



GuideMyGrades

— YOUR GOALS. OUR EXPERTISE. —

EDEXCEL A LEVEL PHYSICS: QUESTIONS BY TOPIC

Materials (4)

A Level Physics Topic 4

90 questions · 567 marks · Mark schemes included

AS & A Level content · Pearson Edexcel 8PH0 / 9PH0 papers, 2016–2025

 [guidemygrades.com](https://www.guidemygrades.com)

 @Guidemygrades

 @Guidemygrades

 @Guidemygrades

 info@guidemygrades.com

 Piccadilly Business Centre, Unit C, Aldow Enterprise Park
Blackett Street, Manchester, M12 6AE

HOW TO USE THIS BOOKLET

Questions are grouped by specification sub-topic and run from the lowest mark tariff to the highest within each one.

Click any row below to jump straight to that sub-topic or question.

On every question page, click ANSWER in the top-right corner to jump to its mark scheme.

Diagrams, graphs, tables and data are printed exactly as they appeared in the original papers.

QUESTION	SOURCE	MARKS	PAGE
4.1 DENSITY, UPTHRUST AND FLOTATION		15 Qs · 111 marks	5
1. Q8	A Level Paper 2 June 2019	1	6
2. Q1	A Level Paper 2 June 2023	1	7
3. Q7	AS Paper 2 June 2024	1	8
4. Q8	AS Paper 2 June 2025	1	9
5. Q2 <i>also Topic 1</i>	A Level Paper 3 June 2017	5	10
6. Q2 <i>also Topic 1</i>	A Level Paper 3 June 2022	6	11
7. Q14	AS Paper 2 June 2023	7	12
8. Q16	A Level Paper 2 June 2017	8	14
9. Q3 <i>also Topic 1</i>	A Level Paper 3 June 2018	8	16
10. Q3 <i>also Topic 1</i>	A Level Paper 3 November 2021	9	18
11. Q7 <i>also Topic 1</i>	A Level Paper 3 June 2025	10	20
12. Q15	AS Paper 1 June 2019	11	22
13. Q17 <i>also Topic 9</i>	A Level Paper 2 June 2024	12	25
14. Q2 <i>also Topic 1</i>	A Level Paper 3 June 2024	15	28
15. Q11 <i>also Topic 1</i>	A Level Paper 3 June 2023	16	30
4.2 FLUID FLOW, VISCOSITY AND STOKES' LAW		20 Qs · 116 marks	33
16. Q4	AS Paper 2 June 2016	1	34
17. Q3	AS Paper 1 June 2017	1	35
18. Q2	AS Paper 2 October 2020	1	36
19. Q1 <i>also Topic 2</i>	A Level Paper 2 June 2022	1	37
20. Q5	A Level Paper 2 June 2023	1	38
21. Q3 <i>also Topic 2</i>	AS Paper 1 June 2023	1	39
22. Q7	A Level Paper 2 June 2025	1	40
23. Q1 <i>also Topic 2</i>	AS Paper 1 June 2025	1	41
24. Q7	AS Paper 2 June 2025	1	42
25. Q16	AS Paper 2 June 2018	5	43
26. Q14	A Level Paper 2 November 2021	6	44
27. Q13	A Level Paper 2 June 2018	7	46
28. Q10 <i>also Topic 1</i>	A Level Paper 3 June 2022	7	48
29. Q13	AS Paper 2 June 2017	9	50
30. Q12	AS Paper 2 June 2019	9	52
31. Q11 <i>also Topic 1</i>	AS Paper 2 June 2022	10	55



QUESTION	SOURCE	MARKS	PAGE
32. Q15	AS Paper 1 June 2016	11	57
33. Q12 <i>also Topic 9</i>	A Level Paper 3 June 2024	13	60
34. Q13	AS Paper 2 June 2024	14	64
35. Q8	A Level Paper 3 June 2025	16	66
4.3 HOOKE'S LAW, SPRINGS AND ELASTIC STRAIN ENERGY	23 Qs · 141 marks		70
36. Q2	A Level Paper 2 June 2017	1	71
37. Q1	AS Paper 2 June 2017	1	72
38. Q3	A Level Paper 2 June 2018	1	73
39. Q2	A Level Paper 2 June 2019	1	74
40. Q4 <i>also Topic 1</i>	AS Paper 2 June 2019	1	75
41. Q3	A Level Paper 2 October 2020	1	76
42. Q3	A Level Paper 2 November 2021	1	77
43. Q4	A Level Paper 2 November 2021	1	78
44. Q8	AS Paper 2 June 2023	1	79
45. Q8	A Level Paper 2 June 2024	1	80
46. Q3	AS Paper 2 June 2025	1	81
47. Q10	AS Paper 2 June 2018	4	82
48. Q1 <i>also Topic 1</i>	A Level Paper 3 June 2022	5	83
49. Q12	AS Paper 2 October 2020	7	85
50. Q6 <i>also Topic 3</i>	A Level Paper 3 June 2018	9	87
51. Q13	AS Paper 2 June 2022	9	89
52. Q16 <i>also Topic 1</i>	AS Paper 1 June 2024	11	91
53. Q15	AS Paper 1 November 2021	12	95
54. Q20 <i>also Topic 13</i>	A Level Paper 2 June 2022	12	98
55. Q16 <i>also Topic 13</i>	A Level Paper 2 June 2023	12	100
56. Q11 <i>also Topic 1</i>	A Level Paper 3 June 2017	14	103
57. Q10 <i>also Topic 1</i>	A Level Paper 3 October 2020	16	107
58. Q10 <i>also Topic 1</i>	A Level Paper 3 November 2021	19	110
4.4 STRESS, STRAIN AND THE YOUNG MODULUS	24 Qs · 152 marks		114
59. Q1	AS Paper 2 June 2018	1	115
60. Q5	A Level Paper 2 November 2021	1	116
61. Q6	AS Paper 2 November 2021	1	117
62. Q2	AS Paper 2 June 2022	1	118
63. Q4	A Level Paper 2 June 2023	1	119
64. Q2 <i>also Topic 1</i>	AS Paper 2 June 2023	1	120
65. Q10	A Level Paper 2 June 2024	1	121
66. Q6 <i>also Topic 1</i>	AS Paper 2 June 2024	1	122
67. Q1 <i>also Topic 1</i>	A Level Paper 2 June 2025	1	123
68. Q10 <i>also Topic 1</i>	AS Paper 2 October 2020	4	124
69. Q10 <i>also Topic 5</i>	AS Paper 2 November 2021	5	125



QUESTION	SOURCE	MARKS	PAGE
70. Q9	AS Paper 2 June 2019	7	126
71. Q10	AS Paper 2 June 2016	8	127
72. Q10	AS Paper 2 June 2023	8	129
73. Q16 <i>also Topic 3</i>	AS Paper 2 June 2017	9	131
74. Q18 <i>also Topic 5</i>	A Level Paper 2 June 2022	9	134
75. Q17 <i>also Topic 2</i>	AS Paper 2 November 2021	10	137
76. Q5 <i>also Topic 1</i>	A Level Paper 3 June 2023	10	139
77. Q19 <i>also Topic 9</i>	A Level Paper 2 June 2025	10	142
78. Q20	A Level Paper 2 June 2025	11	144
79. Q17	AS Paper 1 June 2023	12	147
80. Q16 <i>also Topic 13</i>	A Level Paper 2 June 2019	13	149
81. Q12 <i>also Topic 1</i>	AS Paper 2 June 2024	13	152
82. Q13	AS Paper 2 June 2025	14	155
4.5 MATERIAL PROPERTIES AND STRESS-STRAIN GRAPHS		8 Qs · 47 marks	158
83. Q3	AS Paper 2 June 2016	1	159
84. Q1	AS Paper 2 June 2019	1	160
85. Q9	AS Paper 2 June 2018	6	161
86. Q12 <i>also Topic 5</i>	AS Paper 2 June 2022	6	162
87. Q10 <i>also Topic 6</i>	A Level Paper 3 June 2019	8	164
88. Q15 <i>also Topic 2</i>	AS Paper 2 June 2019	8	166
89. Q1 <i>also Topic 1</i>	A Level Paper 3 June 2024	8	169
90. Q16	AS Paper 1 June 2016	9	171



QUESTIONS

90 questions · 567 marks · 5 sub-topics



SUB-TOPIC 4.1

DENSITY, UPTHRUST AND FLOTATION

Sub-topic 4.1 · 15 questions · 111 marks · lowest tariff first



8 An object of volume V made from a material of density ρ_1 is placed into a fluid of density ρ_2 .

Which of the following gives the upthrust on the object?

☐ A $\rho_1 Vg$

☐ B $\rho_2 Vg$

☐ C $(\rho_2 - \rho_1) Vg$

☐ D $\frac{(\rho_2 + \rho_1)}{2} Vg$

(Total for Question 8 = 1 mark)



- 1 A sphere of radius r is made from material of density ρ_M . The sphere is fully immersed in a liquid of density ρ_L .

Which of the following expressions gives the upthrust on the sphere?

- ☐ A $4\pi r^2 \rho_M$
- ☐ B $\frac{4}{3} \pi r^3 \rho_M g$
- ☐ C $\frac{4}{3} \pi r^3 \rho_L g$
- ☐ D $4\pi r^2 \rho_L g$

(Total for Question 1 = 1 mark)



7 A ball bearing with radius r falls through a fluid with density ρ .

Which of the following is an expression for the upthrust acting on the ball bearing?

- ☐ A $\frac{4\pi r^3 \rho}{3}$
- ☐ B $\frac{4\pi r^3 \rho g}{3}$
- ☐ C $\frac{4\pi r^3 g}{3\rho}$
- ☐ D $4\pi r^2 \rho g$

(Total for Question 7 = 1 mark)



Questions 7 and 8 refer to the experiment described below.

A falling-ball method is used to determine the viscosity of a liquid. The liquid is in a tall container.

A ball bearing is released at the top of the container and falls through the liquid.

8 The ball bearing has a volume V and falls through a liquid of density ρ .

Which of the following is an expression for the upthrust acting on the ball bearing?

☐ A $V\rho g$

☐ B $\frac{Vg}{\rho}$

☐ C $\frac{V}{\rho g}$

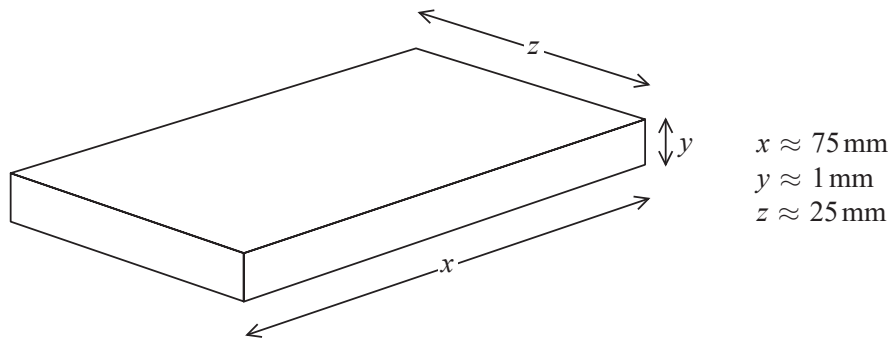
☐ D $\frac{\rho g}{V}$

(Total for Question 8 = 1 mark)



- 2 A student carries out measurements to determine the density of glass. The student has 20 glass microscope slides available.

The approximate dimensions of one slide are shown.



- (a) The density is calculated using the equation

$$\text{density} = \frac{\text{mass}}{\text{volume}}$$

Describe how the student can determine an accurate value for the density of the glass.
Your answer should include the measuring instruments required.

(4)

.....

.....

.....

.....

.....

.....

.....

.....

.....

- (b) State one precaution that the student should take to ensure the measurements are accurate.

(1)

.....

.....

(Total for Question 2 = 5 marks)



- 2 A student was given a box of identical glass microscope slides and asked to determine the density of the glass. She used a micrometer to measure the thickness of one of the slides. She repeated this measurement twice in different places and calculated a mean value for the thickness. The thickness of each slide was approximately 1 mm.

- (a) Explain how she should have measured the thickness of the slides in order to minimise the percentage uncertainty.

(2)

- (b) In her report she wrote

"My value for the mass of the glass slides was precise, because I measured the mass using an electronic balance which was accurate to the nearest 0.01g. I reduced the effect of random error by repeating the measurement several times."

Comment on this statement.

(4)

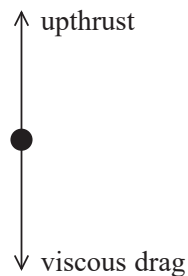
(Total for Question 2 = 6 marks)



14 Carbon monoxide gas is produced in a pond by the decay of organic matter.

- (a) A bubble of carbon monoxide rises at a steady speed through the still water of the pond. The weight of the bubble is negligible.

The free-body force diagram below shows the forces acting on the bubble.



diameter of bubble = 1.5 mm

- (i) Show that the upthrust acting on the bubble is about $1.7 \times 10^{-5} \text{ N}$.

density of water = 997 kg m^{-3}

(3)

.....

.....

.....

.....

.....

.....



(ii) Calculate the steady speed at which the bubble rises.

viscosity of water = 0.0011 Pa s

(2)

.....

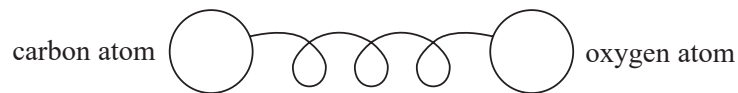
.....

.....

Speed = ...

(b) A molecule of carbon monoxide consists of one atom of carbon bonded to one atom of oxygen.

The bond between the two atoms can be modelled as a spring as shown.



The spring has a stiffness constant k .

At equilibrium the distance d between the two atoms is 12 nm .

External forces caused d to increase to 18 nm .

Calculate the increase in the potential energy between the two atoms.

$k = 1195 \text{ N m}^{-1}$

(2)

.....

.....

.....

.....

Increase in potential energy = ...

(Total for Question 14 = 7 marks)



16 A student is investigating a ‘Cartesian diver’.

The diver is made from a plastic pipette. When placed in a plastic bottle full of water the diver rises to the top and touches the lid.



(a) Show that the downward force of the lid on the diver is about 0.02 N.

volume of diver = $8.0 \times 10^{-6} \text{ m}^3$

mass of diver = 0.0059 kg

density of water = $1.0 \times 10^3 \text{ kg m}^{-3}$

(3)

.....

.....

.....

.....

.....

.....

- (b) When the pressure is increased by squeezing the bottle, water is forced into the diver increasing its weight. The diver sinks, then remains at rest in the position shown.



The volume of air in the empty pipette in part (a) was $8.0 \times 10^{-6} \text{ m}^3$.

Show that the volume now occupied by the air is about $6 \times 10^{-6} \text{ m}^3$.

(3)

.....

.....

.....

.....

.....

.....

- (c) The pressure of the air in the empty pipette in part (a) was $1.01 \times 10^5 \text{ Pa}$.

Calculate the pressure of the air in part (b).

(2)

.....

.....

.....

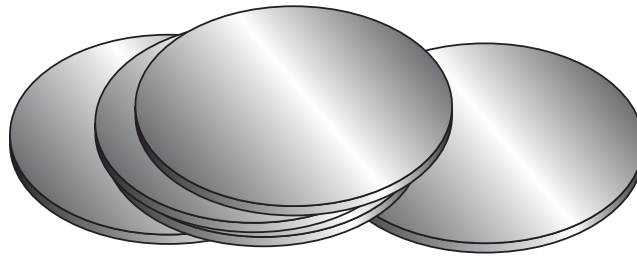
.....

