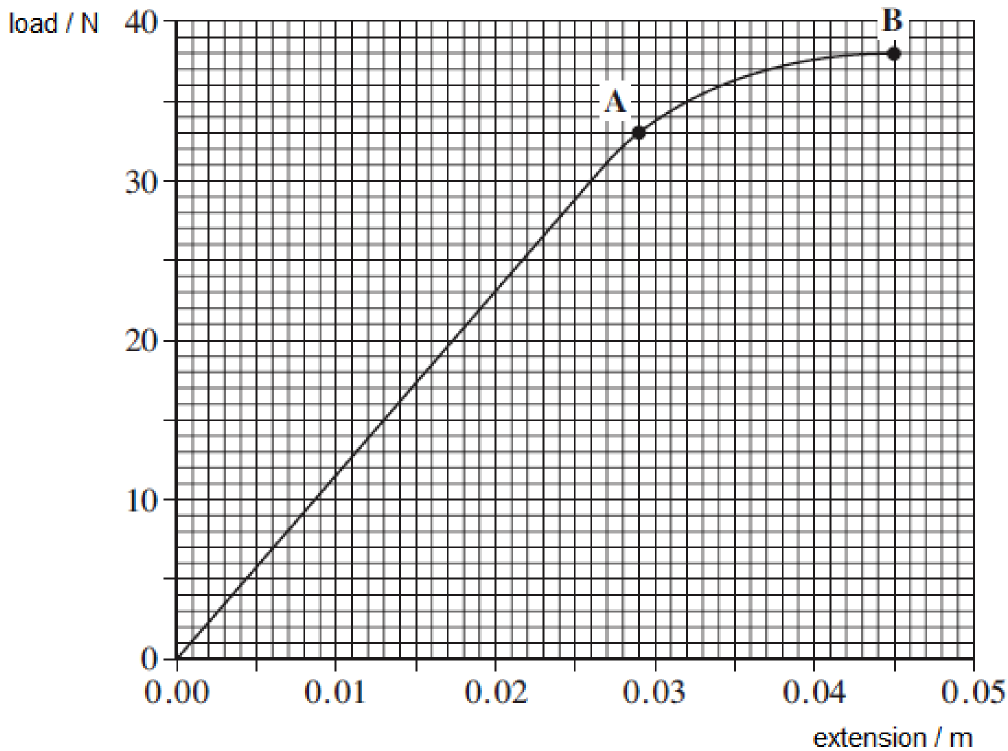
Q1. A manufacturer of springs tests the properties of a spring by measuring the load applied each time the extension is increased. The graph of load against extension is shown below.



(a) State Hooke's law.

....

....

....

(2)

(b) Calculate the spring constant, *k*, for the spring. State an appropriate unit.

spring constant .... unit ....

(3)

(c) Use the graph to find the work done in extending the spring up to point **B**.

work done .... J

(3)

(d) Beyond point **A** the spring undergoes *plastic deformation*.

Explain the meaning of the term plastic deformation.

....

....

(1)

(e) When the spring reaches an extension of 0.045 m, the load on it is gradually reduced to zero. On the graph above sketch how the extension of the spring will vary with load as the load is reduced to zero.

(2)

(f) Without further calculation, compare the total work done by the spring when the load is removed with the work that was done by the load in producing the extension of 0.045 m.

