3.4 Mechanics and Materials

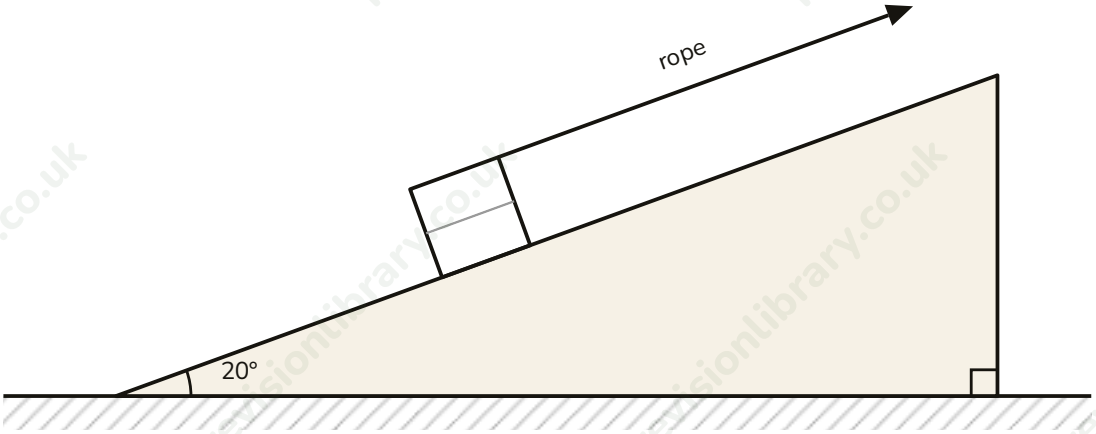
AQA 7408 · Calculator allowed · about 235 minutes · Write-in edition

Total Marks

Name: _____ Date: ____ / ____ / _____

Answer ALL questions. Show all your working.

1 A crate of mass 25 kg is pulled at constant velocity up a rough ramp inclined at 20 degrees to the horizontal, using a rope parallel to the slope. The coefficient of friction between the crate and the ramp is 0.15. Take $g = 9.81\ m/s^2$.



(a) Calculate the component of the crate's weight acting parallel to the slope. **(2)**

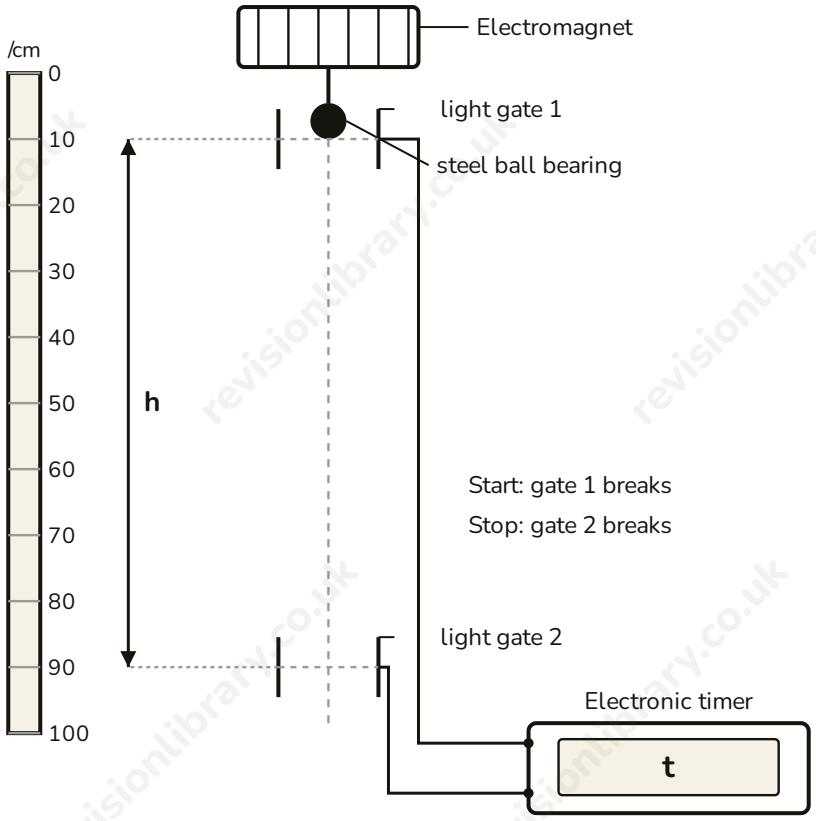
(b) Calculate the normal reaction force acting on the crate. **(2)**

(c) Calculate the frictional force acting on the crate as it moves up the slope. **(2)**

(d) The crate moves up the slope at constant velocity. Calculate the tension in the rope. **(3)**

(Total for Question 1 is 9 marks)

2 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 2 is 11 marks)

3 A car of mass 900 kg, travelling at 18 m/s, collides with a barrier and is brought to rest by the energy-absorbing crumple zone in the front of the car.