.....

Pressure = ...

(Total for Question 16 = 8 marks)

- 3 A student is investigating the properties of steel. He has fifty steel discs available.



Each disc has a diameter $d \approx 1.3$ cm and a thickness $t \approx 2$ mm.

- (a) State a suitable measuring instrument that could be used with a single disc to measure t .

(1)

- (b) A balance which can measure mass with a resolution of 0.2 g is available.

Determine the minimum number of discs that should be placed on the balance together if the percentage uncertainty in the measurement of the mass is to be less than 0.5%.

(4)

density of steel = 7900 kg m^{-3}

Minimum number of discs = ...

- (c) The measured uncertainty in d is ± 0.1 mm and the measured uncertainty for t is ± 0.05 mm.

Determine the percentage uncertainty in the calculated volume of the disc.

(3)

.....

.....

.....

.....

.....

.....

.....

.....

Percentage uncertainty in volume = ...

(Total for Question 3 = 8 marks)



- 3 Genuine crystal balls are made from clarified quartz rather than glass.
A student was given a small crystal ball and wanted to know whether it was genuine.

- (a) The mean diameter of the crystal ball was measured to be 5.06 cm and the mass of the crystal ball was measured to be 175 g.

Show that the density of the material of the crystal ball is about 2600 kg m^{-3} .

(3)

.....

.....

.....

.....

.....



- (b) The student measured the diameter of the crystal ball using vernier calipers with a resolution of 0.01 cm.

She measured the mass of the crystal ball using a balance with a resolution of 1 g.

The table gives the densities of clarified quartz and glass.

Material	Density / kg m^{-3}
Clarified quartz	2650
Glass	2590

Determine whether the crystal ball was genuine.

(6)

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

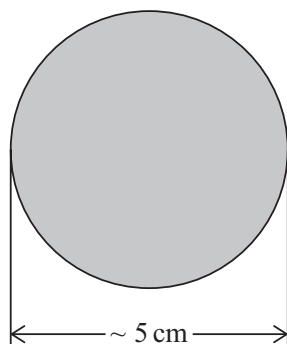
.....

(Total for Question 3 = 9 marks)

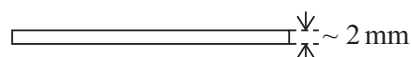


- 7 A student has 10 identical flat metal discs. One of the discs is shown. Each disc has a diameter d of about 5 cm and a thickness t of about 2 mm.

View of disc from above



Side view of disc



The student determined the density of the metal the discs are made from.

She used a half-metre rule to measure d for one of the discs. She used vernier calipers to measure t for one of the discs.

The student then repeated this process for two more discs and calculated average values for d and t of the discs.

- (a) Describe improvements to the student's method that would give more accurate values for d and t of the discs.

(4)

- (b) The student determined the average mass of a disc to be $42.5 \text{ g} \pm 0.5 \text{ g}$.

Calculate the density of the material the discs are made from and the percentage uncertainty in this value.

average diameter of disc = $5.2 \text{ cm} \pm 0.1 \text{ cm}$

average thickness of disc = $1.9 \text{ mm} \pm 0.1 \text{ mm}$

(6)

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

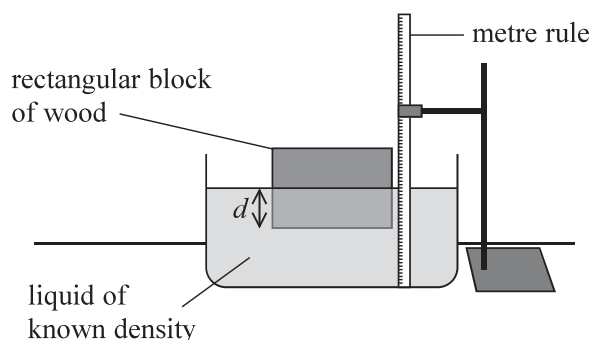
Density = ...

Percentage uncertainty = ...

(Total for Question 7 = 10 marks)



- 15** A student investigated the flotation of a solid rectangular block of wood on the surface of liquids with different densities. A metre rule immersed in the liquid was used to measure the depth d of the block below the surface of the liquid as shown. The wood had a density ρ_s and the block was of height x .



The student predicted that the relationship between the density ρ_L of the liquid and the depth d of the block below the liquid would be

$$\rho_L = \frac{\rho_s x}{d}$$

- (a) The student's results are shown in the table.

She decided to check her prediction by plotting a graph of ρ_L against $\frac{1}{d}$.

Plot the graph on the grid opposite, using the additional column of the table for your processed data.

(5)

Liquid	$\rho_L / \text{kg m}^{-3}$	d / m	
Honey	1420	0.035	
Corn syrup	1330	0.040	
Seawater	1030	0.050	
Vegetable oil	920	0.055	
Baby oil	830	0.060	

A large rectangular area filled with a fine grid of squares, typical of graph paper used for scientific plotting or calculations. The grid is composed of many small squares, with slightly thicker lines forming a larger grid pattern.

(b) Explain how the data supports the student’s prediction.

(2)

(c) The table gives the densities of several different types of wood.

Wood	Density / kg m ⁻³
Birch	670
Chestnut	570
Oak	780
Poplar	350

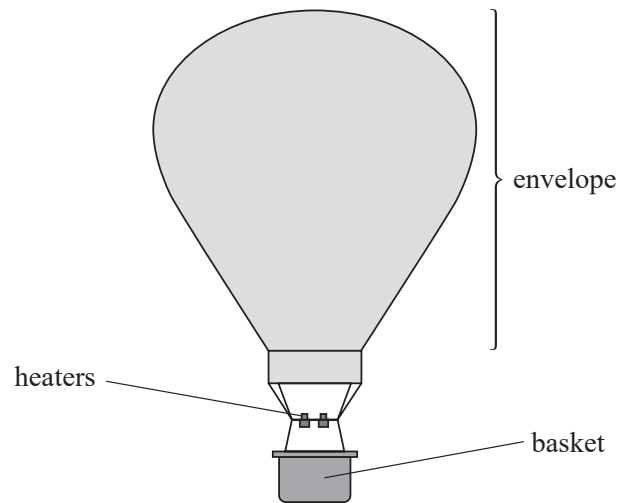
Deduce the type of wood from which the block was made.

$x = 9.0\text{ cm}$

(4)

(Total for Question 15 = 11 marks)

17 (a) A hot air balloon consists of a fabric envelope, heaters and a basket, as shown.



When the balloon is set up, the envelope is partly filled with air at 20°C . The air is then heated to 120°C and expands to fill the envelope and becomes less dense.

The air pressure inside the envelope is always equal to the air pressure outside the envelope because the envelope is open at the bottom.

The balloon takes off when the upthrust is more than the total weight of the balloon, the air in the envelope and the passengers.

Deduce whether the balloon can take off.

volume of air at 120°C in inflated envelope = 2800 m^3

density of air at 20°C = 1.2 kg m^{-3}

mass of balloon = 380 kg

mass of passengers = 340 kg

upthrust when the envelope is full = $33\,000\text{ N}$

(6)



(b) (i) State one assumption of the kinetic theory of gases.

(1)

(ii) Derive an equation to show that, for a gas at temperature T ,

the mean kinetic energy of the molecules = $\frac{3}{2} kT$

(2)



- (iii) Calculate the root-mean-square speed of nitrogen molecules at a temperature of 120°C .

mass of nitrogen molecule = 28 u

(3)

.....

.....

.....

.....

.....

Root-mean-square speed = ...

(Total for Question 17 = 12 marks)



- 2 A student made measurements to determine if some gold coins were made from pure gold. The coins that were available to the student are shown below.



(Source: © Bjoern Wylezich/Shutterstock)

- (a) The student used digital calipers to measure the thickness t and the diameter d of one of the coins.

- (i) Calculate the volume V of the coin, and the percentage uncertainty in V .

$$t = 1.54 \text{ mm}$$

$$d = 22.16 \text{ mm}$$

(7)

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

$$V = \text{.....}$$

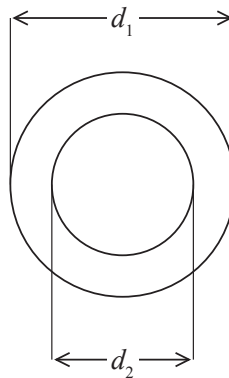
$$\text{Percentage uncertainty in } V = \text{.....}$$

- 11 The photograph shows some metal washers. A student carried out an experiment to determine the density of the metal the washers are made from.



(Source: © NJH Photography/Shutterstock)

Each washer has a diameter d_1 of about 4.5 cm. The internal diameter d_2 of each washer is about 2.5 cm. Each washer has a thickness t of about 4 mm.



- (a) The student used a half metre rule to make measurements of a washer.

Comment on the student's choice of measuring instrument.

(3)

.....

.....

.....

.....

.....

.....

- (b) The student measured t for each of the five washers and then calculated a mean value.

Explain how the student could modify her method to obtain a more accurate mean value for t .

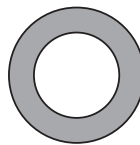
(3)

- (c) The student obtained the following mean values.

$$d_1 = 4.52 \text{ cm} \pm 0.02 \text{ cm}$$

$$d_2 = 2.53 \text{ cm} \pm 0.02 \text{ cm}$$

She calculated the area A of a washer indicated by the shaded section below.



She used the formula $A = \frac{\pi}{4}(d_1 + d_2)(d_1 - d_2)$

- (i) Show that the percentage uncertainty in her value for the area of a washer is about 3%.

(4)



SUB-TOPIC 4.2

FLUID FLOW, VISCOSITY AND STOKES' LAW

Sub-topic 4.2 · 20 questions · 116 marks · lowest tariff first



4 A bubble of air is rising through a vertical column of water.

Which statement, about the motion of the bubble, is correct to a good approximation?

- ☐ A The bubble has a constant velocity because its weight equals the viscous drag.
- ☐ B The bubble has a constant velocity because the upthrust is equal to the viscous drag.
- ☐ C The bubble has an acceleration because its weight is greater than the upthrust.
- ☐ D The bubble has an acceleration because the viscous drag is greater than the upthrust.

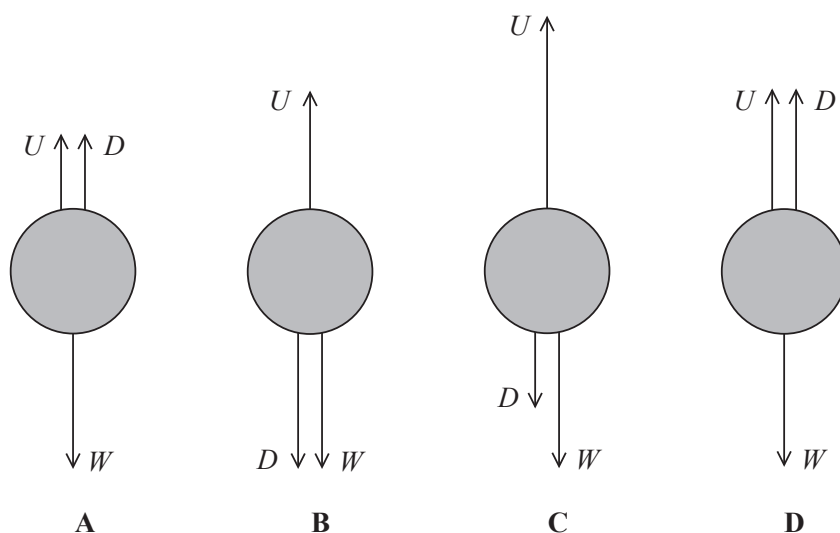
(Total for Question 4 = 1 mark)



3 A small plastic bead is released below the surface of water and rises towards the surface.

The diagrams show the forces acting on the bead as it rises with constant velocity.

U = upthrust, D = drag, W = weight



Which diagram correctly represents the directions and relative magnitudes of the forces?

- ☐ A
- ☐ B
- ☐ C
- ☐ D

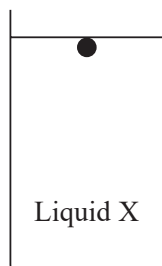
(Total for Question 3 = 1 mark)

- 2 In a falling-ball method to investigate the viscosity of a liquid, ball bearings with two different diameters are allowed to fall through two different liquids, X and Y. The viscosity of liquid X is greater than the viscosity of liquid Y.

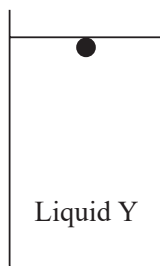
In which set-up shown below will the ball bearing have the greatest terminal velocity?

ball bearing with small diameter

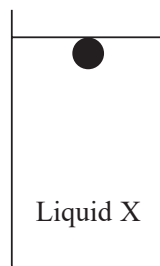
ball bearing with large diameter



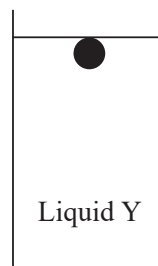
A



B



C



D

☐ A

☐ B

☐ C

☐ D

(Total for Question 2 = 1 mark)

- 1 A skydiver steps out of an aeroplane and falls from rest, towards the ground. Her parachute opens a short time after she reaches terminal velocity.

Which of the following statements is correct for the vertical acceleration a of the skydiver until her parachute opens?

- ☐ A a decreases to zero
- ☐ B a increases to a maximum
- ☐ C a is constant and equal to g
- ☐ D a is constant but less than g

(Total for Question 1 = 1 mark)



- 5 A raindrop is falling through the air with an increasing velocity. The forces on the raindrop are weight W , upthrust U and viscous drag F .

Which of the following shows the relationship between these forces?

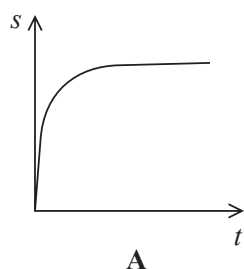
- ☐ A $F + U = W$
- ☐ B $F = W + U$
- ☐ C $F + W < U$
- ☐ D $F + U < W$

(Total for Question 5 = 1 mark)

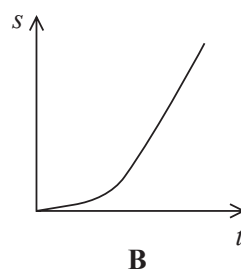


3 A ball falls from rest through glycerine and reaches terminal velocity.

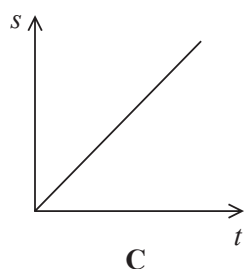
Which of the following graphs shows how displacement s varies with time t for the ball?



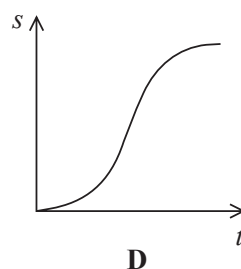
A



B



C



D

- ☐ A
- ☐ B
- ☐ C
- ☐ D

(Total for Question 3 = 1 mark)

7 A small ball bearing falls slowly through a liquid at terminal velocity. The temperature of the liquid is increased.

Which row of the table shows the change in viscosity of the liquid and the change in terminal velocity of the ball bearing?