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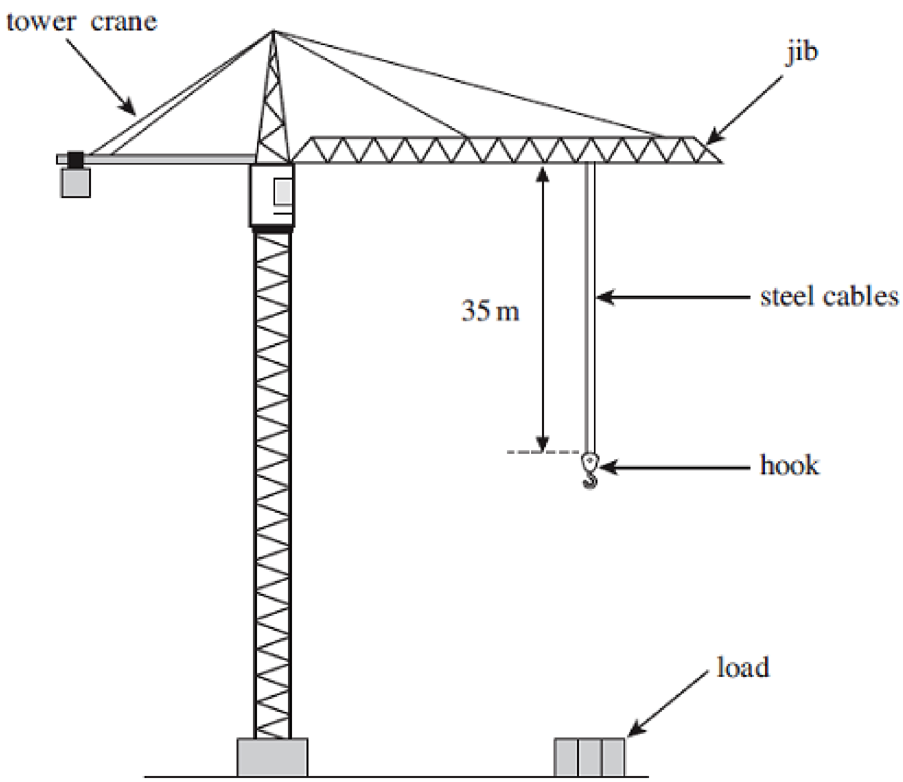
(1)
(Total 12 marks)

Q2. The diagram below shows a tower crane that has two identical steel cables. The length of each steel cable is 35 m from the jib to the hook.



(a) Each cable has a mass of 4.8 kg per metre. Calculate the weight of a 35 m length of one cable.

weight = ... N

(2)

(b) The cables would break if the crane attempted to lift a load of 1.5×10^6 N or more. Calculate the breaking stress of **one** cable.

cross-sectional area of each cable = 6.2×10^{-4} m^2

breaking stress = ... Pa

(2)

(c) When the crane supports a load **each** cable experiences a stress of 400 MPa. Each cable obeys Hooke's law. Ignore the weight of the cables.

Young modulus of steel = 2.1×10^{11} Pa

(i) Calculate the weight of the load.

weight = ... N

(2)

(ii) The unstretched length of each cable is 35 m.

Calculate the extension of each cable when supporting the load.

extension = ... m

(3)

(iii) Calculate the combined stiffness constant, *k*, for the **two** cables.

stiffness constant = ... Nm^{-1}

(2)

(iv) Calculate the total energy stored in both stretched cables.

energy stored = ... J

(2)

(Total 13 marks)

Q3. (a) Describe an experiment to accurately determine the spring constant *k* of a spring that is thought to reach its limit of proportionality when the load is about 20 N.

Include details of the necessary measurements and calculations and describe how you would reduce uncertainty in your measurements. A space is provided for a labelled diagram should you wish to include one.

The quality of your written communication will be assessed in this question.

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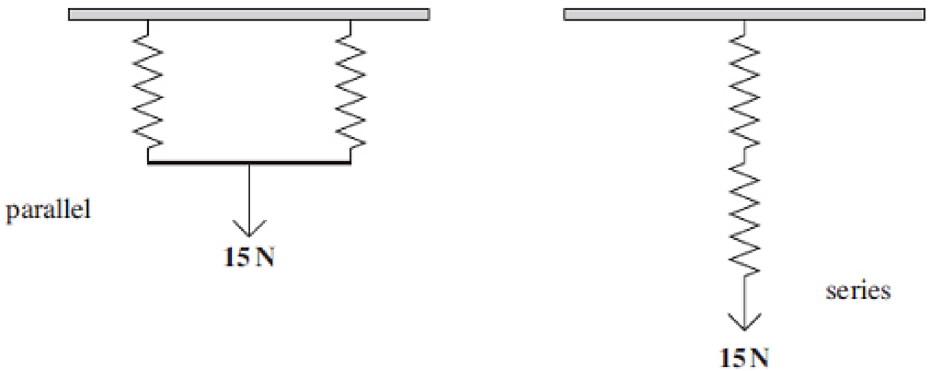
(6)

(b) Two identical springs, each having a spring constant of 85 Nm^{-1}, are shown arranged in parallel and series in the figure below.



A load of 15 N is attached to each arrangement.

