Brittle: A. Most ductile: B. Polymeric elastomer: C. [3]

(b) A fractures at very small strain and has no appreciable plastic region. [1]

(c) A has the greatest initial gradient, so it has the greatest Young modulus / stiffness on the stated common scales. [1]

(d) U is placed at the maximum stress — the peak of curve B — not at the fracture cross. [1]

(e) B undergoes a large strain after its elastic region and before fracture [1], so it shows substantial plastic deformation before breaking. [1]

Teacher prompt / common error: A quantity does not 'become ductile'. The specimen undergoes plastic deformation; ductility is the material behaviour inferred from the large plastic strain before fracture.

3. Do not confuse stiffness with strength [5 marks]

A materials laboratory reports the approximate tensile properties below. Treat the values as results for the tested specimens.

Material	Young modulus / GPa	UTS / MPa	Strain at fracture
Borosilicate glass	70	45	0.00064
Steel alloy	200	550	0.20
Aluminium alloy	69	310	0.12
Polymeric elastomer	0.008	15	4.5

(a) Identify the stiffest material. **[1 mark]**

(b) Identify the material with the greatest tensile strength. **[1 mark]**

(c) Identify the material that reaches the greatest strain before fracture. **[1 mark]**

(d) A pupil says, 'The glass is strongest because its stress-strain graph begins with a steep line.' Explain the error using the table. **[2 marks]**

Answer / mark points: (a) Steel alloy; it has the largest Young modulus, 200 GPa. [1]
(b) Steel alloy; it has the largest UTS, 550 MPa. [1]
(c) Polymeric elastomer; its fracture strain is 4.5. [1]
(d) Initial gradient measures Young modulus / stiffness, not strength. [1] The glass UTS is only 45 MPa, so it reaches a much lower maximum stress than the steel alloy. [1]

Teacher prompt / common error: Ask separately: 'How hard is it to strain?' gives stiffness; 'What maximum stress can it withstand?' gives tensile strength.

4. Elastic and plastic deformation [5 marks]

A ductile steel safety link is loaded first within its elastic region, and later beyond its elastic limit.

(a) Compare what happens to the link after the force is removed in the elastic case and in the plastic case. **[2 marks]**

(b) On a stress-strain graph, explain where an unloading line meets the strain axis when the link has undergone plastic deformation, and what that intercept represents. **[2 marks]**

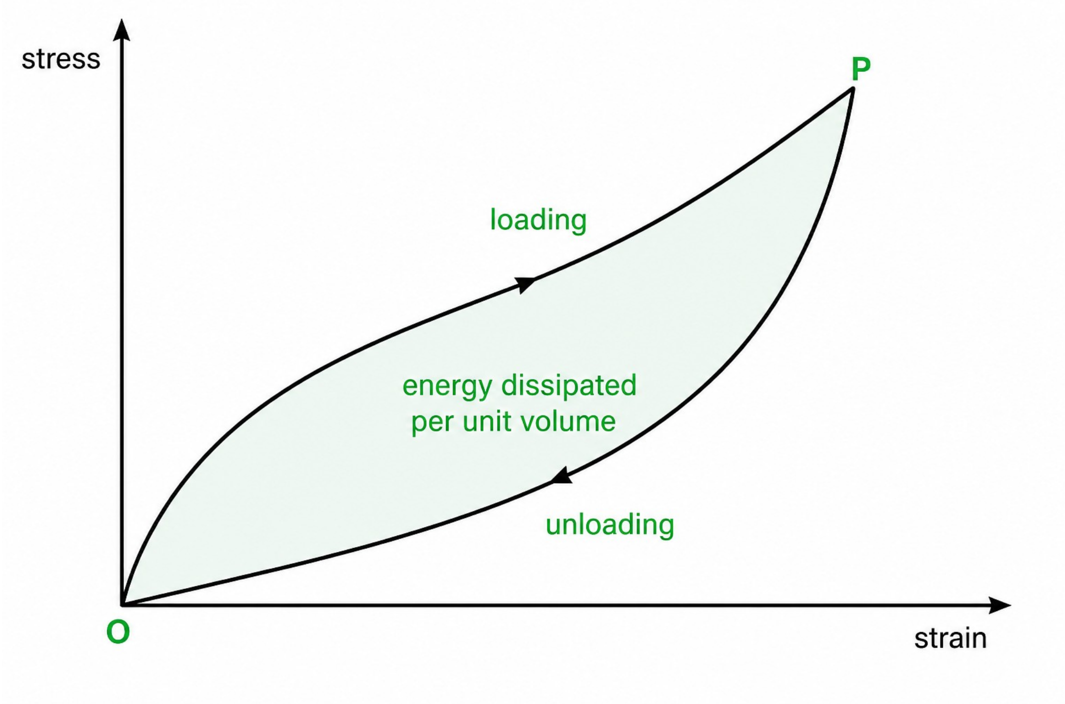
(c) Correct this sentence: 'The stress has plastically deformed.' **[1 mark]**

