3.4 Mechanics and Materials: 1-hour Pack

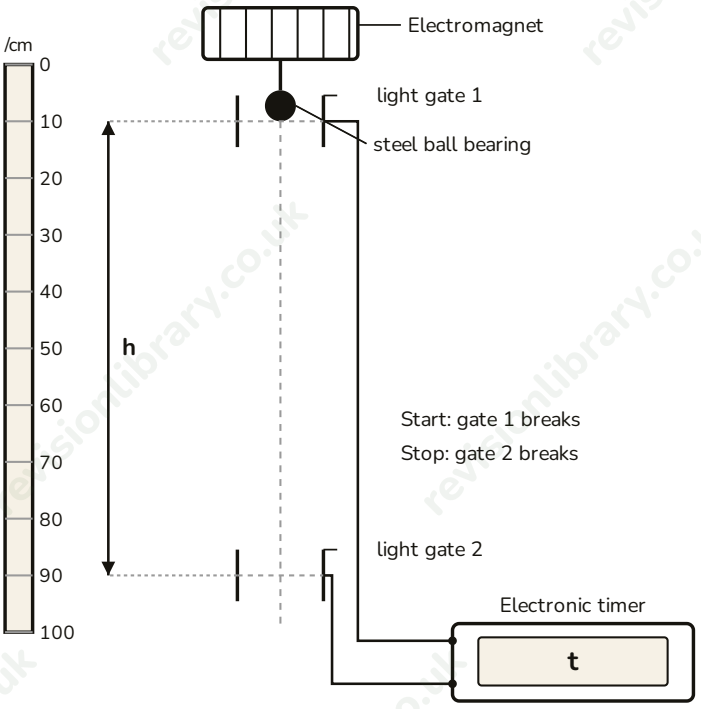
AQA 7408 · Calculator allowed · about 60 minutes

Total Marks

Name: _____ Date: ____ / ____ / _____

Answer ALL questions. Show all your working.

1 This question is based on the required practical: determination of the acceleration due to free fall, g. A steel ball bearing is released from rest by an electromagnet and falls through a measured height, h, between two light gates connected to an electronic timer, which records the total time of fall, t. In one trial, h = 0.800 m and t = 0.404 s.



(a) Show that the average speed of the ball bearing over the fall is about 1.98 m/s. **(2)**

(b) Given that, starting from rest, $g = 2h/t^2$, calculate the experimental value of g from this trial. **(3)**

(c) The accepted value of g is 9.81 m/s^2. Calculate the percentage difference between the experimental value from part (b) and the accepted value. **(2)**

(d) Identify one source of random error in this experiment and state how its effect on the result could be reduced. **(2)**

(e) Explain why using light gates, rather than a hand-operated stopwatch, improves the accuracy of the value obtained for g. **(2)**

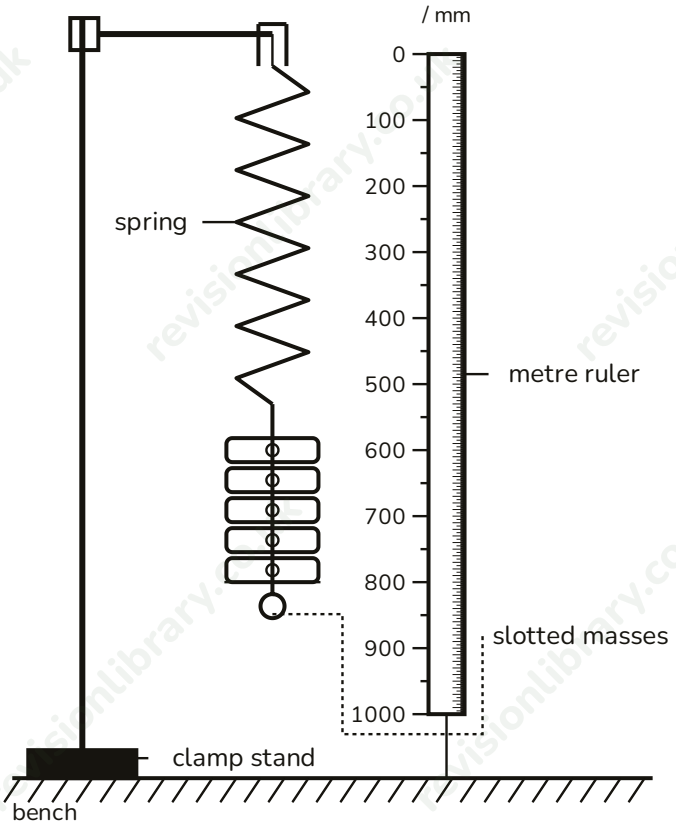
(Total for Question 1 is 11 marks)