(i) Calculate the extension for the parallel arrangement when the load is midway between the lower ends of the springs.

answer = ... m

(2)

(ii) Calculate the extension for the series arrangement.

answer = ... m

(2)

(iii) Calculate the energy stored in the parallel arrangement.

answer = ... J

(2)

(iv) Without further calculation, discuss whether the energy stored in the series arrangement is less, or greater, or the same as in the parallel arrangement.

....

....

....

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....

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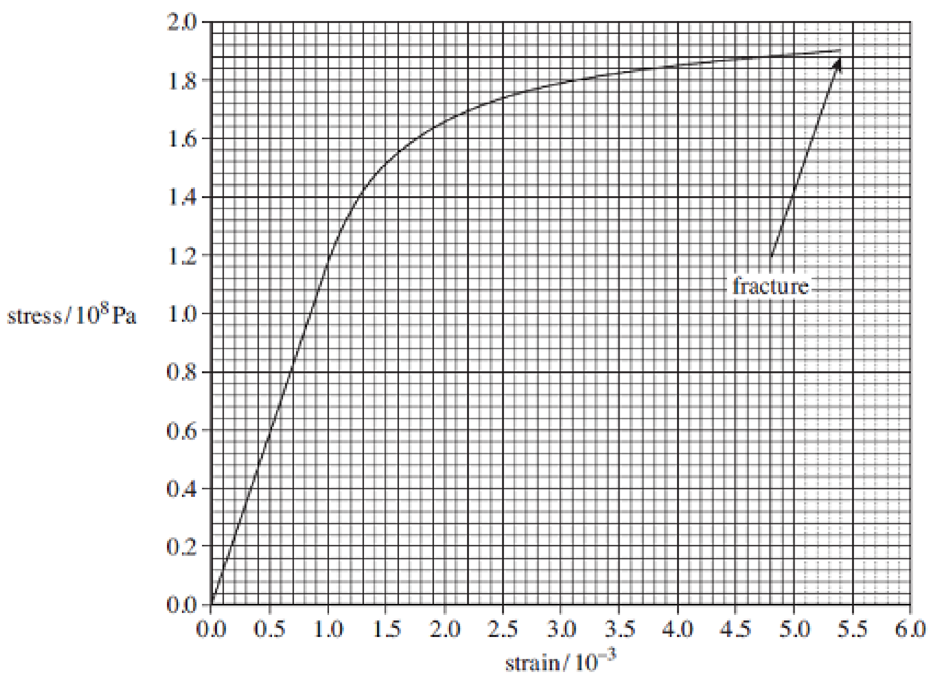
(3)
(Total 15 marks)

Q4. The figure below shows a stress-strain graph for a copper wire.



(a) Define tensile strain.

....

....

(1)

(b) State the breaking stress of this copper wire.

answer = ... Pa

(1)

(c) Mark on the figure above a point on the line where you consider plastic deformation may start.
Label this point **A**.

(1)

(d) Use the graph to calculate the Young modulus of copper. State an appropriate unit for your answer.

answer = ...

(3)

(e) The area under the line in a stress-strain graph represents the work done per unit volume to stretch the wire.

(i) Use the graph to find the work done per unit volume in stretching the wire to a strain of 3.0×10^{-3}.

answer = ...J m^{-3}

(2)

(ii) Calculate the work done to stretch a 0.015 kg sample of this wire to a strain of 3.0×10^{-3}.

The density of copper = 8960 kg m^{-3}.

answer = ...J

(2)

(f) A certain material has a Young modulus greater than copper and undergoes brittle fracture at a stress of 176 MPa.

On the figure above draw a line showing the possible variation of stress with strain for this material.

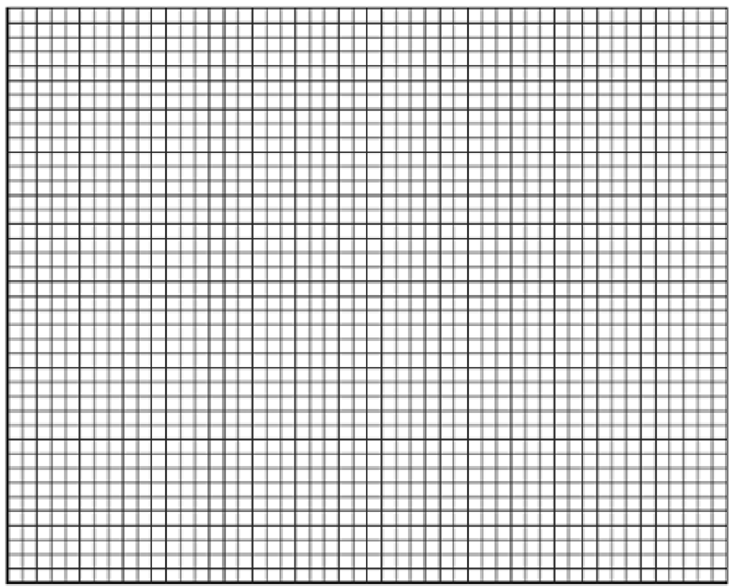
(2)
(Total 12 marks)

Q5. The table below shows the results of an experiment where a force was applied to a sample of metal.