(a) Calculate the change in momentum of the car during the collision. **(2)**

(b) The collision brings the car to rest in 0.12 s. Given that force = change in momentum/time, calculate the average force exerted on the car during the collision. **(3)**

(c) The car is redesigned with a longer crumple zone, so that in an identical collision it now takes 0.20 s to come to rest. Calculate the new average force on the car. **(2)**

(d) Explain, in terms of impulse, why increasing the duration of the collision reduces the risk of injury to the occupants of the car. **(3)**

(Total for Question 3 is 10 marks)

4 A person of mass 70 kg stands on bathroom scales inside a lift in a shopping centre. Take g = 9.81 m/s^2. Use the Physics Equations Sheet where needed.

(a) The lift accelerates upwards from rest at 2.0 m/s^2. Calculate the reading on the scales (the normal reaction force on the person) during this acceleration. **(3)**

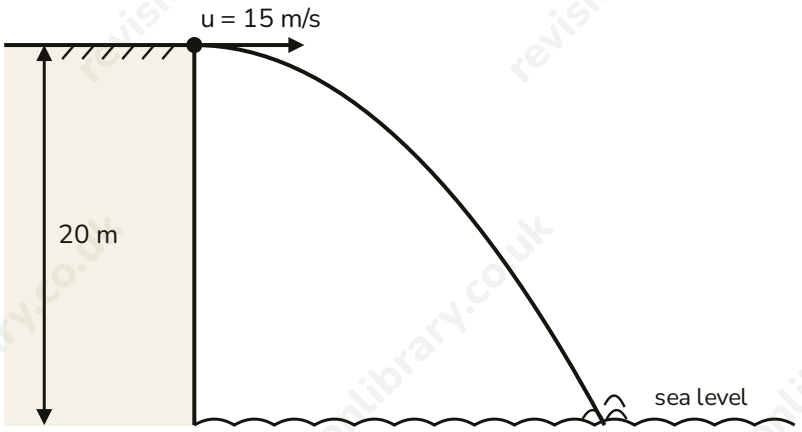
(b) The lift then travels at a constant velocity. Calculate the reading on the scales during this stage. **(2)**

(c) As the lift approaches the top floor it decelerates at 1.5 m/s^2 while still moving upwards. Calculate the reading on the scales during this deceleration. **(3)**

(d) Explain, in terms of Newton's laws, why the person feels lighter while the lift decelerates in part (c). **(2)**

(Total for Question 4 is 10 marks)

5 A stone is thrown horizontally with a speed of 15 m/s from the top of a cliff at Flamborough Head, 20 m above the sea. Air resistance can be ignored. Take $g = 9.81\ m/s^2$. Use the Physics Equations Sheet where needed.



(a) Show that the time taken for the stone to fall to sea level is about 2.0 s. **(2)**

(b) Calculate the horizontal distance travelled by the stone before it lands. **(2)**

(c) Calculate the vertical component of the stone's velocity as it lands. **(2)**

(d) Calculate the magnitude and direction of the stone's resultant velocity as it lands. **(4)**

(Total for Question 5 is 10 marks)

6 Trolley A, of mass 0.80 kg, moves at 3.0 m/s and collides with stationary trolley B, of mass 1.20 kg. The trolleys stick together and move off with a common velocity.

(a) Calculate the momentum of trolley A immediately before the collision. **(2)**

(b) Use conservation of momentum to calculate the common velocity of the trolleys immediately after the collision. **(3)**

(c) Calculate the total kinetic energy before the collision, the total kinetic energy after the collision, and hence the kinetic energy lost in the collision. **(4)**

(d) State and explain what has happened to the kinetic energy lost during the collision. **(2)**

(Total for Question 6 is 11 marks)

7 A statue made from a bronze alloy has a mass of 45 kg and a volume of 5.2×10^{-3} m^3. Density of water = 1000 kg/m^3. Take g = 9.81 m/s^2. Upthrust = density of fluid x volume displaced x g.