Answer / mark points: (a) After elastic deformation the link returns to its original dimensions when the force is removed. [1] After plastic deformation it retains a permanent change in length/shape. [1]
(b) The unloading line meets the strain axis at a non-zero strain. [1] This intercept is the permanent strain remaining when stress has returned to zero. [1]
(c) Accept, for example: 'The link/material has undergone plastic deformation, so a permanent strain remains.' [1]

Teacher prompt / common error: Stress is a quantity; the object or material deforms. Train pupils to say that stress decreases to zero while strain may remain non-zero.

5. A polymeric bumper under repeated loading [6 marks]

An elastomer bumper on the Aster warehouse robot is stretched from O to P and then allowed to return to O. The arrows show the direction of each path.



(a) Identify the loading path and the unloading path. **[2 marks]**

(b) State what the area between the two paths represents and give its SI unit. **[2 marks]**

(c) Explain why this behaviour helps the bumper reduce rebound after an impact. **[2 marks]**

Answer / mark points: (a) The upper O→P path is loading; the lower P→O path is unloading. [2]

(b) The enclosed area is the energy dissipated per unit volume in one loading-unloading cycle. [1] Its unit is J m^{-3}, equivalent to Pa. [1]

(c) Less energy is returned mechanically during unloading [1]; energy transferred to internal/thermal energy therefore reduces the rebound speed/height. [1]

Teacher prompt / common error: For a stress-strain graph, area is energy per unit volume, not energy in joules. Area under a force-extension graph would have unit joule.

6. Selecting materials for the Aster robot **[6 marks]**

Use curves A-D from Question 2. Select one curve for each component and justify each choice from the graph. A curve may be used once, more than once, or not at all.

(a) An optical inspection window is protected from impact but must be stiff and retain its dimensions during normal operation. **[2 marks]**

(b) A sacrificial catch link must deform substantially before fracture so that detached parts remain connected after an overload. **[2 marks]**

(c) A reusable impact pad must undergo a very large reversible strain and dissipate energy during each impact. **[2 marks]**

Answer / mark points: (a) Curve A: its steep initial gradient shows high stiffness / small strain for a given stress. [2] Accept D with a valid stiffness-and-toughness justification if the stated priorities are addressed.

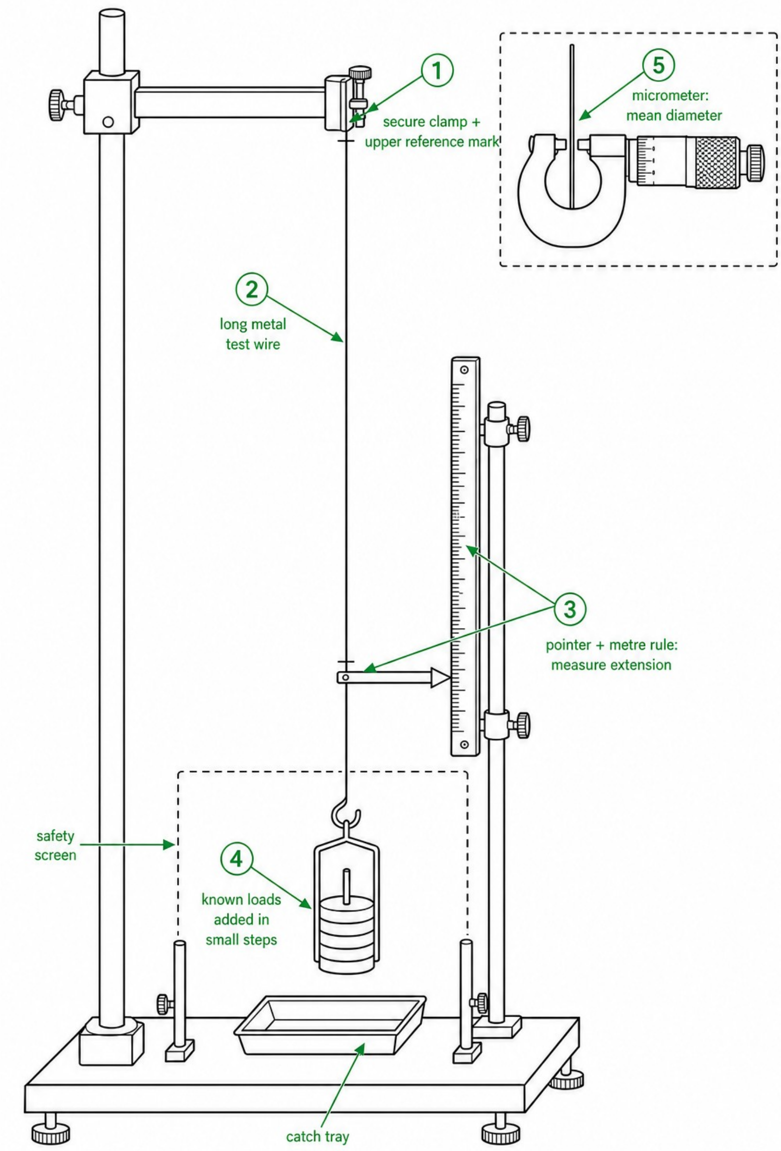
(b) Curve B: it has a long plastic region / large strain before fracture, so the link bends rather than failing suddenly. [2]