(a) On the axes below, plot a graph of stress against strain using the data in the table.

Strain / 10^{-3}	0	1.00	2.00	3.00	4.00	5.00	6.00	7.00	8.00	9.00	10.00
Stress / 10^{8} Pa	0	0.90	2.15	3.15	3.35	3.20	3.30	3.50	3.60	3.60	3.50

stress / 10^{8} Pa



strain / 10^{-3}

(3)

(b) Use your graph to find the Young modulus of the metal.

answer = ... Pa

(2)

(c) A 3.0 m length of steel rod is going to be used in the construction of a bridge. The tension in the rod will be 10 kN and the rod must extend by no more than 1.0mm. Calculate the minimum cross-sectional area required for the rod.

Young modulus of steel = 1.90×10^{11} Pa

answer = ... m^2

(3)

(Total 8 marks)

Q6. (a) The speed of light is given by

$$c = f\lambda$$

State how each of these quantities will change, if at all, when light travels from air to glass.

c ....

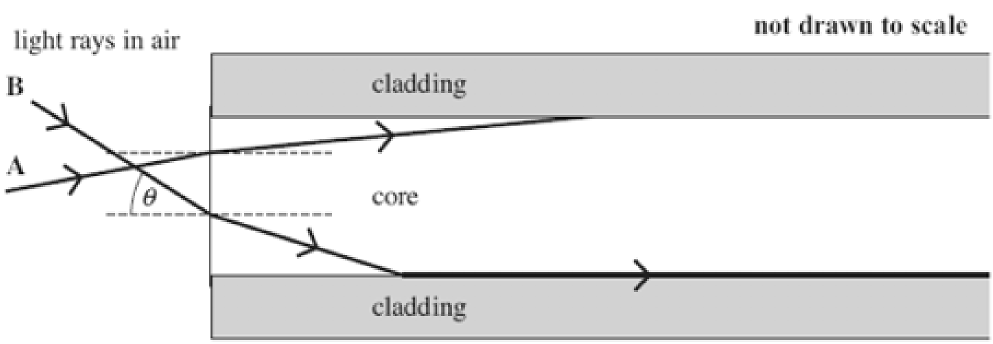
f ....

λ ....

(3)

Figure 1 shows a side view of a step index optical fibre.

Figure 1



(b) Ray **A** enters the end of the fibre and then undergoes total internal reflection.

On **Figure 1** complete the path of this ray along the fibre.

(2)

(c) (i) The speed of light in the core is 2.04×10^{8} ms^{-1}. Show that the refractive index of the core is 1.47.

(2)

(ii) Show that the critical angle at the boundary between the core and the cladding is about 80°.

refractive index of the cladding = 1.45

(2)

(d) Ray **B** enters the end of the fibre and refracts along the core-cladding boundary. Calculate the angle of incidence, *θ*, of this ray at the point of entry to the fibre.

answer = ... degrees

(3)

(e) **Figure 2** shows a pulse of monochromatic light (labelled **X**) that is transmitted a significant distance along the fibre. The shape of the pulse after travelling along the fibre is labelled **Y**. Explain why the pulse at **Y** has a lower amplitude and is longer than it is at **X**.

Figure 2

....

....

....

....

(2)
(Total 14 marks)

M1. (a) Force proportional to extension ✓

up to the limit of proportionality (accept elastic limit) ✓ dependent upon award of first mark

Symbols must be defined
Accept word equation
allow 'F=kΔL (or F ∝ ΔL) up to the limit of proportionality ' ***for the second mark only***
allow stress ∝ strain up to the limit of proportionality' ***for the second mark only***

2

(b) Gradient clearly attempted / use of *k=F / ΔL* ✓

k = 30 / 0.026 = 1154
or 31 / 0.027 = 1148

correct values used to calculate gradient with appropriate 2sf answer given (1100 or 1200)

1100 or 1200 with no other working gets 1 out of 2

OR <u>1154 ± 6</u> seen

Do not allow 32/0.0280 or 33/0.0290 (point A) for second mark.