	Viscosity of liquid	Terminal velocity of ball bearing
☒ A	increases	increases
☒ B	increases	decreases
☒ C	decreases	increases
☒ D	decreases	decreases

(Total for Question 7 = 1 mark)

1 A ball bearing falls from rest through oil.

Which of the following statements is correct during the initial motion of the ball bearing?

- ☐ **A** The resultant force on the ball bearing decreases.
- ☐ **B** The resultant force on the ball bearing increases.
- ☐ **C** The resultant force on the ball bearing decreases then increases.
- ☐ **D** The resultant force on the ball bearing stays constant.

(Total for Question 1 = 1 mark)



Questions 7 and 8 refer to the experiment described below.

A falling-ball method is used to determine the viscosity of a liquid. The liquid is in a tall container.

A ball bearing is released at the top of the container and falls through the liquid.

- 7 Which row of the table gives two conditions for Stokes' law to apply to the ball bearing as it falls?

	Diameter of ball bearing relative to diameter of container	Speed of ball bearing
☐ A	large	fast
☐ B	large	slow
☐ C	small	fast
☐ D	small	slow

(Total for Question 7 = 1 mark)



16 A small helium balloon is released into the air. The balloon initially accelerates upwards.

The resultant force F on the balloon is given by

$$F = \text{upthrust} - \text{weight} - \text{viscous drag}$$

(a) Eventually the balloon reaches a constant upwards speed.

Calculate a value for the viscous drag force acting on the balloon at this speed.

The balloon may be considered as a sphere with radius 12 cm.

(4)

density of air = 1.2 kg m^{-3}

mass of unfilled balloon = 4.0 g

mass of helium in balloon = 1.2 g

.....

.....

.....

.....

.....

.....

.....

.....

.....

Viscous drag force = ...

(b) The viscosity of the air decreases as the balloon rises.

On a warmer day a balloon of the same total mass and radius rises at a lower constant upwards speed.

Give a reason why.

(1)

.....

.....

(Total for Question 16 = 5 marks)



14 A student investigated the terminal velocity of steel spheres falling through oil.

The student obtained the following results.

radius of steel sphere = 1.50 mm

volume of steel sphere = $1.41 \times 10^{-8} \text{ m}^3$

mass of steel sphere = $1.10 \times 10^{-4} \text{ kg}$

maximum speed of sphere = 0.849 m s^{-1}

The student had the following table.

Type of oil	Density at 26°C/kg m ⁻³	Viscosity at 26°C/Pa s
Corn	918	0.0447
Hazelnut	918	0.0504
Sunflower	918	0.0414

(a) Identify which type of oil the student used.

(4)

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....



(b) The values in the table are for oil at 26 °C.

Explain the effect of carrying out the investigation with oil at a lower temperature.

(2)

(Total for Question 14 = 6 marks)



13 Raindrops of different sizes fall with different terminal velocities through air.

The table shows the measured value of the terminal velocity for raindrops of different sizes.

Raindrop size	Drop diameter / mm	Terminal velocity / m s ⁻¹
small	0.5	2.1
medium	2.0	6.5
large	5.0	9.1

(a) Derive, using Stokes' law, the following expression for the terminal velocity v of a spherical raindrop in terms of its radius r .

$$v = \frac{2g\rho r^2}{9\eta}$$

where ρ is the density of rainwater and η is the viscosity of air.

You should ignore upthrust.

(2)

- (b) Show that the expression given in (a) produces a value of about 800 m s^{-1} for the terminal velocity of a large raindrop.

(2)

$$\rho = 1.0 \times 10^3 \text{ kg m}^{-3}$$

$$\eta = 1.8 \times 10^{-5} \text{ Pa s}$$

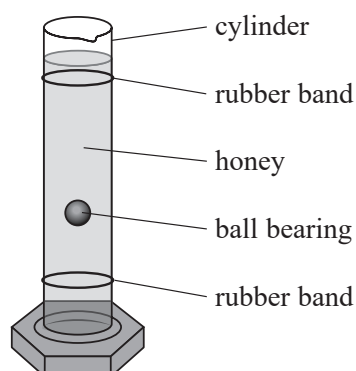
- (c) Explain whether Stokes' law is suitable for calculating the terminal velocity of raindrops.

(3)

(Total for Question 13 = 7 marks)



- 10 A student carried out an experiment to determine the viscosity of some honey. He filled a tall glass cylinder with honey as shown, and timed a ball bearing as it fell through the honey.



- (a) The student placed rubber bands near the top and bottom of the cylinder. He started a stopwatch when the ball bearing passed the first band and stopped the stopwatch when the ball bearing passed the second band. He repeated this several times to determine a mean time.

Criticise the student's method.

(2)

.....

.....

.....

.....

- (b) The time t for the sphere to fall through a distance of 25.0 cm is shown in the table.

t/s			
6.40	6.35	6.36	6.38

- (i) Show that the mean velocity v of the ball bearing is about 0.04 m s^{-1} .

(3)

.....

.....

.....

.....

- (ii) The student had three different types of honey available.

Viscosity η is given by the following expression

$$\eta = \frac{2r^2 g (\rho_B - \rho_H)}{9v}$$

radius r of ball bearing = $5.50 \times 10^{-3} \text{ m}$

density of ball bearing $\rho_B = 7750 \text{ kg m}^{-3}$

density of honey $\rho_H = 1360 \text{ kg m}^{-3}$

Viscosity (at 20 °C) / Pa s		
Honey A	Honey B	Honey C
10.6	12.5	13.6

Deduce which honey the student used.

(2)

.....

.....

.....

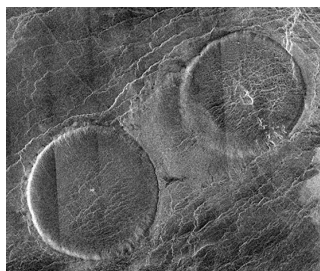
.....

.....

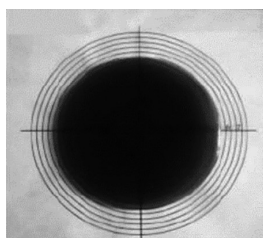
(Total for Question 10 = 7 marks)



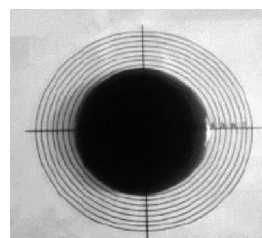
- 12 The photograph shows an image of two “pancake” volcanoes on the surface of the planet Venus. Scientists believe these types of volcano are formed from lava spreading out in all directions onto a flat landscape.



A student investigated the formation of pancake volcanoes. She observed the flow of a viscous liquid at two different temperatures as it spread out from a central spot. The photographs below show the liquid at both temperatures after it had been flowing for the same length of time.



High temperature test



Low temperature test

- (a) Scientists believe that the high temperature of lava when it erupts is one factor that allows the lava to spread out over a large area.

Explain how the student's investigation supports this idea.

(2)

.....

.....

.....

.....

- (b) The student carried out an experiment to determine the viscosity of the liquid at room temperature. She observed a steel sphere falling through the liquid.

She had the following equipment:

- a long, wide cylindrical tube
- two steel spheres with diameters 7.0 mm and 22.0 mm
- video camera
- metre rule

The student observed the sphere with a diameter of 7.0 mm falling through the liquid. The sphere fell 0.80 m in 5.3 s at a constant velocity.

The viscosity η of the liquid can be calculated using the equation

$$\eta = \frac{Vg(\rho_s - \rho_l)}{6\pi r v}$$

providing Stokes' law applies.

- (i) Calculate the viscosity of the liquid.

density of liquid $\rho_l = 1430 \text{ kg m}^{-3}$

density of steel $\rho_s = 7800 \text{ kg m}^{-3}$

(4)

.....

.....

.....

.....

.....

.....

.....

.....

Viscosity of liquid = ... Pa s



- (ii) If the student had used the larger sphere, the equation would not have produced the correct answer.

Explain why.

(2)

- (iii) The student used the video camera to record the sphere falling through the liquid.

State **one** benefit of using the video camera to record the motion of the sphere.

(1)

(Total for Question 12 = 9 marks)



- 11 A student used steel ball bearings falling through a viscous liquid to investigate the relationship between the terminal velocity v of a ball bearing and its radius r .

(a) The student used ball bearings with different radii.

Describe how the student can make measurements of the ball bearing to determine its radius.

(3)

.....

.....

.....

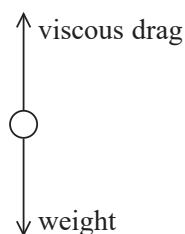
.....

.....

.....

- (b) A free body force diagram for a ball bearing of radius 5.00 mm falling through the liquid is shown. The upthrust on the ball bearing has been ignored.

Diagram **NOT** to scale



- (i) Show that the weight of a ball bearing with a radius of 5.0 mm is about 4×10^{-2} N.

density of steel = $8.0 \times 10^3 \text{ kg m}^{-3}$

(3)

.....

.....

.....

.....

.....

.....



- (ii) Calculate the terminal velocity of the ball bearing as it falls through the liquid.
You may ignore the upthrust on the ball bearing.

viscosity of liquid = 1.8 Pa s

(2)

Terminal velocity = ...

- (c) Explain how the student can ensure that Stokes' law will apply to the ball bearings falling through the viscous liquid.

(2)

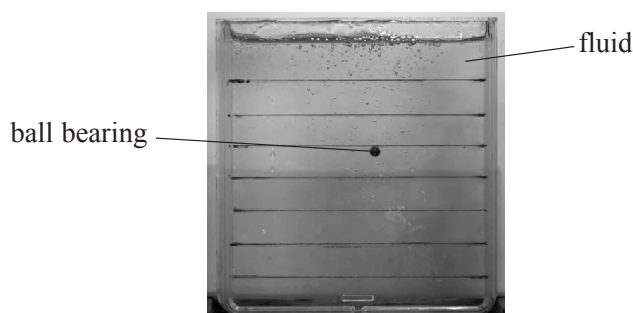
(Total for Question 11 = 10 marks)



15 A student carried out an experiment to identify a fluid from its viscosity at room temperature.

A ball bearing of diameter d was released at the top of a container containing the fluid. The motion of the ball bearing was recorded using a video camera and hence the terminal velocity v of the ball bearing was determined.

This was repeated for ball bearings of increasing diameter with the fluid at a constant temperature.



(a) To determine the viscosity η , the student used the equation $v = \frac{d^2 g (\rho_b - \rho_f)}{18\eta}$

where ρ_b = density of the material of the ball bearing

ρ_f = density of the fluid.

Explain why a graph of v on the y -axis and d^2 on the x -axis should be a straight line through the origin.

(3)

.....

.....

.....

.....

.....

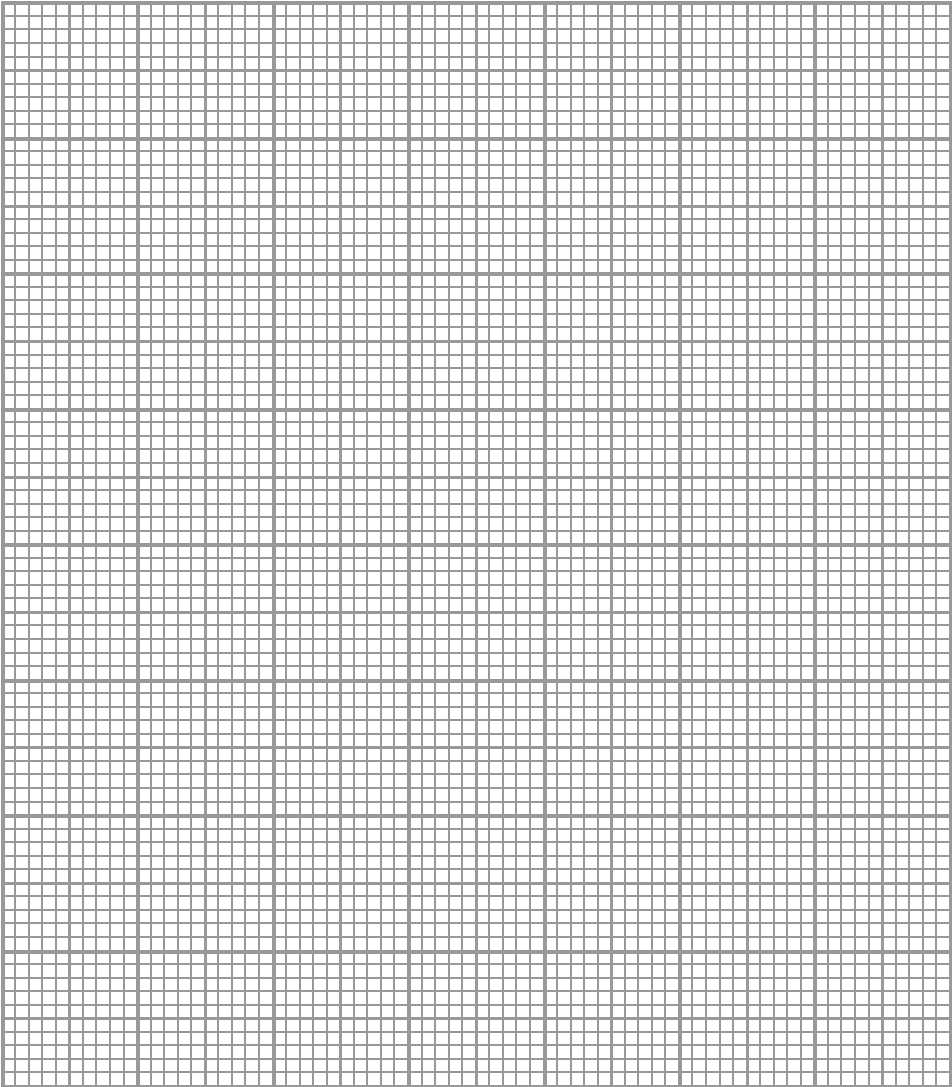
.....

(b) The student obtained the following data.

$d / 10^{-3} \text{ m}$	$d^2 / 10^{-6} \text{ m}^2$	$v / 10^{-3} \text{ m s}^{-1}$
1.0	1.0	2.3
2.0	4.0	11
3.0	9.0	23
4.0	16.0	39
5.0	25.0	64

Plot the graph of v against d^2 .

(4)



(c) The table shows the viscosity of some different fluids.

Fluid	Viscosity at room temperature / Pa s
castor oil	1.0
glycerol	1.2
corn syrup	1.4
honey	1.9

Use the graph to deduce which fluid the student used.

density of ball bearing = 8000 kg m^{-3}

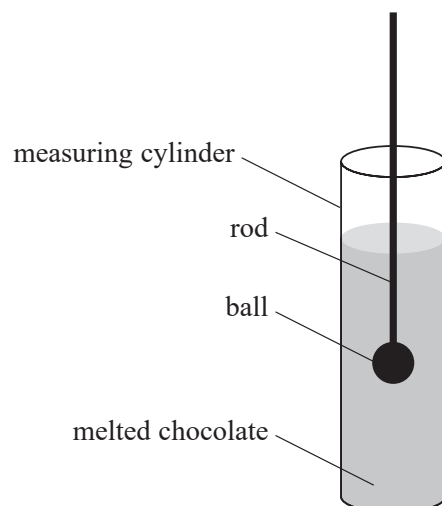
density of fluid = 1260 kg m^{-3}

(4)

(Total for Question 15 = 11 marks)

12 Chocolate is a solid at room temperature, but melts just below body temperature.

- (a) A student investigated the viscosity of some melted chocolate using a falling-ball method. Since chocolate is opaque, a thin rod was attached to the ball so that the movement of the ball could be monitored. The apparatus is shown in the diagram.