(a) Calculate the density of the bronze alloy. **(2)**

(b) The statue is fully submerged in a tank of water for cleaning. Calculate the upthrust acting on it. **(3)**

(c) Calculate the apparent weight of the statue while it is fully submerged. **(3)**

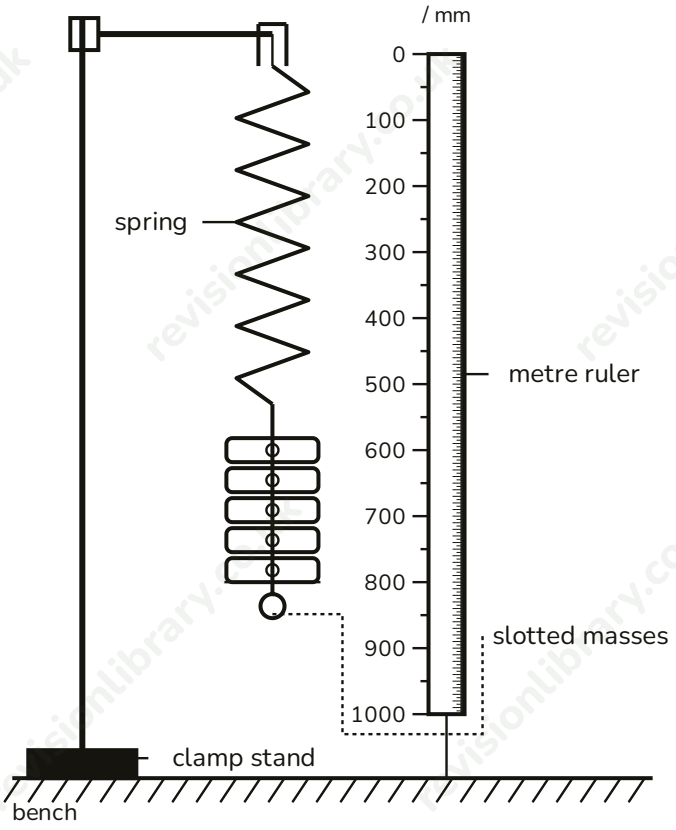
(d) Explain, using the concept of upthrust, why the reading on a support balance holding the statue decreases when it is lowered into the water. **(2)**

(Total for Question 7 is 10 marks)

8 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)**

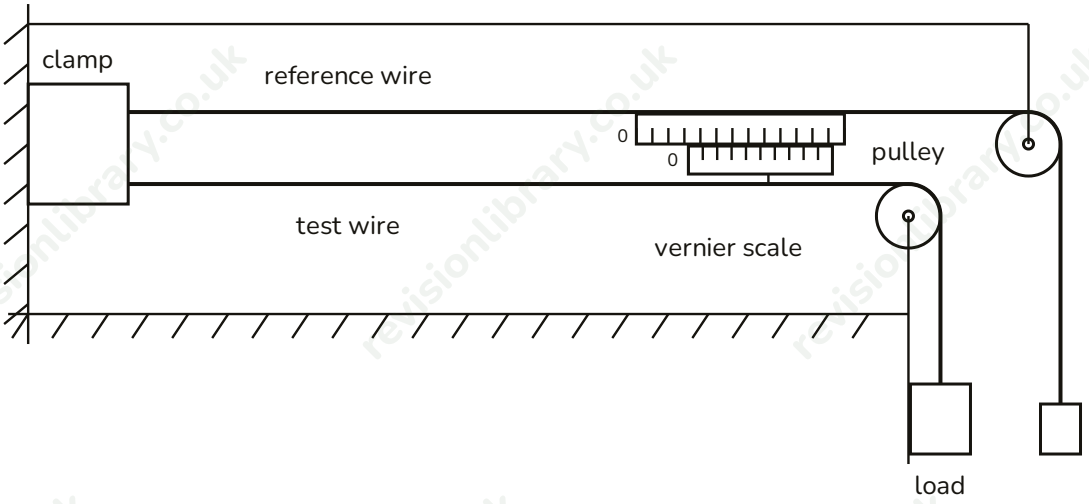
(b) Use the student's data to calculate the spring constant, k, of the spring in N/m. **(3)**

(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 8 is 14 marks)

9 This question is based on the required practical: determination of the Young modulus of a metal wire. A student sets up a copper test wire of original length 2.00 m and diameter 0.28 mm, clamped horizontally and passed over a pulley with a load attached, alongside a fixed reference wire and vernier scale to measure extension. A load of 20 N produces an extension of 5.6 mm, which is within the elastic limit of the wire. Assume the wire has a uniform circular cross-section.



(a) Calculate the cross-sectional area of the wire. **(3)**

(b) Calculate the strain in the wire. **(2)**

(c) Calculate the stress in the wire when it supports the 20 N load. **(2)**

(d) Calculate the Young modulus of the copper wire from this data. **(2)**

(e) State one precaution taken in this experiment that improves the reliability of the result. **(1)**

(f) Given that the elastic strain energy stored in a stretched wire is E_stored = 1/2 F x, calculate the elastic strain energy stored in the wire when the 20 N load produces the 5.6 mm extension. **(3)**

(Total for Question 9 is 13 marks)

10 A ball of mass 0.16 kg travelling at 12 m/s strikes a wall at right angles and rebounds at 9.0 m/s. The ball is in contact with the wall for 0.050 s.