AND <u>load used >= 15</u> ✓ (= 1100 or 1200 (2sf))

32 / 0.028 is outside tolerance. 32/0.0277 is just inside.

Nm^{-1} / N / m (newtons per metre) ✓ (not n / m, n / M, N / M)

3

(c) any area calculated or link energy with area / use of 1 / 2FΔL ✓

(or 0.001 Nm for little squares)

35 whole squares, 16 part gives 43 ± 1.0
OR equivalent correct method to find whole area ✓

0.025 Nm per (1cm) square × candidates number of squares and correctly evaluated
OR (= 1.075) = 1.1 (J) (1.05 to 1.10 if not rounded) ✓

3

(d) permanent deformation / permanent extension ✓

Allow: 'doesn't return to original length'; correct reference to 'yield'
*e.g. allow '**extension beyond the yield point**'*
do not accept: 'does not obey Hooke's law' or 'ceases to obey Hooke's law',

1

(e) any line from B to a point on the x axis from 0.005 to 0.020 ✓

straight line from B to x axis (and no further) that reaches x axis for 0.010<=ΔL<= 0.014 ✓

2

(f) work done by spring < work done by the load

Accept 'less work' or 'it is less' (we assume they are referring to the work done by spring)

1

[12]

M2. (a) ($W = mg$)

$= 4.8 \times 35 \times 9.81$ ✓

$=1600$ (1648 N) ✓

Allow g=10 : 1680 (1700 N)
g = 9.8 → 1646 N
max 1 for doubling or halving.
Max 1 for use of grammes

2

(b) (stress = tension / area)

For first mark, forgive absence of or incorrect doubling / halving.

$= (0.5 \times)\ 1.5 \times 10^{6} / 6.2 \times 10^{-4}$ OR $= 1.5 \times 10^{6} / (2 \times)\ 6.2 \times 10^{-4}$ ✓

$= 1.2 \times 10^{9}$ (1.21 GPa) ✓

Forgive incorrect prefix if correct answer seen.

2

(c) (i) (weight = stress × area)

max 1 mark for incorrect power of ten in first marking point

$= 400 \times (10^{6}) \times 6.2 \times 10^{-4}$ (= 248 000 N) ✓

max 1 mark for doubling or halving both stress and area

$(\times 2 =)$ 5.0×10^{5} (496 000 N) ✓

Forgive incorrect prefix if correct answer seen.Look out for YM ÷ 400k Pa which gives correct answer but scores zero.

2

(ii) $\Delta L = \frac{F\ L}{A\ E}$ **OR** correct substitution into a correct equation (forgive incorrect doubling or halving for this mark only ✓

OR alternative method:
strain = stress / E
then ΔL = L × strain

$= \frac{(\text{Ans 4ci}/2) \times 35}{6.2\times10^{-4} \times 2.1\times 10^{11}}$ **OR** $\frac{\text{Ans 4ci } \times 35}{2 \times 6.2\times10^{-4} \times 2.1\times 10^{11}}$ ✓ ecf from 4ci

If answer to 4ci is used, it must be halved, unless area is doubled, for this mark

$\left(= \frac{(4.96\times10^{5}/2) \times 35}{6.2\times10^{-4} \times 2.1\times 10^{11}} = \right)$ 6.7×10^{-2} (6.667×10^{-2} m) ✓ ecf from 4ci

Any incorrect doubling or halving is max 1 mark.
Allow 0.07

3

(iii)

$\left(k = \frac{F}{\Delta L} \right)$

$= \frac{2 \times 248\,000}{6.667 \times 10^{-2}}$ OR correct substitution into $F = k\Delta L$ ✓ ecf ci and cii (answer 4c(i) ÷ answer 4c(ii))

Allow halving extension for force on one cable

= 7.4(4)× 10^6 ✓(Nm^{-1})

Correct answer gains both marks

2

(iv) $\left(E = \frac{1}{2}F\Delta L \text{ or } E = \frac{1}{2}k\Delta L^2 \right)$

Correct answer gains both marks

= ½ × 496 000 × 6.667 × 10^{-2} OR ½ × 7.4(4) × 10^6 × (6.667 × 10^{-2} $)^2$ ✓ ecf ci, cii, ciii

= 1.6(5) × 10^4 (J) ✓

Forgive incorrect prefix if correct answer seen.