The chocolate was maintained at a constant temperature during the investigation.

- (i) The student used a stopwatch to measure the time t for the ball to fall 22.5 cm whilst travelling at its terminal velocity v .

Her results are shown in the table.

t_1 / s	t_2 / s	t_3 / s
9.6	9.9	9.6

v is given by the formula

$$v = \frac{2r^2g(\rho_B - \rho_C)}{9\eta}$$

where

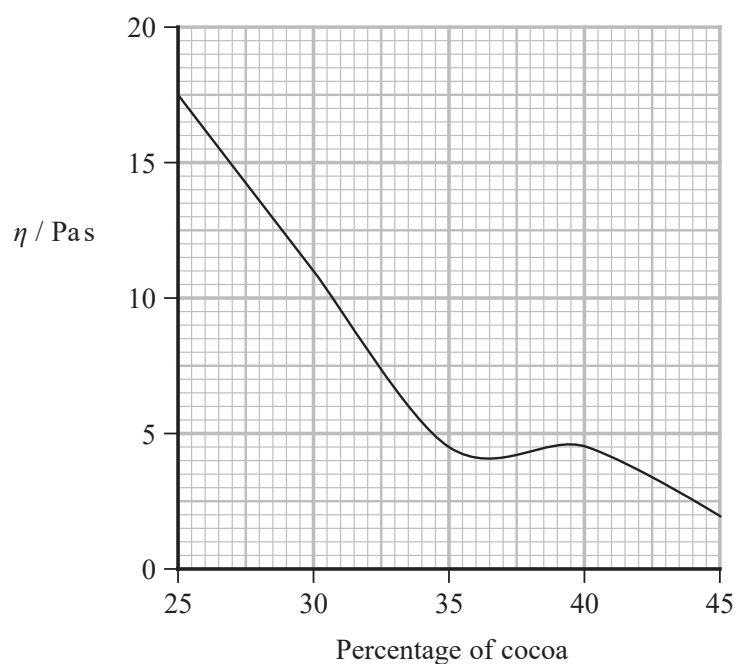
r is the radius of the ball

ρ_B is the density of the ball

ρ_C is the density of the chocolate

η is the viscosity of the chocolate.

The graph is taken from a commercial website. It shows how, at the temperature of the experiment, η depends on the percentage of cocoa in the chocolate.



The chocolate wrapper indicated that the chocolate had a 35% cocoa content.

Assess whether the student's timing data supports this percentage cocoa content.

$$r = 4.25 \times 10^{-3} \text{ m}$$

$$\rho_B = 7750 \text{ kg m}^{-3}$$

$$\rho_C = 1330 \text{ kg m}^{-3}$$

(5)

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....



- (ii) Explain one reason why the student's data may have led to an inaccurate conclusion about the cocoa content.

(2)



(b) One type of chocolate melts at a temperature of 32°C .

The energy released when 65 g of this chocolate is digested is 345 kcal.

It is suggested that the energy used to melt a piece of this chocolate is at least 15% of the energy released when the chocolate is digested.

Assess the accuracy of this suggestion.

initial temperature of chocolate = 15°C

specific heat capacity of chocolate = $3.9 \times 10^3 \text{ J kg}^{-1} \text{ K}^{-1}$

specific latent heat of chocolate = $1.50 \times 10^5 \text{ J kg}^{-1}$

1 kcal = 4200 J

(6)

(Total for Question 12 = 13 marks)



- (c) (i) A ball bearing fell at terminal velocity through a liquid.

The ball bearing fell 0.75 m in a time of 3.4 s.

viscosity of liquid = 1.8 Pa s

radius of ball bearing = 5.0 mm

Calculate the viscous drag force on the ball bearing.

(3)

.....

.....

.....

.....

.....

.....

Viscous drag force = ...

- (ii) A student considers what would happen if the temperature of the liquid increases.

The student writes the following statement.

"When the temperature of the liquid increases the viscosity decreases. Therefore, when the ball bearing is falling at terminal velocity the viscous drag force will be less."

Assess the validity of the student's statement.

(3)

.....

.....

.....

.....

.....

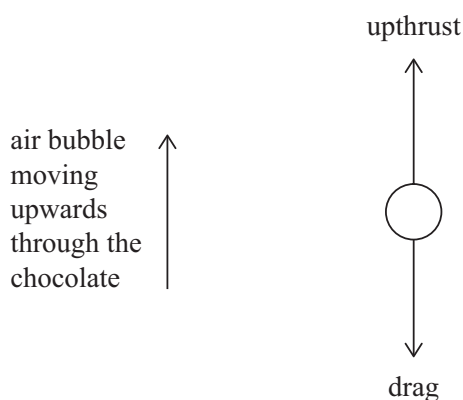
.....

(Total for Question 13 = 14 marks)



8 An object moving through a fluid experiences a drag force due to the viscosity of the fluid.

- (a) Some liquid chocolate is poured into a mould. Within the chocolate a bubble of air is formed. The bubble has negligible weight and moves upwards at a constant speed, as shown.



Calculate the constant speed at which the air bubble moves upwards in the liquid chocolate.

radius of air bubble = $6.8 \times 10^{-3} \text{ m}$

density of liquid chocolate = 925 kg m^{-3}

viscosity of liquid chocolate = 52.6 Pa s

(5)

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

Speed air bubble moves upwards = ...

- (b) The viscosity of a gas increases with temperature.
- (i) It is suggested that the relationship between viscosity η and temperature T is of the form

$$\eta = AT^B$$

where A and B are constants.

Explain why a graph of $\log \eta$ against $\log T$ would give a straight line.

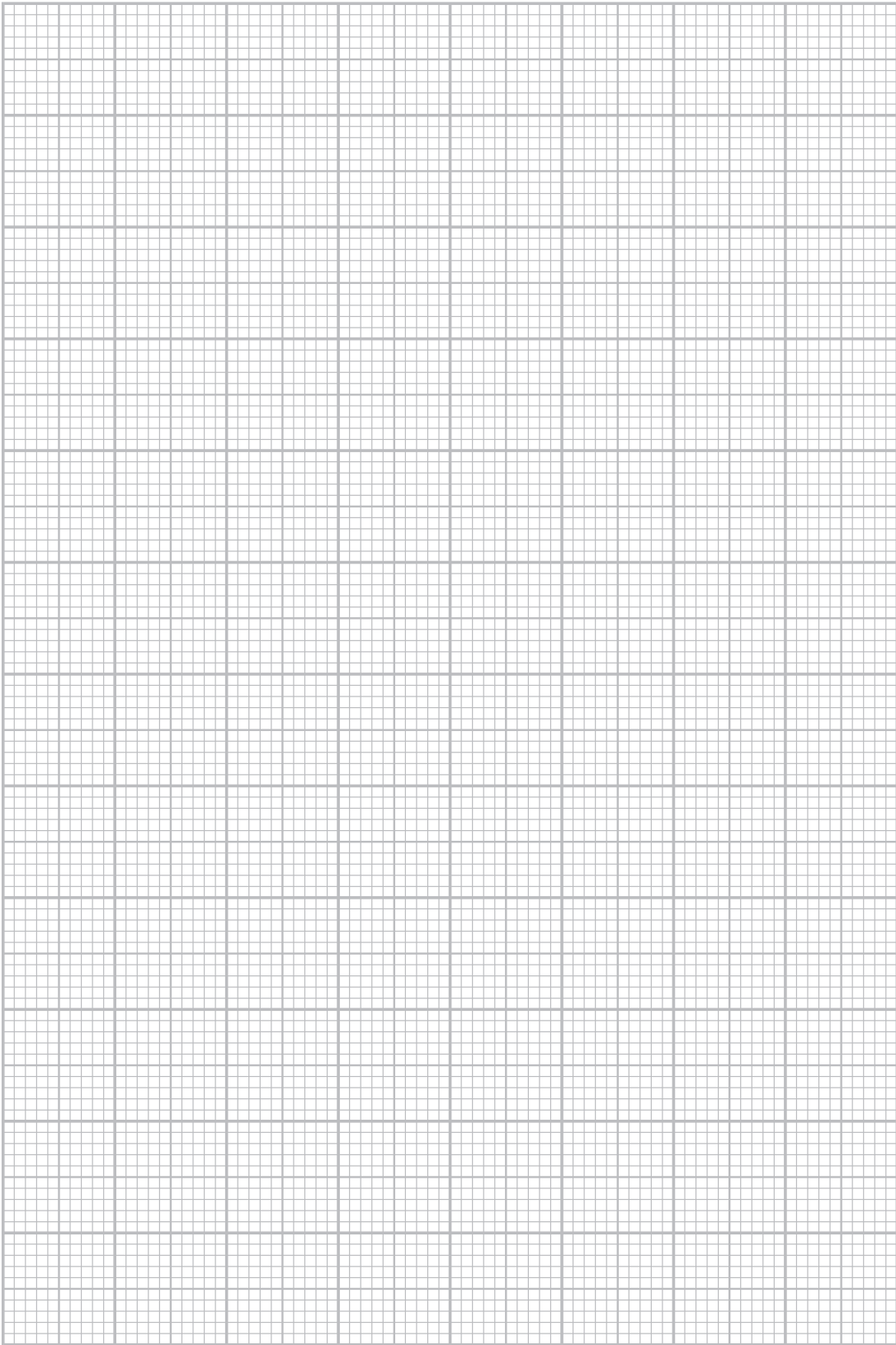
(2)

- (ii) The table shows data for the viscosity of hydrogen gas over a range of temperatures.

T/K	$\eta/\text{mPa s}$		
123	4.60		
173	6.00		
273	8.30		
373	10.4		
473	12.0		

Plot a graph of $\log \eta$ against $\log T$. You should use the columns provided to show any processed data.

(5)



(iii) Determine values for A and B . You are not required to state the units of A .

(4)

.....

.....

.....

.....

.....

.....

$A =$

$B =$

(Total for Question 8 = 16 marks)

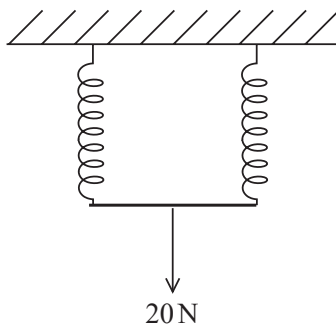
SUB-TOPIC 4.3

HOOKE'S LAW, SPRINGS AND ELASTIC STRAIN ENERGY

Sub-topic 4.3 · 23 questions · 141 marks · lowest tariff first



- 2 Two identical springs are arranged side by side as shown.



When a force of 20 N is applied, an extension of 8 cm is obtained.

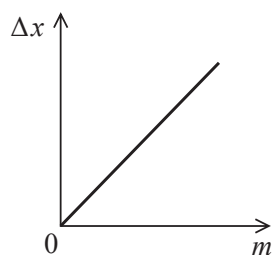
A force of 5 N is applied to one of the springs on its own.

Which of the following is the extension obtained?

- ☐ A 2 cm
- ☐ B 4 cm
- ☐ C 8 cm
- ☐ D 16 cm

(Total for Question 2 = 1 mark)

- 1 A spring is hung vertically and masses are added to the lower end.
The graph shows how the extension Δx of the spring varies with the mass m added.



The work done in extending the spring can be expressed as

- ☐ A $mg\Delta x$
- ☐ B $\frac{mg}{\Delta x}$
- ☐ C $\frac{1}{2}mg\Delta x$
- ☐ D $\frac{mg}{2\Delta x}$

(Total for Question 1 = 1 mark)

3 A deforming force is applied to a sample of material.

Which row of the table shows the axes of a graph for which the gradient is stiffness k ?

	y-axis	x-axis
☐ A	extension	force
☐ B	force	length
☐ C	stress	strain
☐ D	strain	length

(Total for Question 3 = 1 mark)



- 2 A mass is supported by a single spring as shown.



The strain energy stored by the spring is E .

The mass is then supported by two springs, each identical to the first spring, as shown.



What is the total strain energy stored with two springs arranged in this way?

- ☒ A $\frac{1}{4} E$
- ☒ B $\frac{1}{2} E$
- ☒ C E
- ☒ D $2E$

(Total for Question 2 = 1 mark)

4 The Hooke's law equation is:

$$\Delta F = k\Delta x$$

Which of the following gives the base units of k ?

- ☐ A kg s^{-2}
- ☐ B kg m s^{-2}
- ☐ C N m
- ☐ D N m^{-1}

(Total for Question 4 = 1 mark)



3 When a force F is applied to a spring with stiffness k , the elastic potential energy stored is E .

What is the elastic potential energy stored when a force $2F$ is applied to a spring with stiffness $2k$?

- ☐ A $\frac{E}{2}$
- ☐ B E
- ☐ C $2E$
- ☐ D $8E$

(Total for Question 3 = 1 mark)

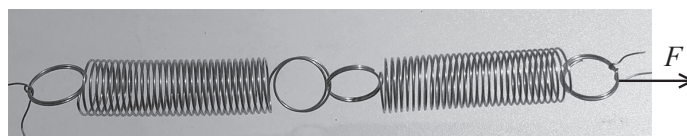


Questions 3 and 4 refer to the following information.

A horizontal force F is applied to a horizontal spring, fixed at one end.

The stiffness of the spring is k and the elastic strain energy stored is E .

A second, identical spring is added and the same force is applied to the combination of springs, as shown.



3 What is the stiffness of the combination of springs?

- ☐ A $\frac{k}{2}$
- ☐ B k
- ☐ C $2k$
- ☐ D $4k$

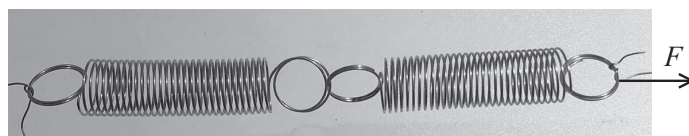
(Total for Question 3 = 1 mark)

Questions 3 and 4 refer to the following information.

A horizontal force F is applied to a horizontal spring, fixed at one end.

The stiffness of the spring is k and the elastic strain energy stored is E .

A second, identical spring is added and the same force is applied to the combination of springs, as shown.

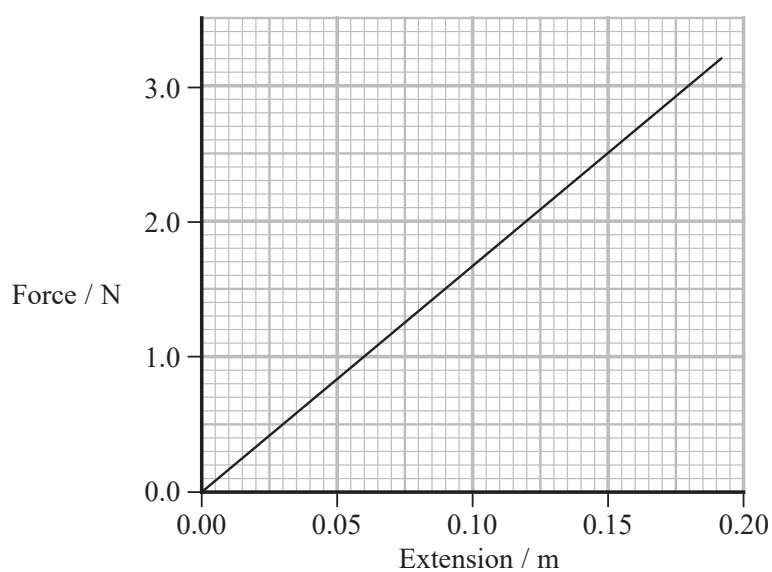


4 What is the elastic strain energy stored for the combination of springs?

- ☐ A $\frac{E}{2}$
- ☐ B E
- ☐ C $2E$
- ☐ D $8E$

(Total for Question 4 = 1 mark)

8 A force-extension graph for a spring is shown.



Which of the following gives the work done, in joules, in extending the spring by 0.15 m from its original length?