(a) Calculate the change in momentum of the ball during the collision, taking the direction of the initial velocity as positive. **(2)**

(b) Calculate the magnitude of the average force exerted by the wall on the ball. **(3)**

(Total for Question 10 is 5 marks)

11 Two ice skaters, initially at rest and in contact, push apart on frictionless ice. Skater A has mass 55 kg and skater B has mass 75 kg. After the push, skater A moves off at 3.2 m/s.

(a) Explain, with reference to Newton's third law, why the total momentum of the two-skater system remains zero after the push. **(2)**

(b) Calculate the speed at which skater B moves off. **(3)**

(c) Calculate the total kinetic energy generated during the push-off. **(3)**

(Total for Question 11 is 8 marks)

12 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.

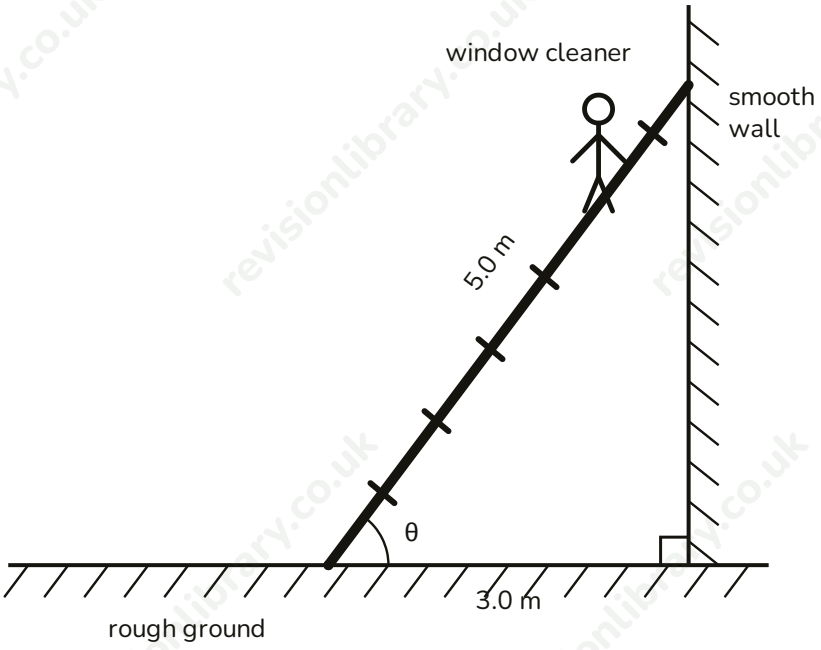
(a) State the condition, in terms of moments, that must be satisfied for the beam to be in equilibrium. **(1)**

(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 12 is 6 marks)

13 A uniform ladder of length 5.0 m and weight 120 N rests with its foot on rough ground, 3.0 m horizontally from a smooth vertical wall against which the top of the ladder leans. A window cleaner of weight 700 N stands three-quarters of the way up the ladder from the foot. Take g = 9.81 m/s^2.



(a) Calculate the angle between the ladder and the ground. **(2)**

(b) By taking moments about the foot of the ladder, calculate the normal reaction force exerted by the (smooth) wall on the ladder. **(4)**