Doubling the force gets zero.

2

[13]

M3. (a) **The candidate's writing should be legible and the spelling, punctuation and grammar should be sufficiently accurate for the meaning to be clear.** The candidate's answer will be assessed holistically. The answer will be assigned to one of three levels according to the following criteria.

High Level (Good to excellent): 5 or 6 marks

The information conveyed by the answer is clearly organised, logical and coherent, using appropriate specialist vocabulary correctly. The form and style of writing is appropriate to answer the question.

Candidate must suggest

- drawing a graph of *F* vs *ΔL* (or *vice versa*)
- AND that *k* is in some way linked to the gradient
- AND use of a suitable named instrument to measure or determine extension
- AND 1 further means of reducing uncertainty: repeats / minimum 8 different readings / use of vernier scale / check values of mass with balance / parallax elimination with set square, pointer in contact with scale, mirror.

For 6 marks:

must also give suitable range at least up to 10N but not beyond 20N (accept ‘up to 20N’ / ‘not beyond 20N’)

AND minimum **8 different readings** OR **parallax** elimination must be included

AND **repeats** must be included

AND correctly explains how k is obtained from their graph.

Intermediate Level (Modest to adequate): 3 or 4 marks

The information conveyed by the answer may be less well organised and not fully coherent. There is less use of specialist vocabulary, or specialist vocabulary may be used incorrectly. The form and style of writing is less appropriate.

Candidate must suggest:

- to measure / determine extension OR initial and final length
- AND to use $F = k\,\Delta L$ or $k = F / \Delta L$
  OR drawing a graph of F vs ΔL (or *vice versa*)
- AND use of suitable **instrument** to measure extension
  OR 1 means of reducing **uncertainty**:
  repeats / use of vernier scale / check values of mass with balance / parallax elimination with set square, pointer in contact with scale,
  mirror / minimum 8 different readings / graphical approach

For 4 marks, **uncertainty** comment AND **instrument** required

Low Level (Poor to limited): 1 or 2 marks

The information conveyed by the answer is poorly organised and may not be relevant or coherent. There is little correct use of specialist vocabulary. The form and style of writing may be only partly appropriate.

Any relevant statement from the marking points above

For 2 marks: must mention minimum two points including:

- to measure / determine extension OR initial and final length

6

(b) (i) ($k = 2 \times 85 = 170$ ($N\,m^{-1}$))

($\Delta L = F / k =$) 15 / 170 (or 7.5 / 85) ✓

= 0.088 ✓ (m) (0.0882)

2

(ii) ($k = ½ \times 85 = 42.5$)

($\Delta L = F / k =$) 15/42.5 (or 2 x 15/85) ✓

= 0.35 ✓ (m) (0.3529)

2

(iii) (W = ½ $F\Delta L$ or ½ $k\,\Delta L^2$)

= ½ × 15 × 0.0882 (or 2 x ½ × 7.5 × 0.0882) ✓ ecf 5bi

= 0.66 ✓ (J) (0.6615) ecf 5bi

2

(iv) (series) **greater** ✓ ecf for answer 'less' or 'same' where candidates incorrect answers to bi and bii support this.

extension is more (in series) and the **force is the same** (in both situations) ✓

AND quotes Energy stored = (½)Fs or ½ $F\Delta L$ OR energy proportional to extension ✓

3

[15]

M4. (a) extension divided by its **original** length ✓

do not allow symbols unless defined ✓

1

(b) 1.9×10^8 (Pa) ✓

1

(c) point on line **marked 'A'** between a strain of 1.0×10^{-3} and 3.5×10^{-3} ✓

1

(d) clear evidence of gradient calculation for **straight section** eg 1.18 (1.2) × $10^8/1.0 \times 10^{-3}$ ✓

= 120 GPa **and stress used $\geq$ 0.6 × 10^8 Pa** ✓ allow range 116 − 120 GPa

Pa or Nm^{-2} or N/m^2 ✓

3

(e) (i) clear attempt to calculate correct area (evidence on graph is sufficient) ✓

(32 whole squares + 12 part/2 = 38 squares)