- ☐ A 0.15×2.5
- ☒ B $0.5 \times 0.15 \times 2.5$
- ☐ C $\frac{2.5}{0.15}$
- ☐ D $\frac{0.15}{2.5}$

(Total for Question 8 = 1 mark)

8 A weight of 2 N is suspended from a spring of spring constant 50 N m^{-1} .

What is the elastic strain energy stored by the spring in joules?

☐ A $\frac{1}{2} \times 2 \times 50$

☐ B $\frac{1}{2} \times 2 \times 50^2$

☐ C $\frac{1}{2} \times \frac{2}{50}$

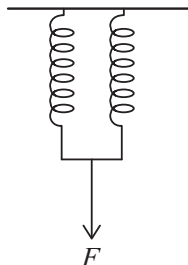
☐ D $\frac{1}{2} \times \frac{2^2}{50}$

(Total for Question 8 = 1 mark)



- 3 When a force F is applied to a spring, the spring extends by a distance x . The spring has a spring constant k .

A second identical spring is connected in parallel with the first spring. The same force F is applied to the arrangement, as shown.



What is the extension of this arrangement?

- ☐ A $0.25x$
- ☐ B $0.5x$
- ☐ C x
- ☐ D $2x$

(Total for Question 3 = 1 mark)

10 A student is investigating the extension of a spring.

A force of 29 N is applied to the spring and it extends by 32 cm. The spring obeys Hooke's law.

(a) Calculate the work done on the spring.

(2)

.....

.....

.....

.....

Work done = ...

(b) Calculate the extension of the spring when a force of 27 N is applied.

(2)

.....

.....

.....

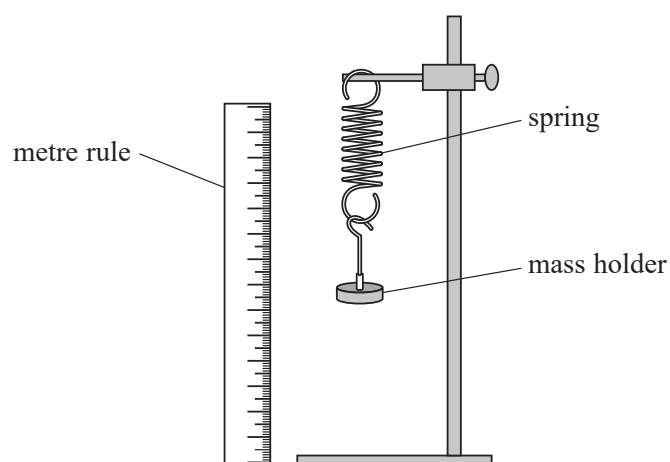
.....

Extension = ...

(Total for Question 10 = 4 marks)



- 1 A student investigated the behaviour of a spring under tension. The spring was hung vertically with a mass holder attached, as shown. The position of the bottom of the mass holder was determined using a metre rule.



- (a) The position of the bottom of the mass holder was recorded. The spring was stretched by adding masses to the mass holder and the new positions were determined. The extension of the spring for each mass was calculated.

The results are shown in the table.

Mass / kg	Extension / m
0.05	0.019
0.10	0.042
0.15	0.058
0.20	0.085
0.25	0.1
0.35	0.14

Criticise the recording of these results.

(2)

.....

.....

.....

.....

(b) Describe how the student should determine the extension of the spring as accurately as possible.

(3)

(Total for Question 1 = 5 marks)

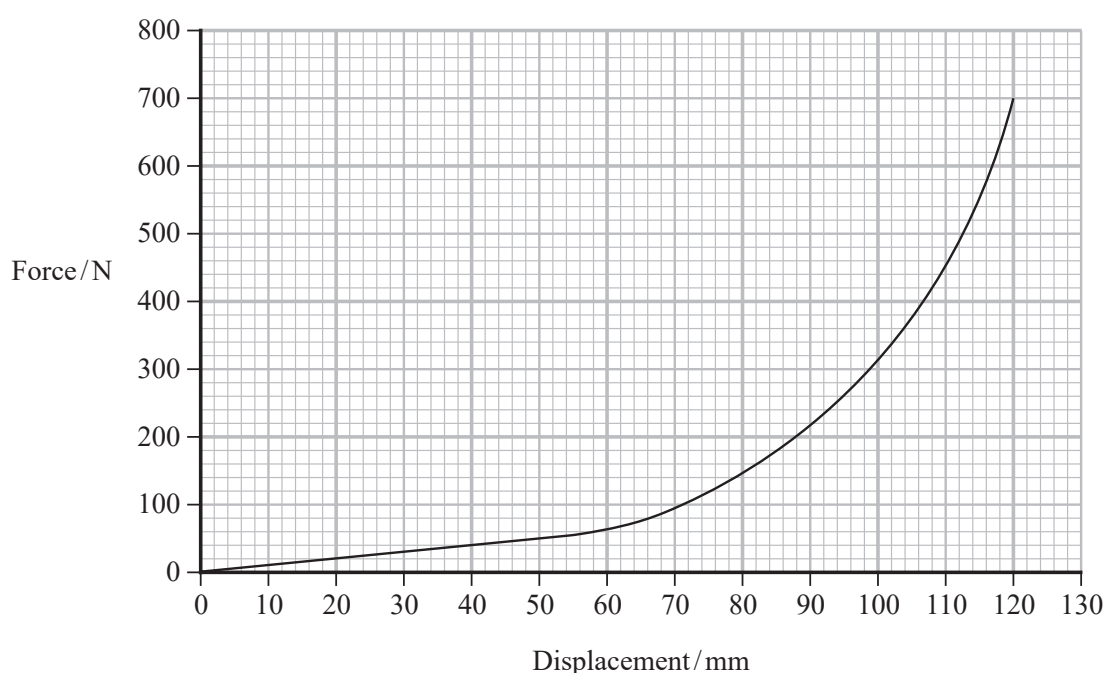


- 12 In a conical spring the diameter of the coils increases over its length. The spring can be designed so that each coil fits into the inner diameter of the next coil so they take up minimal space when fully compressed.



(Source: © Anatolii Riabokon/Alamy Stock Vector)

A conical spring is compressed against a flat surface. The graph shows the force-displacement graph for the spring as the compression force increases from 0 N to the point when the spring is fully compressed.



The spring obeys Hooke's law for small compression forces.

- (a) Determine a value for the spring constant of the spring for compression forces up to 60 N. (2)

.....

.....

.....

.....

Spring constant = ...

- (b) The compression force is increased from 60 N to 220 N.

Determine a value for the additional energy stored in the spring due to this increase in force.

(3)

.....

.....

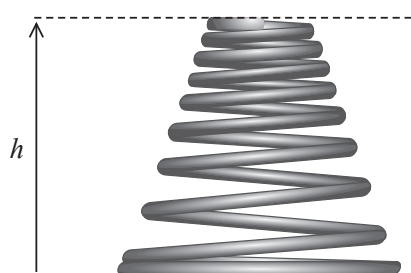
.....

.....

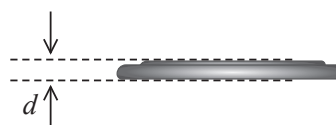
.....

Additional energy = ...

- (c) When fully compressed all the coils lie flat inside each other.



unloaded



fully compressed

The height h of the spring when unloaded is 126 mm.

Calculate the diameter d of the wire in the spring.

(2)

.....

.....

.....

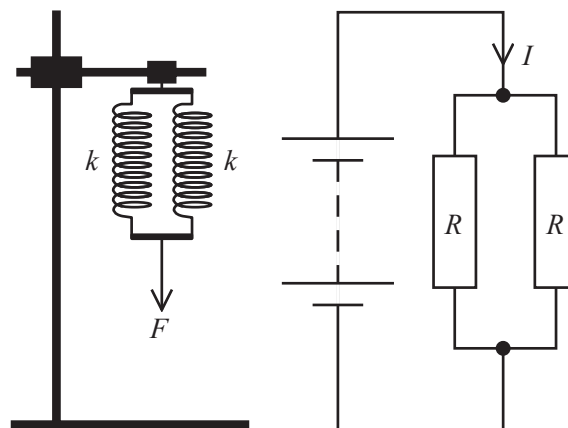
.....

Diameter = ...

(Total for Question 12 = 7 marks)

- 6 A student is experimenting with different combinations of springs and recalls that in physics it is often possible to model different physical situations in similar ways.

The student suggests that a parallel combination of springs could be a model for a parallel combination of resistors in a circuit.



- (a) Derive an expression for the effective resistance R_{eff} of two resistors R_1 and R_2 connected in parallel in a circuit.

(3)

.....

.....

.....

.....

.....

.....

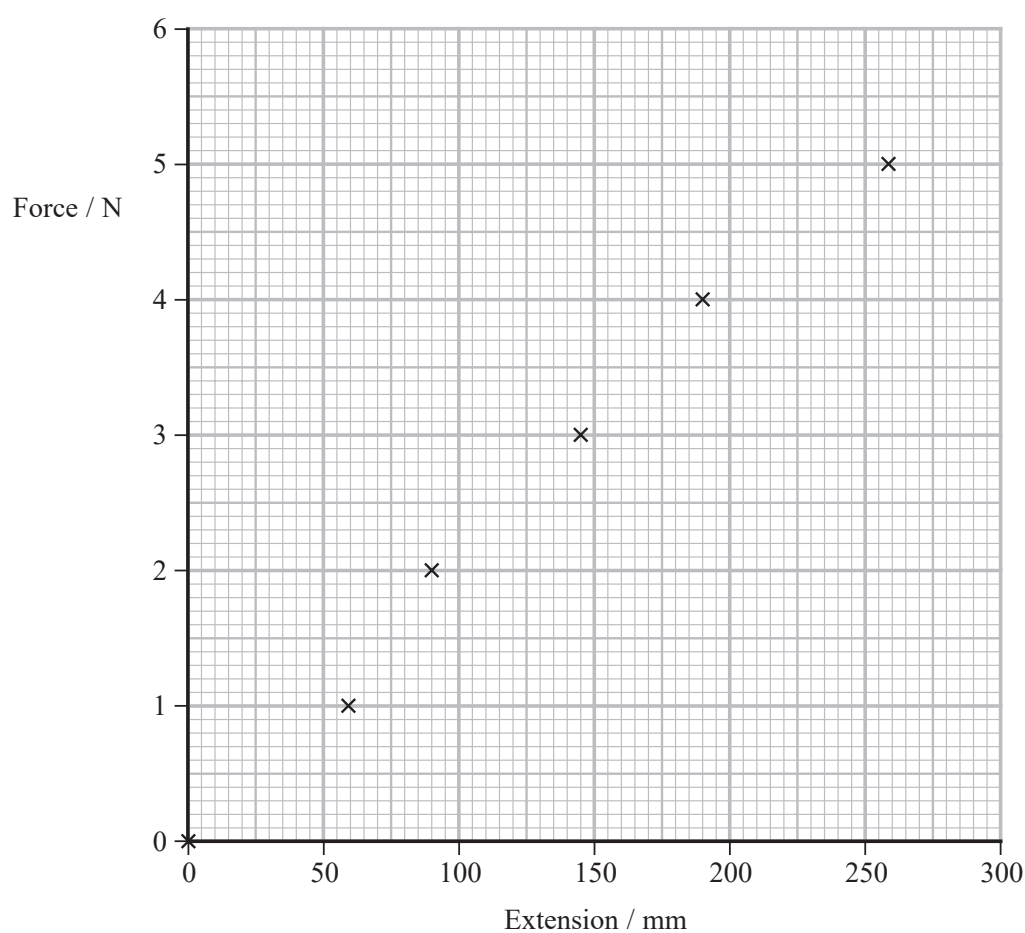
13 A manufacturer gives the following information about a spring.

1. Follows Hooke's law up to loads of 5 N
2. Maximum extension without permanent deformation 0.4 m
3. Stiffness $21 \text{ N m}^{-1} \pm 5\%$
4. Stores up to 1.6 J

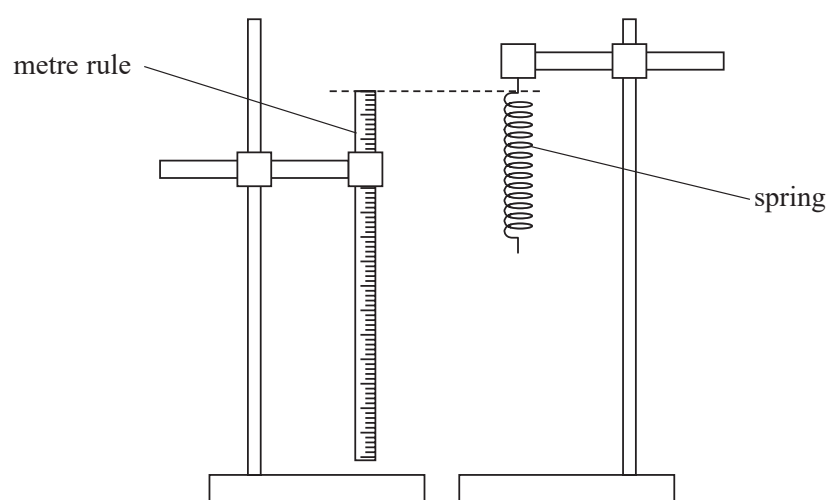
A student carried out an investigation on the spring to test this information.

She applied a range of forces from 0 N to 5 N to the spring. She measured the length of the spring and recorded the extension for each force.

She plotted a graph of force against extension.



16 A spring was hung from a clamp, as shown.



(a) A student used the metre rule to measure the unstretched length of the spring.

Describe how the student could make this measurement as accurate as possible.

(2)

.....

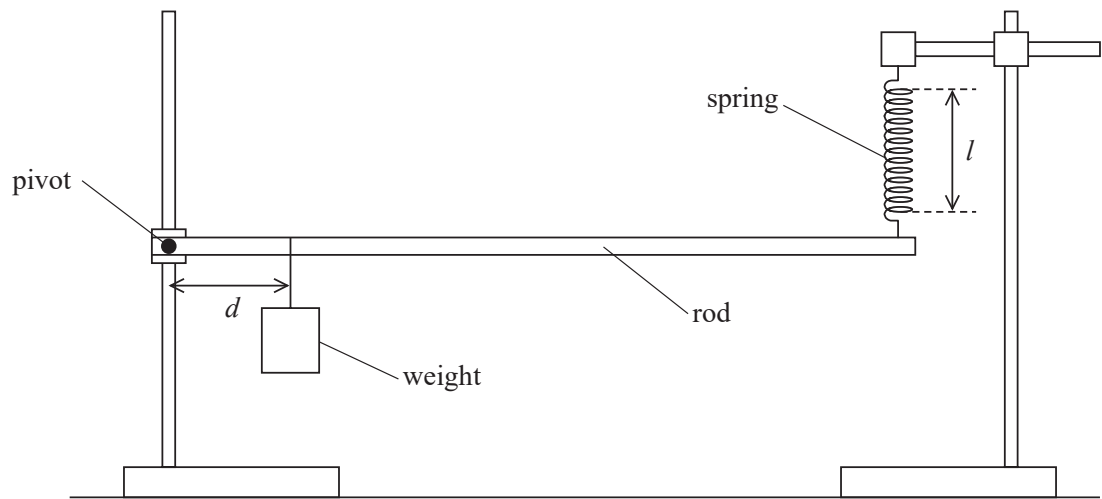
.....