(c) Curve C together with the hysteresis behaviour in Question 5: it reaches very large strain and can return toward its original shape [1], while the loop shows energy dissipation. [1]

Teacher prompt / common error: Credit a selection only when its justification uses the required property. 'Strong' is not a substitute for stiff, ductile or energy-dissipating.

7. Determining Young modulus experimentally [6 marks]

A technician uses the direct tensile arrangement below to determine the Young modulus of a metal wire.



Answer / mark points: Level 3 (5-6): a logically sequenced, workable method with appropriate measurements, repeated diameter readings, controlled loading, graph analysis linked correctly to E, and relevant quality/safety detail.

Level 2 (3-4): a mostly workable method with some correct measurements or analysis, but one important link or quality detail is incomplete.

Level 1 (1-2): isolated relevant points with limited experimental or analytical detail. No credit for vague statements that do not connect measurements to E.

Indicative points: measure original length L between reference marks with a metre rule/tape; measure diameter d with a micrometer screw gauge at at least three positions, ideally in two perpendicular orientations, then calculate the mean and $A = \pi d^2/4$. Suitably precise vernier/digital callipers are acceptable for a thicker strip, but a micrometer is preferred for a thin wire.

Clamp a long wire securely; add known masses in small increments so $F = mg$; allow readings to settle and measure extension ΔL from the pointer/scale for each force; avoid parallax or use a travelling microscope/video system; repeat readings where practicable.

Keep the data within the straight-line proportional/elastic region. Plot F against ΔL and obtain a best-fit gradient $\Delta F/\Delta L$ using a large triangle, then $E = (L/A)(\Delta F/\Delta L)$. Equivalently, plot stress against strain and take its gradient.

Use a secure stand, eye protection/safety screen and a catch tray for falling masses or a snapping wire.

Teacher prompt / common error: The strongest answers say exactly where diameter is measured, calculate a mean before area, name both graph axes, and state how the gradient becomes Young modulus.

8. Diagnosing a weak practical method [4 marks]

A pupil takes one calliper reading of a thin wire to the nearest 0.1 mm, adds a single large load, continues after a permanent extension appears, then plots ΔL vertically against F horizontally and states that the gradient is E.

(a) Give four specific corrections to this method or analysis. **[4 marks]**

Answer / mark points: Any four, one mark each: use a micrometer screw gauge for a thin wire / justify sufficiently precise callipers for a thicker strip; measure at least three positions and preferably two perpendicular orientations; calculate a mean diameter; add several small known load increments; take repeated extension readings; stop before permanent deformation / remain in the proportional region; use a best-fit graph rather than one load; plot F against ΔL and use $E = (L/A) \times$ gradient; or, if plotting ΔL against F, use the reciprocal gradient in $E = L/(A \times \text{gradient})$. [4]

Teacher prompt / common error: A ΔL-against-F graph is not inherently invalid; the error is claiming that its gradient is E. Reward pupils who correct the relationship rather than merely swapping axes.

Review emphasis

Insist on evidence-led language: the specimen deforms; stress and strain are quantities; UTS is a maximum stress; and the area of a stress-strain loop is energy dissipated per unit volume.