(38 × 10000 =) 380000 (J m^{-3}) ✓ allow range 375000 to 400000

2

(ii) $V = m/\rho$ **or** 0.015/8960 **or** 1.674×10^{-6} (m^3) ✓

380 000 × 1.674×10^{-6} = 0.64 (0.6362 J) ✓ ecf from ei

2

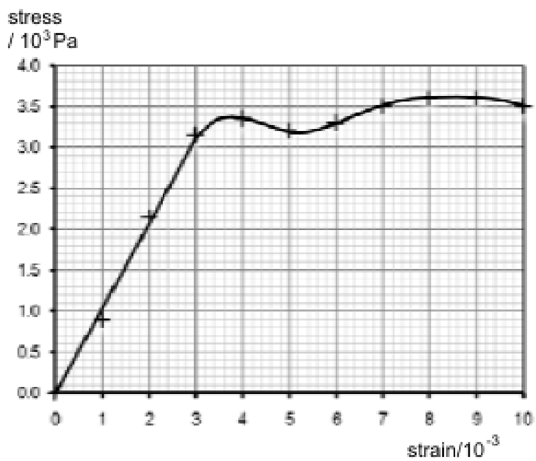
(f) straight line passing through origin (small curvature to the right only above 160 MPa is acceptable) end at 176 MPa ✓ (allow 174 to 178)

straight section to the left of the line for copper (steeper gradient) ✓

2

[12]

M5. (a)



Suitable scale on both axes (eg not going up in 3s) **and** > ½ space used ✓

≥ points correct (within half a small square) ✓

line is straight up to at least stress = 2.5×10^8 **and** curve is smooth beyond straight section ✓

3

(b) understanding that E = gradient (= $\Delta y/\Delta x$) ✓

allow y/x if line passes through origin

= 1.05×10^{11} (Pa) (allow 0.90 to 1.1) **ecf** from their line in (a) if answer outside this range **and** uses a y value ≥ 2 ✓

when values used from table;

- two marks can be scored only if candidates line passes through them
- one mark only can be scored if these points are not on their line

2

(c) correct rearrangement of symbols or numbers ignoring incorrect

powers of ten, eg $A = \frac{FL}{E\Delta L}$ ✓

correct substitution in any correct form of the equation,

eg = $\frac{10(000) \times 3.0}{1.90(\times 10^{11}) \times 1.0(\times 10^{-3})}$ ✓

allow incorrect powers of ten for this mark

= 1.6×10^{-4} ✓ (1.5789) (m^2)

3

[8]

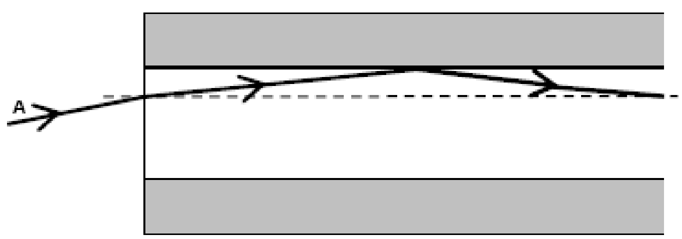
M6. (a) decrease ✓

constant ✓

decrease ✓

3

(b)



straight ray (ignore arrow) reflecting to the right ✓

reflected angle = incident angle ✓

(accept correct angle labels if reflected angle is outside tolerance)

2

(c) (i) ($n = \frac{c}{c_s}$) use of 3 ($\times 10^8$) ✓ = $\frac{300(\times 10^8)}{2.04(\times 10^8)}$ = 1.47 ✓ (1.4706)

(must see 3 sf or more)

2

(ii) $\sin \theta_c = \frac{1.45}{1.47(06)}$ or correct substitution in un-rearranged formula ✓

θ_c = 80.4 ✓ (80.401) (80.3 to 80.54) (≈ 80°) must see 3 sf or more

2

(d) angle of refraction = 180 – 90 – 80.4 = 9.6° ✓

$\sin\theta$ = 147(06) sin 9.6 ✓ = 0.25 ecf from first mark

θ = 14 (= 14.194°) ✓ ecf from first mark

range **13 to 15°** due to use of rounded values

3

(e) (reduced amplitude) due to absorption/energy loss (within the fibre)/attenuation/scattering (by the medium) /loss from fibre ✓

(pulse broadening caused by) multi-path (modal) dispersion /different rays/modes propagating at different angles/non axial rays take longer time to travel same distance along fibre as axial rays ✓

2

[14]