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2 This question investigates the force-extension characteristics of a spring (Hooke's law). A student hangs a spring vertically from a clamp stand and adds masses one at a time, measuring the total extension with a metre ruler fixed alongside the spring. Her results are:

Force / N: 1.0, 2.0, 3.0, 4.0, 5.0

Extension / mm: 12, 25, 37, 50, 61



(a) Describe one step the student could take to improve the accuracy of her extension measurements, and explain how it does this. **(2)**

(b) Use the student's data to calculate the spring constant, k, of the spring in N/m. **(3)**

(c) Given that the elastic potential energy stored in a spring is $E = 1/2\ k\ x^2$, calculate the elastic potential energy stored in the spring when it is extended by 61 mm. **(3)**

(d) Evaluate this method for determining the spring constant of a spring, suggesting improvements that would reduce random and/or systematic error. **(6)**

(Total for Question 2 is 14 marks)

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3 A uniform horizontal beam AB of length 4.0 m rests on supports at each end, A and B. The beam itself has a weight of 60 N acting at its midpoint, and an additional load of 90 N is placed on the beam 1.0 m from end A. The beam remains in equilibrium.

(a) State the condition, in terms of moments, that must be satisfied for the beam to be in equilibrium. **(1)**

(b) By taking moments about end A, calculate the reaction force at support B. **(3)**

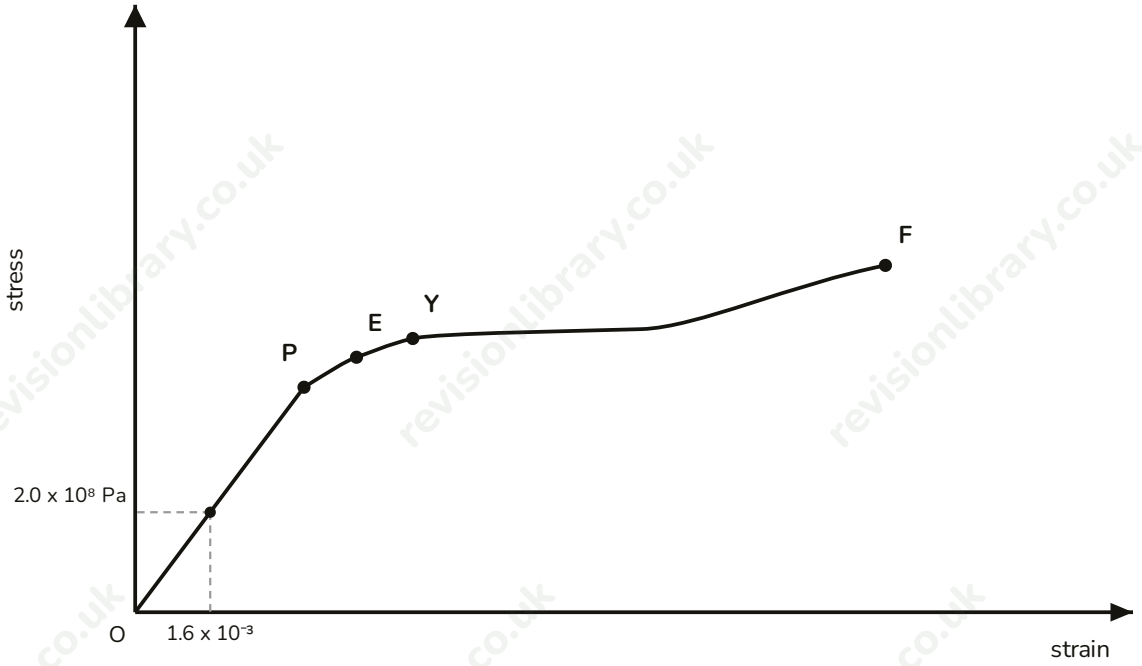
(c) Using vertical equilibrium, calculate the reaction force at support A. **(2)**