.....

.....

(b) The student used the spring to investigate the forces on a uniform rod. One end of the rod was attached to a pivot and the other end was supported by the spring. The distance between the pivot and the spring stayed constant.

A weight was attached to the rod at a distance d from the pivot, as shown.
The stretched length of the spring was l .



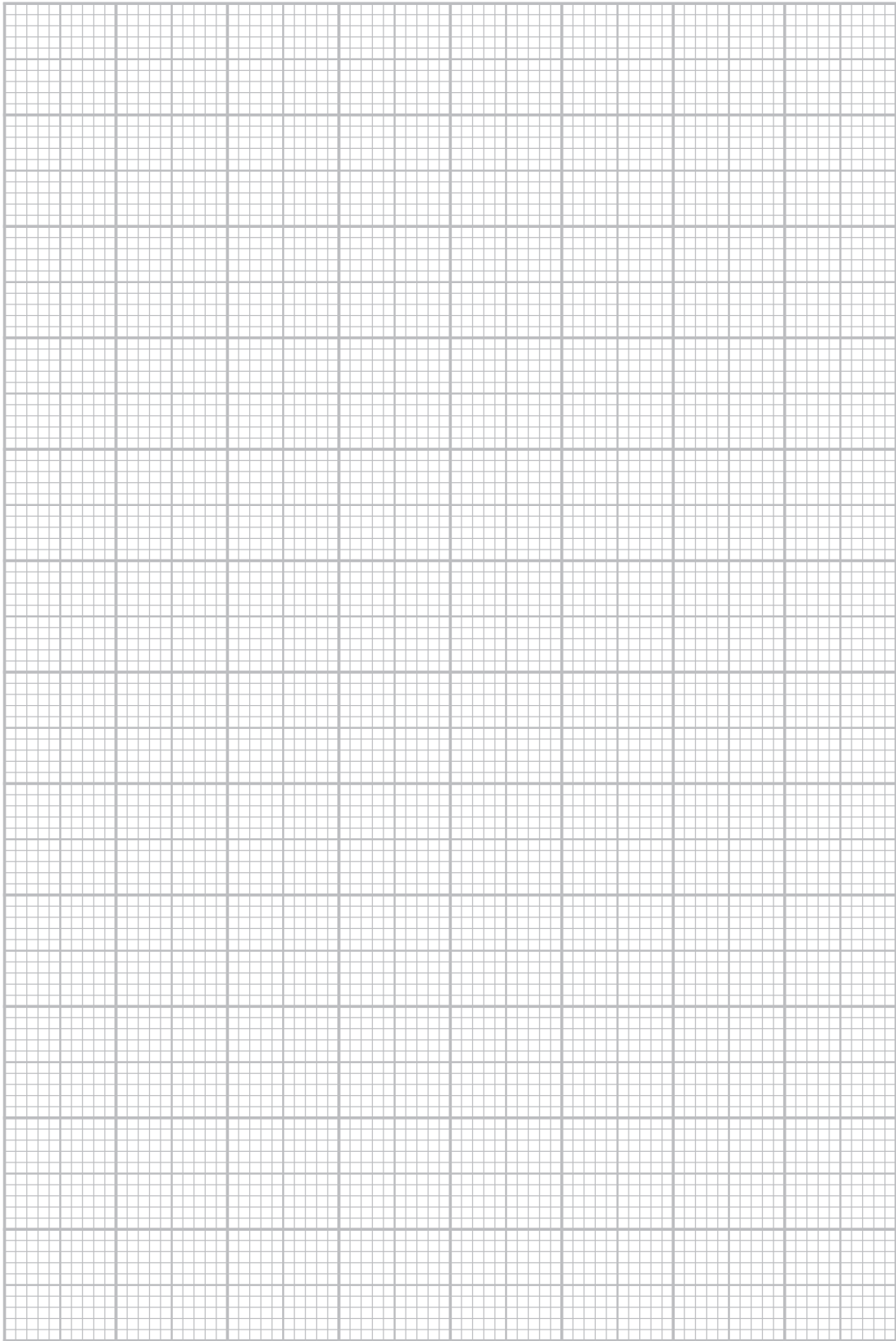
The student changed the position of the weight to vary d and measured corresponding values of l . The results are recorded below.

d/cm	l/cm	
10.0	6.6	
20.0	8.4	
30.0	10.9	
40.0	13.0	
50.0	15.3	
60.0	17.3	

(i) Plot a graph of the extension Δl of the spring on the y -axis against d on the x -axis on the grid opposite. Use the additional column of the table for your processed data.

unstretched length of spring = 3.5 cm

(5)



(ii) The student was given the following relationship

$$\Delta l = \frac{Wd}{kD} + C$$

where C is a constant

D is the distance from the pivot to the spring = 0.875 m

W is the weight on the rod = 5.00 N

Determine the spring constant k using data from the graph.

(4)

.....

.....

.....

.....

.....

.....

.....

.....

$k =$

(Total for Question 16 = 11 marks)



15 A force meter measures force by making use of Hooke's Law.

The extension of a spring inside the force meter allows the magnitude of the force applied to be read from a scale.

(a) The spring in one type of force meter extends by 5.5 cm when a force of 2.5 N is applied.

(i) Show that the stiffness of the spring is about 50 N m^{-1} .

(2)

.....

.....

.....

.....

(ii) Two identical force meters of this type support a mass of 0.400 kg as shown.

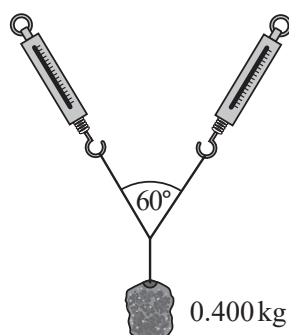


Diagram not to scale

(Source: adapted from <https://image.slidesharecdn.com/balancedunbalancedgravityfriction-170509114658/95/balanced-unbalanced-gravity-friction-14-638.jpg?cb=1494330595>)

Calculate the extension Δx of each spring.

(4)

.....

.....

.....

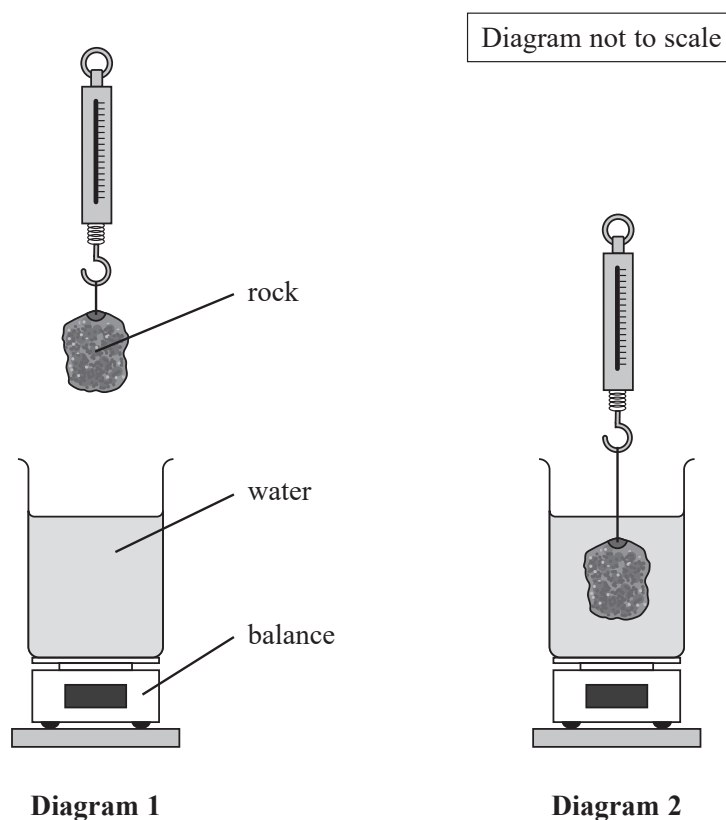
.....

.....

$\Delta x =$

- *(b) A beaker of water is placed on a balance and a rock is hung from a force meter as shown in diagram 1.

The initial reading on the balance is R , and the initial reading on the force meter is F . The rock is lowered gently into the beaker of water until it is completely submerged.



(Source: adapted from <https://passnownow.com/wp-content/uploads/2014/06/upthrust>)

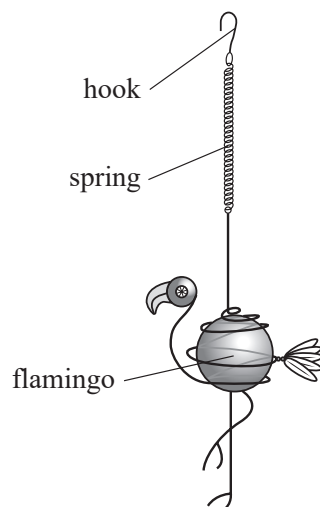
Explain any changes in the readings R and F as the rock is lowered into the water as shown in diagram 2.

(6)

(Total for Question 15 = 12 marks)



- 20 A garden ornament consists of a metal flamingo suspended from a spring as shown. The spring is hung from a support using the hook.



- (a) The mass of the flamingo is 65 g. When the flamingo is suspended vertically the spring extends by 8.5 cm.

The flamingo is pulled downwards by a small extra displacement and then released. The flamingo undergoes simple harmonic motion vertically.

The instructions state that the flamingo will oscillate with a frequency of 2.5 Hz.

Deduce whether this statement is correct.

(5)

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

- (b) After being set into vertical oscillation, the flamingo comes to rest after a short time.

Explain why the flamingo comes to rest.

(2)

- (c) In a slight breeze the flamingo swings from side to side and behaves as a simple pendulum.

- (i) Show that the period of oscillation of the flamingo pendulum is about 2.2 s.

pendulum length = 1.25 m

(2)

- (ii) The amplitude of oscillation of the flamingo pendulum is 7.5 cm.

Calculate the maximum velocity of the flamingo pendulum.

(3)

Maximum velocity = ...

(Total for Question 20 = 12 marks)



16 The suspension system in a car includes a spring attached to each wheel as shown.



(Source: © Macrovector/Shutterstock)

The car, of mass 1100 kg, is stationary. Each spring is compressed by 152 mm due to a quarter of the weight of the car. Each spring is well within both the limit of proportionality and the elastic limit.

(a) State what is meant by within the elastic limit.

(1)

(b) (i) Show that the stiffness of each spring is about $18\,000\text{ N m}^{-1}$.

(3)

- (ii) A force is applied to the car which results in a further small compression of each spring. The force is then removed, and the body of the car oscillates with simple harmonic motion.

Determine the frequency of the oscillations.

(3)

.....

.....

.....

.....

.....

Frequency = ...

- (c) State the conditions for simple harmonic motion.

(2)

.....

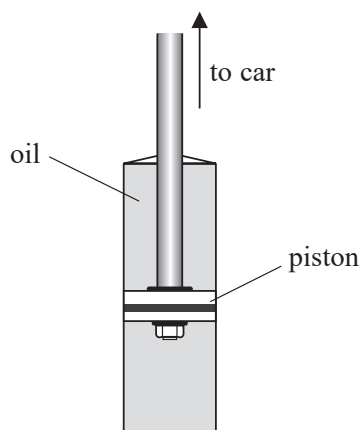
.....

.....

.....



- (d) The oscillations are heavily damped by a piston in the suspension system. The piston moves within a cylinder filled with oil, as shown. The oil has a high viscosity.



Explain why using oil of high viscosity will produce heavy damping.

(3)

.....

.....

.....

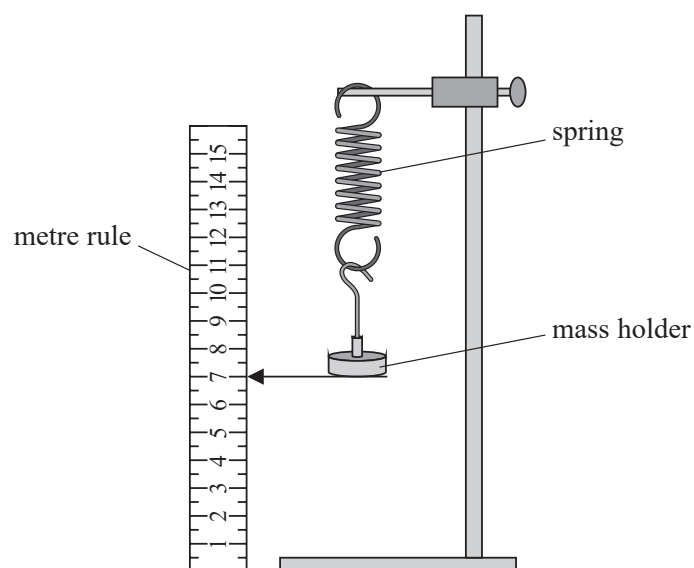
.....

.....

.....

(Total for Question 16 = 12 marks)

- 11 A student investigated the behaviour of a spring under tension. The spring was hung vertically with a mass holder attached.



The position of the bottom of the mass holder was recorded. The spring was stretched by adding masses to the mass holder and the new positions were recorded. The extension of the spring each time was calculated.

The student produced the following table.

Mass added / g	Extension / cm	Stretching force / N
50	1.9	0.49
70	3	0.69
90	3.5	0.9
110	4.5	1.08
130	5.3	1.28
150	5.8	1.47

- (a) Criticise the student's table.

(2)

.....

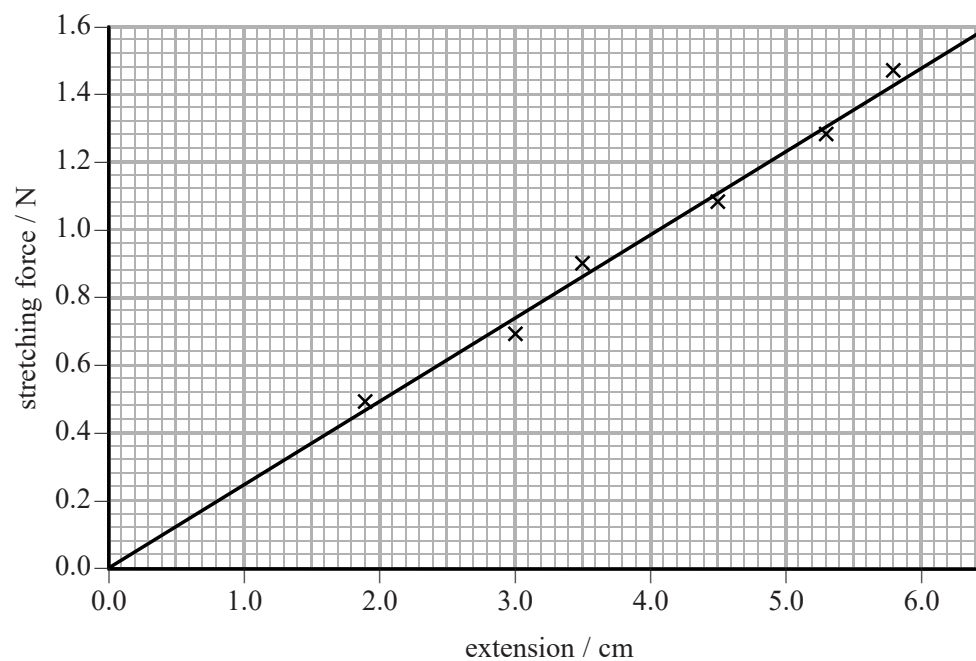
.....