(c) Calculate the frictional force acting at the foot of the ladder. **(2)**

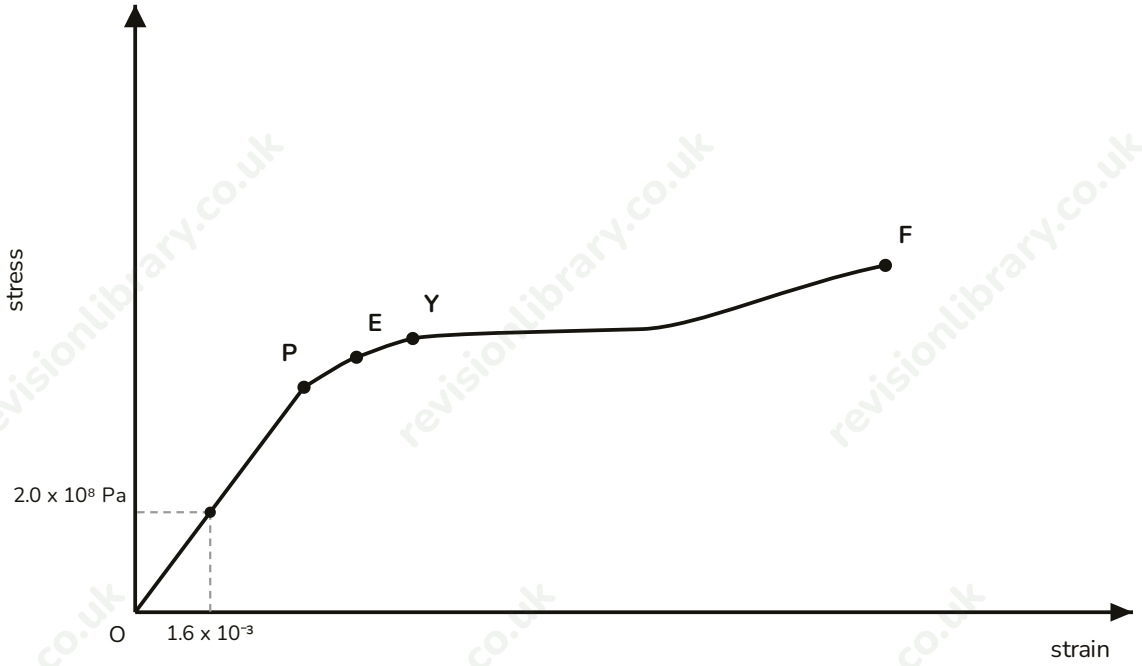
(d) Calculate the normal reaction force from the ground acting on the ladder. **(2)**

(e) Calculate the minimum coefficient of friction between the ladder and the ground needed to prevent the ladder slipping. **(2)**

(Total for Question 13 is 12 marks)

14 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 14 is 11 marks)

15 Car manufacturers design the front of a car to include a crumple zone: a section of the body structure that deforms plastically during a collision, absorbing energy, rather than remaining rigid. Evaluate how principles of work and energy, and the mechanical properties of the materials used, both contribute to reducing the risk of injury to occupants in a frontal collision. In your answer, refer to the work-energy relationship for bringing the car to rest, and to how the area under a force-extension (or stress-strain) graph for the crumple zone material represents energy absorbed through plastic deformation.

(Total for Question 15 is 6 marks)

16 A conveyor belt in a warehouse carries crates of mass 40 kg up a ramp inclined at 15 degrees to the horizontal. The ramp is 6.0 m long and a constant friction force of 45 N opposes the motion of each crate. Crates are loaded onto the belt at a rate of 3 per minute and the belt moves at constant velocity. The motor driving the belt has an efficiency of 78%. Take g = 9.81 m/s^2.

(a) Calculate the vertical height gained by a crate travelling the full length of the ramp. **(2)**

(b) Calculate the total work done on one crate against gravity and against friction as it travels up the full length of the ramp. **(3)**

(c) Given that crates are loaded at a rate of 3 per minute, calculate the useful mechanical power output of the belt. **(3)**

(d) Given that the motor is 78% efficient, calculate the electrical power that must be supplied to the motor. **(2)**

(Total for Question 16 is 10 marks)

17 A block is placed on a ramp whose angle of incline can be increased. For the first surface, the block just begins to slide when the ramp angle reaches 22 degrees. A second block, on a different, rougher surface, just begins to slide at an angle of 31 degrees.

(a) By resolving the weight of the block into components parallel and perpendicular to the ramp surface, and considering the forces at the point of slipping, show that the coefficient of static friction is given by $\mu = \tan(\theta_c)$, where θ_c is the angle at which sliding just begins. **(3)**

(b) Calculate the coefficient of static friction for the first surface. **(2)**

(c) Calculate the coefficient of static friction for the second surface, and state which of the two surfaces provides more grip. **(2)**

(Total for Question 17 is 7 marks)

Mark scheme · 3.4 Mechanics and Materials

Question 1

(a) correct substitution into W sin(20), using W = mg = 245 N (or 245.25 N), oe **M1**

(a) 83.9 N (accept 83.6-84.0 N), cao **A1**

(a) Answer: 83.9 N

(b) correct substitution into N = W cos(20), oe **M1**

(b) 230 N (accept 229-231 N), awrt **A1**

(b) Answer: 230.5 N

(c) correct substitution into F = μ N, using N from part (b), ft **M1**

(c) 34.6 N (ft from (b)), cao **A1**

(c) Answer: 34.6 N

(d) recognise equilibrium along the slope: T = weight component (a) + friction (c) **M1**