(Total for Question 3 is 6 marks)

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4 Figure 2 shows the stress-strain graph for a metal wire, stretched from zero up to fracture. Along the curve, point P marks the limit of proportionality, point E marks the elastic limit, point Y marks the yield point, and the wire fractures at point F, well beyond Y. Within the linear region (up to P), a stress of 2.0×10^{8} Pa produces a strain of 1.6×10^{-3}.

Figure 2: stress-strain graph for the wire



P = limit of proportionality E = elastic limit Y = yield point F = fracture

(a) State what is meant by the limit of proportionality. **(1)**

(b) State what happens to the wire at the yield point, Y. **(1)**

(c) Use the gradient of the linear region of the graph to calculate the Young modulus of the wire. **(3)**

(d) Compare the mechanical behaviour of this ductile metal wire with that of a brittle glass fibre when both are stressed to fracture, explaining the difference in terms of the structure of each material. **(6)**

(Total for Question 4 is 11 marks)

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Mark scheme · 3.4 Mechanics and Materials: 1-hour Pack

Question 1

(a) average speed = h/t substitution **M1**

(a) cso: 1.98 m/s **A1**

(a) Answer: 1.98 m/s

(b) correct rearrangement/use of $g = 2h/t^2$ **M1**

(b) correct substitution: $g = 2(0.800)/(0.404)^2$ **M1**

(b) 9.80 m/s^2 (accept 9.79-9.81 m/s^2), awrt **A1**

(b) Answer: 9.80 m/s^2

(c) % difference = (|experimental - accepted|/accepted) x 100, ft from (b) **M1**

(c) 0.10% (accept 0.07-0.11%, ft), awrt **A1**

(c) Answer: 0.10%

(d) valid random error, e.g. small variation in the height h measured with a ruler (parallax), or slight variation in the release of the ball bearing each time **B1**

(d) valid method to reduce its effect, e.g. repeat the drop several times at the same height and calculate a mean value of t (or g), oe **B1**

(d) Answer: Slight variation in the release of the ball bearing causes random variation in the measured time. Repeat the drop several times at the same height and take a mean value of t (or g) to reduce its effect.

(e) light gates start and stop the timing electronically at the instant the ball passes, removing the effect of human reaction time **B1**

(e) this removes a (systematic) timing error that would otherwise make the measured time too long or inconsistent, giving a more accurate value of g, oe **B1**

(e) Answer: Light gates remove human reaction time error, giving a more accurate value of t and hence g.

Question 2

(a) named valid technique, e.g. use a set square (or fiducial marker) held against the ruler at the reading, or view the scale at eye level **B1**

(a) linked to reduction of parallax error when reading the extension, oe **B1**

(a) Answer: Using a set square against the scale reduces parallax error.

(b) correctly convert extensions to metres (e.g. 12 mm = 0.012 m, 61 mm = 0.061 m) **M1**

(b) gradient = change in force/change in extension, using two data points, oe **M1**

(b) 81.6 N/m (accept 80-83 N/m), awrt **A1**

(b) Answer: 81.6 N/m

(c) recall/apply $E = 1/2\ k\ x^2$ **M1**

(c) correct substitution: k from (b), x = 0.061 m, ft **M1**

(c) 0.152 J (accept 0.148-0.156 J, ft), awrt **A1**

(c) Answer: 0.152 J

(d) **L1** Basic, isolated statements about sources of error, with little or no reference to the specific method and limited or no suggestions for improvement. **1-2**