.....

.....

.....

(b) The student used her data to plot a graph as shown.



Determine a value for the force constant k of the spring.

(2)

.....

.....

.....

.....

.....

.....

.....

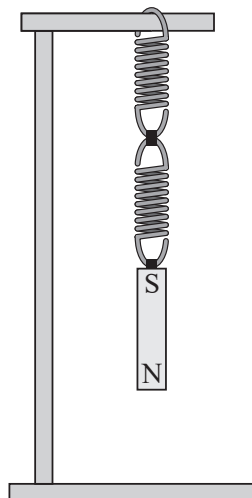
.....

.....

$k =$



(c) Two identical springs are joined in series and a bar magnet is hung from one end as shown.



The bar magnet is displaced a small distance vertically from its equilibrium position and released.

Calculate the frequency at which the system oscillates.

mass of magnet = 120 g

spring constant of each spring = 22 N m^{-1}

(4)

.....

.....

.....

.....

.....

.....

.....

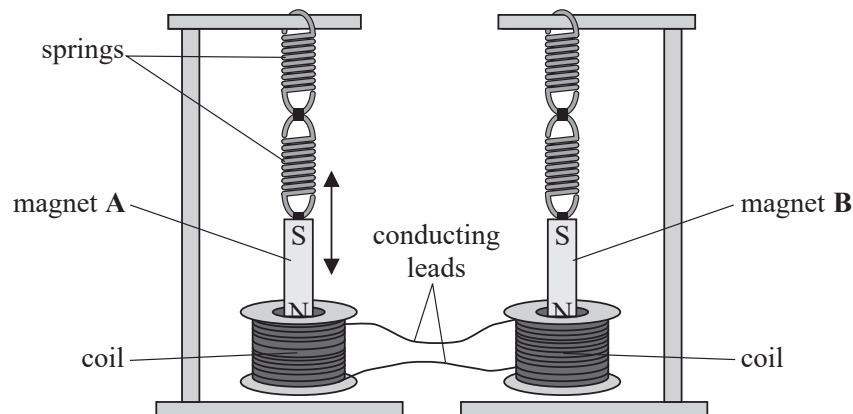
.....

.....

.....

Frequency = ...

*(d) Identical bar magnets are suspended from identical springs, with the North pole of each magnet inside a coil of wire as shown. The two coils are connected together with conducting leads.



Magnet A is displaced so that it oscillates vertically. The North pole of magnet A moves into and out of the coil of wire with simple harmonic motion. As this motion continues, magnet B starts to oscillate. The amplitude of oscillation of magnet B increases over time.

Explain why magnet B starts to oscillate with an increasing amplitude.

(6)

(Total for Question 11 = 14 marks)

10 A spring is made from loops of thick steel wire as shown.



There are two extra loops, one on each end of the spring.

- (a) A student determined the length of steel used to make the spring by using vernier calipers to measure the width w of the spring.

The length of wire l on each loop is given by $l = \pi w$

The student obtained the following values for w .

w / mm	15.3	15.2	15.4	15.3
-----------------	------	------	------	------

- (i) Calculate l .

(3)

.....

.....

.....

.....

.....

.....

.....

$l =$

- (ii) Estimate the percentage uncertainty in your value for l .

(2)

.....

.....

.....

.....

% uncertainty in $l =$

(iii) Calculate the total length L of wire used to make the spring.

(2)

.....

.....

.....

$L =$

(b) The student measured the diameter d of the steel wire and obtained a value of 2.52 mm.

(i) Explain which instrument he used to measure the diameter.

(2)

.....

.....

.....

(ii) Estimate the percentage uncertainty in the student's value for d .

(1)

.....

.....

.....

% uncertainty in $d =$

(iii) The student used a balance to measure the mass m of the spring.
He obtained a value of 32.0 ± 0.5 g.

Estimate the percentage uncertainty in the mass of the spring.

(1)

.....

.....

.....

% uncertainty in $m =$

(iv) The student calculated the density ρ of the steel using the equation

$$\rho = \frac{m}{V}$$

Calculate the percentage uncertainty in his value for the density of steel.

(1)

.....

.....

.....

% uncertainty in value for density of steel = ...



- (v) Determine whether the data collected leads to a value for the density of steel in agreement with the standard value.

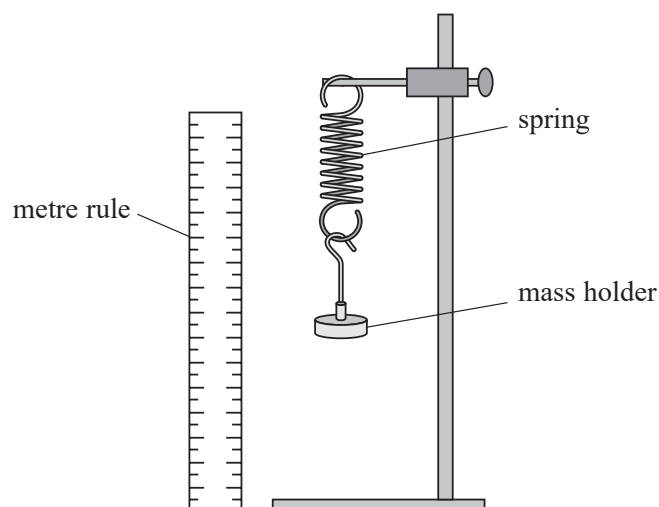
density of steel = 7800 kg m^{-3}

(4)

(Total for Question 10 = 16 marks)



- 10** A student investigated the behaviour of a spring under tension. The spring was hung vertically with a mass holder attached as shown.



- (a) The student measured the length of the spring as he added masses to the holder. The rule was held as shown to measure the distance between the top and bottom coils of the spring. He determined the extension for each value of total mass on the holder. He did this by subtracting the original length of the spring from each extended length.
- (i) Explain whether this method would produce accurate values for the extensions of the spring.

(4)

.....

.....

.....

.....

.....

.....

.....

.....

- (ii) Explain how the student could modify his method in order to obtain more accurate values for the extensions of the spring.

(5)

.....

.....

.....

.....

.....

.....

.....

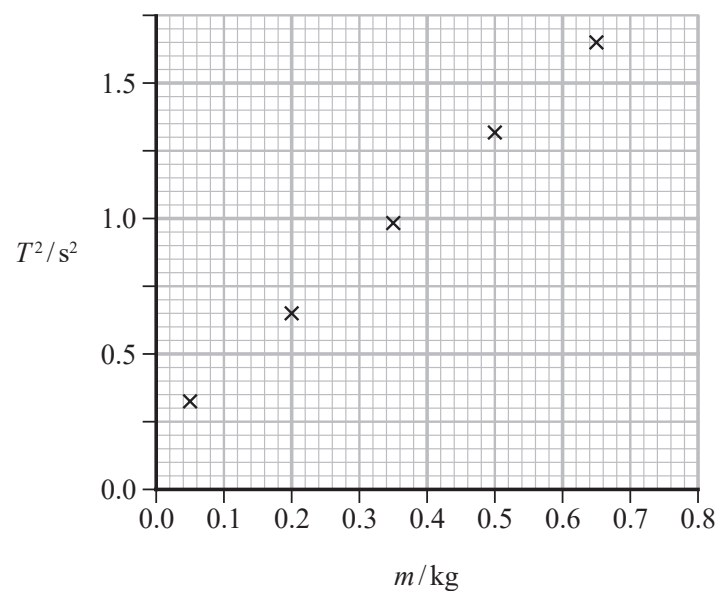
.....

.....

.....

- (b) In another experiment, the student displaced the mass vertically each time a mass was added to the spring. He used a stopwatch to determine the period of vertical oscillations of each mass.

The student used his data to plot a graph of T^2 against m as shown.



The student expected the graph to be a straight line through the origin. He thought that there may be systematic error due to reaction time.

- (i) Give an example of another possible systematic error in this experiment.

(1)

.....

.....

- (ii) Another student suggests that to reduce the uncertainty in the value for the period, a data logger connected to a light gate could be used to measure time.

Comment on the student's suggestion.

(3)

.....

.....

.....

.....

.....

.....

- (iii) Determine a value for the stiffness of the spring.

(3)

.....

.....

.....

.....

.....

Stiffness of spring = ...



- (c) When determining the period of oscillation for each mass, the student measured the time for 20 oscillations. He repeated this measurement to obtain a mean time for 20 oscillations.

Explain how the student's procedure contributed to the accuracy of the measurement.

(3)

(Total for Question 10 = 19 marks)



SUB-TOPIC 4.4

STRESS, STRAIN AND THE YOUNG MODULUS

Sub-topic 4.4 · 24 questions · 152 marks · lowest tariff first



- 1 The Young Modulus of a material can be expressed by the formula $E = \frac{Fx}{A\Delta x}$.
The derivation of this formula is

$$E = \frac{\sigma}{\varepsilon}$$

So $E = \dots\dots\dots$

And $E = \frac{Fx}{A\Delta x}$

Which of the following completes the second line of the derivation?

☐ A $\frac{\frac{x}{\Delta x}}{\frac{F}{A}}$

☐ B $\frac{\frac{\Delta x}{x}}{\frac{F}{A}}$

☐ C $\frac{\frac{F}{A}}{\frac{\Delta x}{x}}$

☐ D $\frac{\frac{F}{A}}{\frac{x}{\Delta x}}$

(Total for Question 1 = 1 mark)

- 5 A mass of 24 kg is suspended from a steel wire of length 1.5 m. The wire has cross-sectional area $3.1 \times 10^{-6} \text{ m}^2$.

The Young modulus of steel is $1.8 \times 10^{11} \text{ Pa}$.

Which of the following gives the extension of the wire?

☐ A $\frac{24 \times 1.5}{1.8 \times 10^{11} \times 3.1 \times 10^{-6}}$

☐ B $\frac{24 \times 9.81 \times 1.5}{1.8 \times 10^{11} \times 3.1 \times 10^{-6}}$

☐ C $\frac{1.8 \times 10^{11} \times 3.1 \times 10^{-6}}{24 \times 1.5}$

☐ D $\frac{1.8 \times 10^{11} \times 3.1 \times 10^{-6}}{24 \times 9.81 \times 1.5}$

(Total for Question 5 = 1 mark)



6 The following measurements were made to determine the Young modulus of a metal bar.

original length of bar = 0.50 m

area of cross section = $4.5 \times 10^{-4} \text{ m}^2$

tensile force applied to bar = 36 000 N

extension of bar = $2.0 \times 10^{-4} \text{ m}$

Which of the following gives the Young modulus of the metal?

☐ A $\frac{36\,000 \times 0.50}{4.5 \times 10^{-4} \times 2.0 \times 10^{-4}}$

☐ B $\frac{4.5 \times 10^{-4} \times 2.0 \times 10^{-4}}{36\,000 \times 0.50}$

☐ C $\frac{36\,000 \times 2.0 \times 10^{-4}}{4.5 \times 10^{-4} \times 0.50}$

☐ D $\frac{4.5 \times 10^{-4} \times 0.50}{36\,000 \times 2.0 \times 10^{-4}}$

(Total for Question 6 = 1 mark)



- 2 In an investigation to determine the Young modulus of steel in the form of a wire, a student plots a straight line graph. The Young modulus is numerically equal to the gradient of the graph.

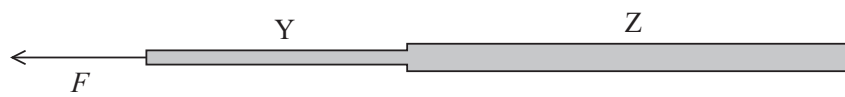
What quantities did the student plot on each axis on the graph?

	y-axis	x-axis
☐ A	strain	stress
☐ B	stress	strain
☐ C	$\frac{1}{\text{strain}}$	stress
☐ D	$\frac{1}{\text{stress}}$	strain

(Total for Question 2 = 1 mark)



- 4 A wire Y of cross-sectional area A and length l is joined to a second wire Z of cross-sectional area $2A$ and length $2l$ as shown. Wire Z is fixed at one end and a force F is applied to the other end of wire Y.



The wires are made of the same material.

Wire Y extends by a distance x .

Which of the following is the extension of wire Z?

- ☐ A $4x$
- ☐ B $2x$
- ☐ C x
- ☐ D $\frac{x}{2}$

(Total for Question 4 = 1 mark)

2 A student carries out an investigation to determine the Young modulus of a material.

Which of the following gives two measuring instruments the student should use?

- ☐ **A** calipers and stopwatch
- ☐ **B** metre rule and micrometer
- ☐ **C** metre rule and stopwatch
- ☐ **D** micrometer and calipers

(Total for Question 2 = 1 mark)



10 A wire of length L and diameter d is fixed at one end. A force F is applied to the wire causing an extension e .

A second wire, made of the same material, of length $2L$ and diameter $\frac{d}{2}$, is fixed in the same way. A force $2F$ is applied to this wire.

What is the extension of the second wire?

- ☐ **A** $\frac{e}{4}$
- ☐ **B** e
- ☐ **C** $8e$
- ☐ **D** $16e$

(Total for Question 10 = 1 mark)



6 Which of the following is the S.I. base unit for breaking stress?

- ☐ A Pa
- ☐ B $\text{kg m}^2 \text{s}^{-2}$
- ☐ C Nm^{-2}
- ☐ D $\text{kg m}^{-1} \text{s}^{-2}$

(Total for Question 6 = 1 mark)



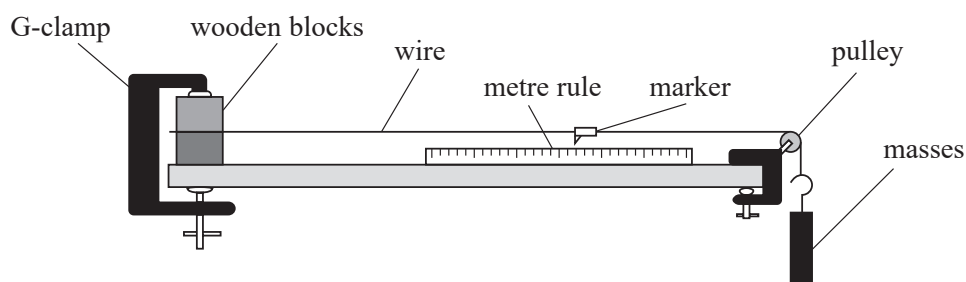
1 Which of the following gives the SI base units of stress?

- ☐ A kg m s^{-2}
- ☐ B $\text{kg m}^{-1} \text{s}^{-2}$
- ☐ C N m^{-2}
- ☐ D Pa

(Total for Question 1 = 1 mark)



- 10** A student carries out an investigation to measure the Young modulus of the material of a wire. He clamps one end of the wire and passes the other end over a pulley as shown.



The student measures the length and diameter of the wire. He hangs masses from the free end of the wire and completes a table with values of mass and extension.