(d) correct substitution using values from (a) and (c), ft **M1**

(d) 118.5 N (accept 118-119 N, ft), cao **A1**

(d) Answer: 118.5 N

Question 2

(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 3

(a) change in momentum = m x change in velocity, substitution **M1**

(a) 16200 kg m/s (1.62 x 10^4 kg m/s), cao **A1**

(a) Answer: 16200 kg m/s

(b) recall/apply F = change in momentum/time **M1**

(b) correct substitution using (a) and t = 0.12 s, ft **M1**

(b) 1.35 x 10^5 N, cao/ft **A1**

(b) Answer: 1.35 x 10^5 N

(c) correct substitution using (a) and new t = 0.20 s, ft **M1**

(c) 8.1 x 10^4 N, cao/ft **A1**

(c) Answer: 8.1 x 10^4 N

(d) the impulse (change in momentum) needed to stop the car is the same in both cases **B1**

(d) since force = change in momentum/time, increasing the collision time for the same change in momentum means the average force is smaller **B1**

(d) a smaller average force means a smaller deceleration of the occupants, reducing the risk of injury, oe **B1**

(d) Answer: For the same change in momentum, a longer collision time reduces the average force, and hence the deceleration and injury risk to occupants.

Question 4

(a) resultant force equation: R - mg = ma, oe **M1**

(a) correct substitution: R = 70(9.81 + 2.0) **M1**

(a) 827 N (accept 826-828 N), awrt **A1**

(a) Answer: 827 N

(b) recognise a = 0, so R = mg **M1**

(b) 687 N (awrt), cao **A1**

(b) Answer: 687 N

(c) resultant force equation for deceleration: mg - R = ma, oe, i.e. R = m(g - a) **M1**

(c) correct substitution: R = 70(9.81 - 1.5) **M1**

(c) 582 N (accept 580-583 N), awrt **A1**

(c) Answer: 582 N

(d) resultant force on the person acts downwards, so the normal reaction (support) force from the scales is smaller than the person's weight **B1**

(d) by Newton's third law the scales push up on the person with this smaller force, which is sensed as feeling lighter, oe **B1**

(d) Answer: The reduced normal reaction force during deceleration is felt as a reduced sensation of weight.

Question 5

(a) rearrange $s = 1/2\ g\ t^2$ to make t the subject: $t = \sqrt{2s/g}$ **M1**

(a) cso: $t = \sqrt{2 \times 20/9.81} = 2.02$ s, which is 2.0 s to 2 s.f. **A1**

(a) Answer: t = 2.0 s (2.02 s to 3 s.f.)

(b) x = v x t, using t = 2.02 s (ft from (a)) **M1**

(b) 30.3 m (accept 30-30.4 m), awrt **A1**

(b) Answer: 30.3 m

(c) v = g t, using t = 2.02 s (ft from (a)) **M1**

(c) 19.8 m/s (awrt), cao **A1**

(c) Answer: 19.8 m/s

(d) use Pythagoras: $v_{resultant} = \sqrt{vx^2 + vy^2}$, using values from (b)/(c), ft **M1**

(d) 24.8 m/s (accept 24.7-24.9 m/s), awrt **A1**

(d) use $\tan(\theta) = vy/vx$ (or equivalent) to find the angle below the horizontal **M1**

(d) 52.9 degrees below the horizontal (accept 52-53 degrees), awrt **A1**

(d) Answer: 24.8 m/s at 52.9 degrees below the horizontal

Question 6

(a) p = m v substitution **M1**

(a) 2.4 kg m/s, cao **A1**

(a) Answer: 2.4 kg m/s

(b) apply conservation of momentum: $m_A\ u_A + m_B\ u_B = (m_A + m_B)\ v$ **M1**

(b) correct substitution: $0.80(3.0) + 1.20(0) = 2.00\ v$ **M1**

(b) v = 1.2 m/s, cao **A1**

(b) Answer: 1.2 m/s

(c) KE before = $1/2\ (0.80)(3.0)^2 = 3.6$ J **M1**

(c) KE after = $1/2\ (2.00)(1.2)^2 = 1.44$ J, ft from (b) **M1**

(c) correct method: energy lost = KE before - KE after **A1**

(c) 2.16 J, cao/ft **A1**

(c) Answer: KE before = 3.6 J; KE after = 1.44 J; energy lost = 2.16 J

(d) momentum is conserved but kinetic energy is not, because the collision is inelastic **B1**

(d) the lost KE is transferred to other forms such as heat, sound and/or the permanent deformation of the trolleys, oe **B1**

(d) Answer: The collision is inelastic; kinetic energy is transferred to heat, sound and deformation of the trolleys.