(d) **L2** Some relevant sources of error and improvements are identified, showing some application to this specific method, but explanations may be incomplete or the link between error and improvement unclear. **3-4**

(d) **L3** A range of relevant sources of error is identified with clear, well-linked improvements that show detailed understanding of how each improvement increases accuracy or reduces uncertainty in this specific method. **5-6**

(d) Indicative content:

- Parallax error when reading the extension from the ruler; reduced by using a set square or fiducial marker aligned with the pointer, read at eye level
- No check for a zero error before adding masses; the unstretched (zero-load) position should be recorded and subtracted from later readings
- Masses may oscillate when added, causing a blurred/uncertain reading; allow the spring to come to rest before each reading, or add masses gently
- Random error reduced by repeating each measurement and taking a mean extension for each load
- At high loads the spring may exceed its elastic limit; check that the force-extension graph remains a straight line through the origin and discard any non-linear data when finding k
- Using the gradient of a graph of all data points (rather than one pair of readings) reduces the effect of random error and anomalies on the calculated value of k
- A more precise instrument, such as a vernier scale or travelling microscope, could be used to measure extension with greater resolution

(d) Answer: See levels of response and indicative content.

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Question 3

(a) the sum of the clockwise moments about any point equals the sum of the anticlockwise moments about that point oe **B1**

(a) Answer: The sum of clockwise moments about any point equals the sum of anticlockwise moments about that point.

(b) set up moment equation about A: R(B) x 4.0 = 60 x 2.0 + 90 x 1.0 **M1**

(b) solve: R(B) x 4.0 = 120 + 90 = 210 **M1**

(b) R(B) = 52.5 N cao **A1**

(b) Answer: 52.5 N

(c) R(A) + R(B) = total downward force = 60 + 90 = 150 N **M1**

(c) R(A) = 150 - 52.5 = 97.5 N cao **A1**

(c) Answer: 97.5 N

Question 4

(a) the point beyond which strain is no longer directly proportional to stress (Hooke's law is no longer obeyed), oe **B1**

(a) Answer: The point beyond which stress is no longer directly proportional to strain.

(b) the material begins to deform plastically (extends significantly) with little or no further increase in stress/load, oe **B1**

(b) Answer: The wire begins to stretch plastically with little or no increase in stress.

(c) recognise Young modulus = gradient of linear region = stress/strain **M1**

(c) correct substitution: $2.0 \times 10^{8} / 1.6 \times 10^{-3}$ **M1**

(c) 1.25×10^{11} Pa (125 GPa), cao **A1**

(c) Answer: 1.25×10^{11} Pa

(d) **L1** Basic comparison with limited reference to structure; may only describe the shapes of the graphs without explanation. **1-2**

(d) **L2** Some valid comparisons of behaviour and structure are made, with partial explanation of the link between them. **3-4**

(d) **L3** A clear, well-linked comparison of the mechanical behaviour and underlying structure of both materials is given, explaining why each material behaves as it does. **5-6**

(d) Indicative content:

- The metal wire shows an initial linear (elastic) region up to the limit of proportionality, then yields and deforms plastically over a large range of strain before fracturing
- In a metal, atoms are arranged in ordered layers/planes held together by metallic bonding; beyond the elastic limit these planes of atoms (via dislocation movement) can slide over one another
- This sliding allows permanent (plastic) deformation without the material breaking, which is why metals are ductile and show a large plastic region before fracture
- Glass has an amorphous, covalent network structure with no regular planes of atoms able to slide past one another
- With no mechanism for atoms to move relative to each other, glass deforms elastically (approximately along the linear region only) with little or no plastic deformation
- Glass therefore fractures suddenly at a relatively low strain (brittle fracture), often initiated at microscopic surface cracks that concentrate stress
- The Young modulus (gradient of the linear region) may be of similar order for both materials, but the metal absorbs far more energy (larger area under the graph) before fracture than the glass

(d) Answer: See levels of response and indicative content.

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