Question 7

(a) density = mass/volume substitution **M1**

(a) 8650 kg/m^3 (accept 8600-8700 kg/m^3), awrt **A1**

(a) Answer: 8650 kg/m^3

(b) recall/apply upthrust = density of water x volume x g **M1**

(b) correct substitution: $1000 \times 5.2 \times 10^{-3} \times 9.81$ **M1**

(b) 51.0 N (accept 50.8-51.2 N), cao **A1**

(b) Answer: 51.0 N

(c) true weight = mg = 45 x 9.81 = 441 N **M1**

(c) apparent weight = true weight - upthrust, ft from (b) **M1**

(c) 390 N (accept 388-392 N, ft), cao **A1**

(c) Answer: 390 N

(d) the water exerts an upward force (upthrust) on the statue equal to the weight of water displaced **B1**

(d) this upthrust supports part of the statue's weight, so the force needed from the balance (and hence the reading) decreases, oe **B1**

(d) Answer: Upthrust from the displaced water supports part of the statue's weight, reducing the balance reading.

Question 8

(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.

Question 9

(a) radius = diameter/2 = 0.14 mm = 1.4×10^{-4} m **M1**

(a) correct substitution into $A = \pi r^2$ **M1**

(a) 6.16×10^{-8} m^2 (accept 6.1-6.2 $\times 10^{-8}$ m^2), awrt **A1**

(a) Answer: 6.16×10^{-8} m^2

(b) strain = extension/original length substitution **M1**

(b) 2.8×10^{-3}, cao **A1**

(b) Answer: 2.8×10^{-3}

(c) stress = force/area, using area from (a), ft **M1**

(c) 3.25×10^{8} Pa (accept 3.2-3.3 $\times 10^{8}$ Pa, ft), awrt **A1**

(c) Answer: 3.25×10^{8} Pa

(d) Young modulus = stress/strain, using (b) and (c), ft **M1**

(d) 1.16×10^{11} Pa (accept 1.1-1.2 $\times 10^{11}$ Pa, ft), awrt **A1**

(d) Answer: 1.16×10^{11} Pa

(e) valid precaution, e.g. use of a reference wire alongside the test wire to compensate for the effects of temperature change and to support the vernier scale, or measuring the diameter at several points/orientations along the wire and using a mean value **B1**

(e) Answer: Use of a reference wire to compensate for temperature effects (or measuring the diameter at several points and averaging).

(f) recall/apply $E_{stored} = 1/2\ F\ x$ **M1**

(f) correct substitution: F = 20 N, x = 5.6×10^{-3} m **M1**

(f) 0.056 J (accept 0.055-0.057 J), awrt **A1**

(f) Answer: 0.056 J

Question 10

(a) change in momentum = m(v - u) = 0.16 x (-9.0 - 12) **M1**

(a) = -3.36 kg m/s (magnitude 3.36 kg m/s) cao **A1**

(a) Answer: -3.36 kg m/s (magnitude 3.4 kg m/s)

(b) quote impulse = change in momentum = F x t **M1**

(b) substitute F = 3.36 / 0.050 **M1**

(b) F = 67.2 N cao **A1**

(b) Answer: 67.2 N

Question 11

(a) by Newton's third law the force exerted by A on B is equal and opposite to the force exerted by B on A, and they act for the same time **B1**

(a) so the impulses (changes in momentum) of A and B are equal and opposite, meaning the total momentum change of the system is zero and momentum is conserved (no external horizontal forces act) oe **B1**

(a) Answer: The push forces on A and B form a Newton's third law pair, equal in magnitude and opposite in direction, acting for the same time, so the impulses (and hence momentum changes) of A and B are equal and opposite; with no external horizontal force, total momentum stays at zero.

(b) use conservation of momentum: mA vA = mB vB (momenta equal and opposite, total zero) **M1**

(b) substitute vB = (55 x 3.2) / 75 **M1**

(b) vB = 2.3 m/s cao **A1**

(b) Answer: 2.3 m/s

(c) KE(A) = 0.5 x 55 x 3.2^2 = 282 J **M1**

(c) KE(B) = 0.5 x 75 x 2.347^2 = 207 J **M1**

(c) total KE = 488 J cao **A1**

(c) Answer: 488 J

Question 12

(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 13

(a) use trigonometry, e.g. cos(θ) = 3.0/5.0 (or equivalent using the 3-4-5 triangle) **M1**

(a) 53.1 degrees (accept 53-53.2 degrees), awrt **A1**

(a) Answer: 53.1 degrees

(b) correct moment of the ladder's weight about the foot: 120 x 1.5 (weight x horizontal distance to centre of mass) **M1**

(b) correct moment of the person's weight about the foot: 700 x 2.25 (weight x horizontal distance to person's position) **M1**

(b) correct moments equation: R_wall x 4.0 = 120(1.5) + 700(2.25) **M1**

(b) 439 N (accept 438-440 N), awrt **A1**

(b) Answer: 439 N

(c) recognise horizontal equilibrium: since the wall is smooth, friction at the foot must equal the wall's reaction force, ft from (b) **M1**

(c) 439 N (ft), cao **A1**

(c) Answer: 439 N

(d) recognise vertical equilibrium: N = weight of ladder + weight of person **M1**

(d) 820 N, cao **A1**

(d) Answer: 820 N

(e) μ = friction force/normal reaction force, using (c) and (d), ft **M1**

(e) 0.535 (accept 0.53-0.54, ft), awrt **A1**

(e) Answer: 0.535

Question 14

(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.

Question 15

Level 3 Clear, well-linked evaluation that correctly uses the work-energy relationship (work done to stop the car = initial kinetic energy = average force x stopping distance) to explain that increasing the stopping distance (via crumple zone deformation) reduces the average force and deceleration experienced by occupants, AND explains that the crumple zone material is chosen to deform plastically beyond its elastic limit, absorbing a large amount of energy (area under the force-extension/stress-strain graph, including the permanent plastic deformation region) rather than transmitting force elastically to the passenger cell. Reaches a justified conclusion connecting both mechanics (energy/force) and materials (plastic behaviour) principles. **5-6**

Level 2 Correctly explains one of the two principles (either the work-energy/stopping-distance argument, or the plastic deformation/energy-absorption argument) in reasonable detail, with only partial or underdeveloped treatment of the other. **3-4**

Level 1 Basic answer that mentions crumple zones absorb energy or reduce force, without correctly applying the work-energy relationship or explaining the role of plastic deformation in the material. **1-2**

Indicative content:

- Work-energy principle: the kinetic energy of the car must be removed by the work done by the (average) resistive force over the stopping distance, W = F x d = initial KE.
- For a fixed initial kinetic energy, increasing the stopping distance d (by allowing the front of the car to crumple over some distance) reduces the average force F needed to stop the car, and hence reduces the deceleration and force transmitted to occupants.
- A rigid (non-deforming) car structure would stop over a much shorter distance, producing a much larger average force and deceleration, increasing injury risk.
- Materials principle: the crumple zone is made from a material designed to deform plastically (beyond its elastic limit) during the collision, rather than behave purely elastically.
- The energy absorbed by the material as it deforms is represented by the area under its force-extension (or stress-strain) graph; permanent (plastic) deformation absorbs much more energy than purely elastic deformation for a given force, converting kinetic energy into other forms (heat, sound, permanent structural change) rather than elastic strain energy that could otherwise be released back into the passenger cell.
- Overall: the combination of a longer controlled stopping distance (mechanics) and a material that absorbs energy through plastic deformation (materials) both act to reduce the force and deceleration experienced by occupants, improving safety.

Question 16

(a) h = 6.0 x sin(15) **M1**

(a) h = 1.55 m cao **A1**

(a) Answer: 1.55 m

(b) work against gravity = mgh = 40 x 9.81 x 1.55 **M1**

(b) work against friction = F x d = 45 x 6.0 = 270 J **M1**

(b) total work = 879 J (609 + 270) cao **A1**

(b) Answer: 879 J

(c) time per crate = 60/3 = 20 s **M1**

(c) power = work per crate / time per crate = 879.4 / 20 **M1**

(c) power = 44.0 W cao **A1**

(c) Answer: 44.0 W

(d) input power = output power / efficiency = 44.0 / 0.78 **M1**

(d) input power = 56.4 W cao **A1**

(d) Answer: 56.4 W

Question 17

(a) at the point of slipping, the maximum friction force equals the component of weight parallel to the ramp: F(friction, max) = mg $\sin(\theta_c)$ **M1**

(a) the normal reaction force equals the component of weight perpendicular to the ramp: N = mg $\cos(\theta_c)$ **M1**

(a) since F(friction, max) = μ N, dividing gives μ = mg $\sin(\theta_c)$ / (mg $\cos(\theta_c)$) = $\tan(\theta_c)$ **A1**

(a) Answer: μ = $\tan(\theta_c)$

(b) μ = tan(22 degrees) **M1**

(b) μ = 0.40 cao **A1**

(b) Answer: 0.40

(c) μ = tan(31 degrees) = 0.60 **M1**

(c) the second surface provides more grip, since it has the larger coefficient of friction cao **A1**

(c) Answer: μ = 0.60; the second surface provides more grip.