Describe how the data collected should be used to determine the Young modulus using a graphical method. Your answer should include a sketch of the expected graph.

(4)

.....

.....

.....

.....

.....

.....

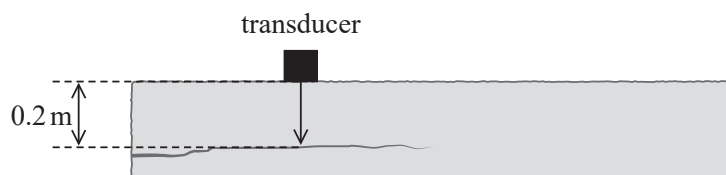
.....

.....

(Total for Question 10 = 4 marks)

10 Concrete is a material used in buildings due to its high compressive strength.

- (a) A concrete post can be checked for internal cracks using a pulse-echo technique. A transducer that transmits and receives ultrasound pulses is positioned against the side of the post as shown.



A pulse hits a crack and is reflected and is then detected by the transducer.

Deduce whether a crack at a depth of 0.2 m can be detected.

time between pulses = $160\ \mu\text{s}$

speed of sound in concrete = $3200\ \text{m s}^{-1}$

(3)

.....

.....

.....

.....

.....

- (b) Another concrete post is reinforced with steel rods, to increase its tensile strength. A steel rod is under a tensile load of 130 N and extends by $4.0 \times 10^{-4}\ \text{m}$. The steel has not reached its elastic limit.

Calculate the elastic strain energy in the steel rod.

(2)

.....

.....

.....

Elastic strain energy = ...

(Total for Question 10 = 5 marks)

- 9 In an investigation to determine the Young modulus of a material in the form of a wire, a tensile force of 14 N was applied to the wire. The length of the wire was 2.0 m. The diameter of the wire was 2.5 mm. The length of the wire increased by 0.20%.

(a) Calculate the Young modulus of the material.

(3)

.....

.....

.....

.....

Young modulus = ...

(b) Calculate the energy stored in the stretched wire.

(2)

.....

.....

.....

.....

Energy stored = ...

(c) Explain why the wire chosen should be as long as possible.

(2)

.....

.....

.....

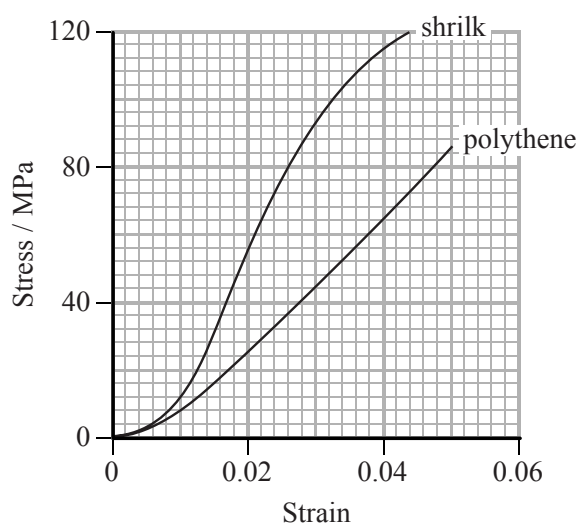
.....

(Total for Question 9 = 7 marks)



- 10** Shrilk is a new material made from discarded shrimp shells. It is biodegradable and is easily moulded into different shapes. Shrilk is an alternative to polythene and could be used to make waste bags in the future.

The graph shows a stress-strain curve for a 25.0 cm length of shrilk and for a similar length of polythene, up to breaking point.



- (a) (i) Calculate the force applied to the shrilk at a strain of 0.02

cross-sectional area = $1.2 \times 10^{-6} \text{ m}^2$

(3)

.....

.....

.....

.....

Force = ...

- (ii) Determine the extension of the shrilk at a strain of 0.04

(2)

.....

.....

.....

.....

.....

Extension = ...



(b) Deduce whether shrink or polythene is better for making waste bags.

(3)

(Total for Question 10 = 8 marks)



- 10** The speed of the blood in a blood vessel can indicate a person's health. A high speed may indicate a high stress on the walls of the blood vessel.

(a) The speed v of the blood in a blood vessel with a diameter d is given by

$$v = \frac{k\eta}{\rho d}$$

where η is the viscosity of the blood

ρ is the density of the blood

k is a constant with no units.

Show that the unit for η is Pa s.

(3)

.....

.....

.....

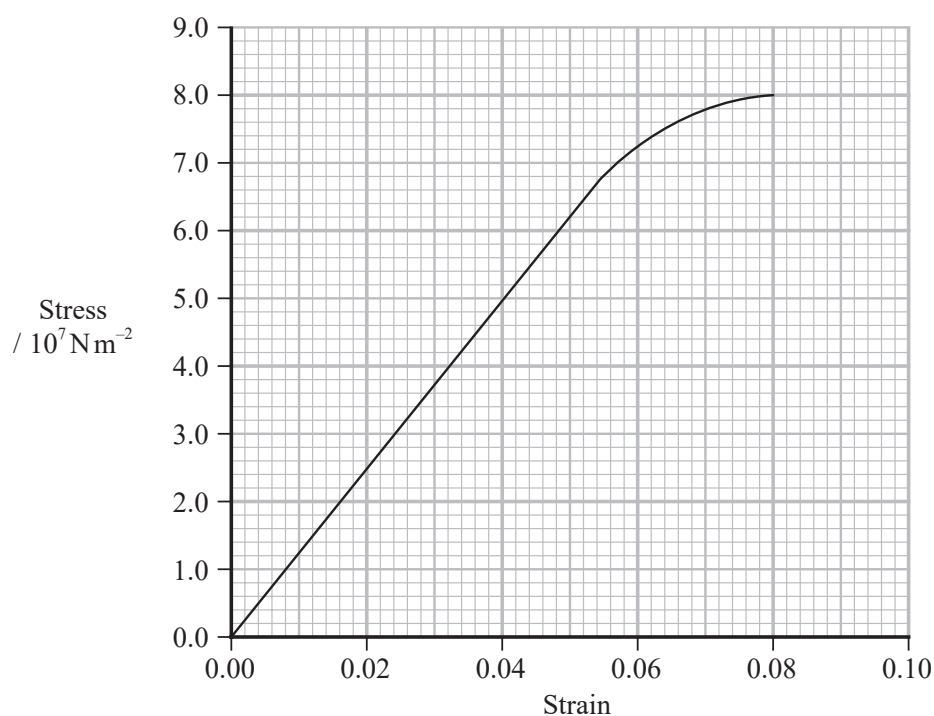
.....

.....

- (b) As the speed of the blood changes, the wall of the blood vessel expands and contracts.

The wall of a blood vessel consists of collagen fibres.

The graph shows the stress-strain relationship up to the breaking stress of the collagen fibres.



- (i) Calculate the Young modulus of collagen fibres.

(2)

.....

.....

.....

.....

Young modulus = ...

- (ii) Describe the behaviour of collagen fibres when the stress in the fibres is increased from the elastic limit until the fibres break.

(3)

.....

.....

.....

.....

.....

.....

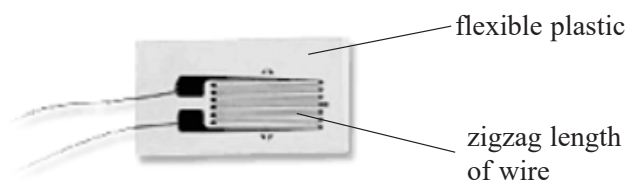
(Total for Question 10 = 8 marks)



- 16 A medical scanner uses a moving table to position the patient. Strain gauges are used to monitor the shape of the table which enables a more precise positioning of the patient.



Strain gauges consist of a thin length of wire attached, in a zigzag pattern, to a small flexible piece of plastic. The strain gauge is attached to the table. When the table is subjected to forces, the dimensions of the plastic change. This causes a change in the length of the wire and hence a change in the resistance of the wire.



- (a) Resistance can be measured directly using an ohmmeter or indirectly using measurements from a voltmeter and ammeter.

Describe **two** benefits of using an ohmmeter compared to using a voltmeter and an ammeter.

(2)

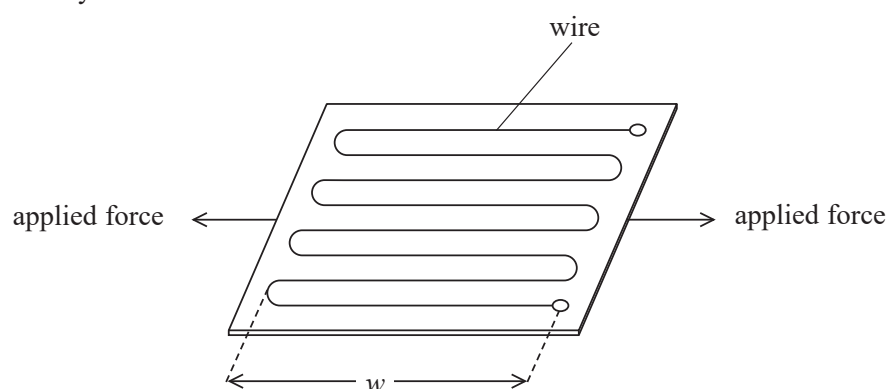
.....

.....

.....

.....

- (b) The diagram shows forces applied to a strain gauge. The 'width' of the strain gauge is defined by the distance w .



- (i) State and justify how the applied forces change the resistance of the wire.

(2)

.....

.....

.....

.....

(ii) The gauge factor GF of a strain gauge is given by

$$GF = \frac{\Delta R}{\varepsilon R}$$

where ε is the strain

R is the initial resistance

ΔR is the change in resistance

When forces are applied to the strain gauge, the resistance of the gauge changes by 0.10%.

Calculate the change in the width of the strain gauge.

$$w = 5.0 \text{ cm}$$

$$GF = 2.0$$

(3)

.....

.....

.....

.....

.....

.....

Change in width = ...

(c) Explain the benefit of arranging the wire in a zigzag pattern.

(2)

.....

.....

.....

.....

(Total for Question 16 = 9 marks)



18 The harp is a musical instrument with many strings, as shown.



(Source: © Peter Voronov/Shutterstock)

All the strings are under tension.

The strings on one type of harp are made from nylon of density 1070 kg m^{-3} . One string has a diameter of 1.14 mm .

(a) (i) Show that the mass per unit length μ of the string is about $1.1 \times 10^{-3} \text{ kg m}^{-1}$.

(2)

.....

.....

.....

.....

.....

- (ii) When the middle of the string is plucked, a note of frequency 440 Hz is produced.

Calculate the tension in the string.

length of string = 41.0 cm

(4)

.....

.....

.....

.....

.....

.....

.....

.....

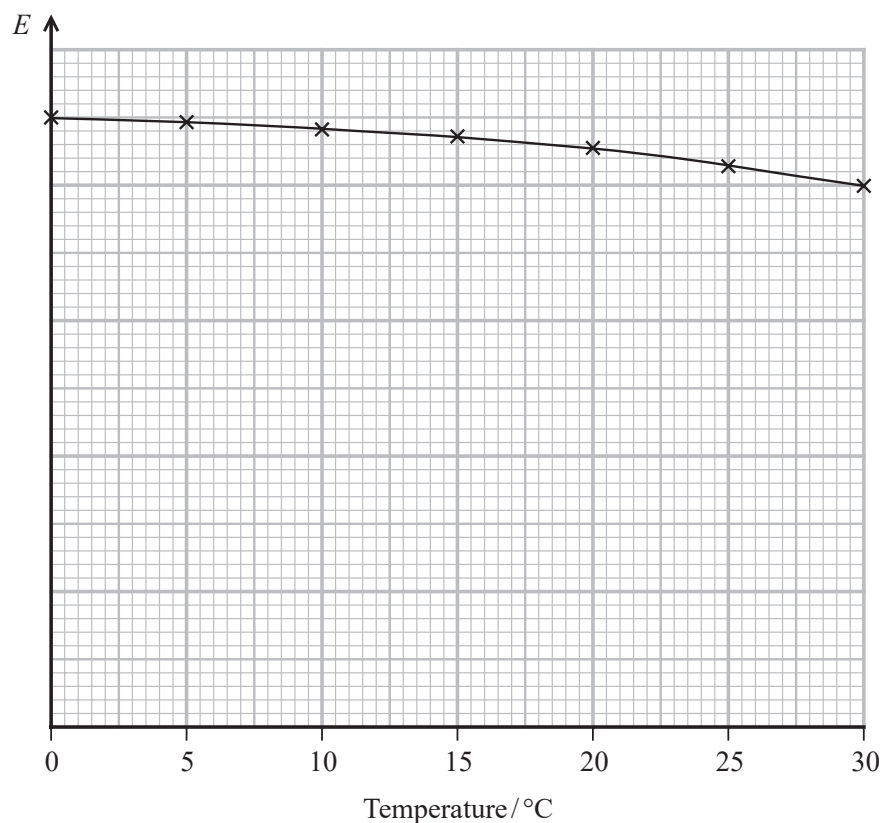
.....

.....

Tension in string = ...



(b) The graph shows how the Young modulus E of the nylon varies with temperature.



When the harp is played, the temperature of the string increases.

Explain how this temperature change would affect the frequency of the note produced when the string is plucked.

(3)

.....

.....

.....

.....

.....

.....

.....

.....

(Total for Question 18 = 9 marks)



17 Some sports place high stresses on the bones in the body, which can result in injury.

- (a) A gymnast of mass 45 kg dismounts from a beam. Her centre of mass is displaced through 1.6 m vertically before her feet touch the ground.

As she lands, the bones in the lower part of her legs experience a force from the ground. The time between hitting the ground and coming to rest is 0.90 s.

- (i) Calculate the mean force from the ground on the gymnast.

(4)

.....

.....

.....

.....

.....

.....

.....

.....

Mean force from the ground = ...

- (ii) Explain how bending both knees when landing helps the gymnast prevent an injury.

(3)

.....

.....

.....

.....

.....

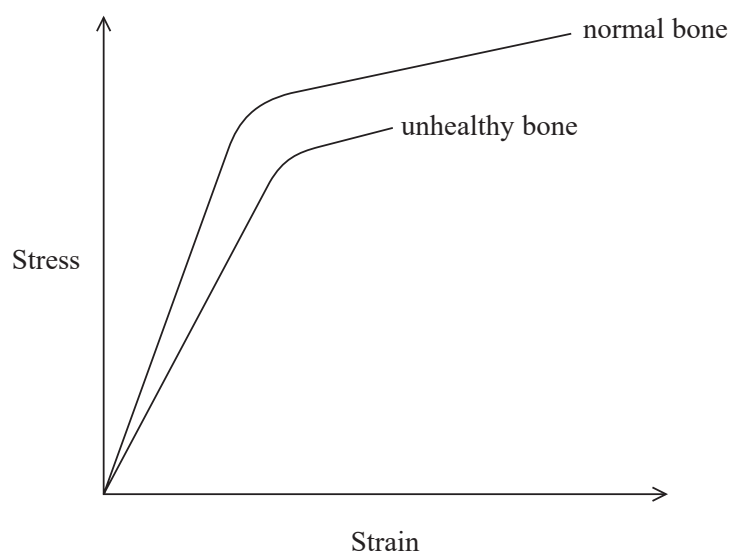
.....

.....

.....



- (b) The graph shows how stress varies with strain for normal bone and for unhealthy bone.



Describe how the graph shows that unhealthy bone under stress is more likely to break than normal bone.

(3)

.....

.....

.....

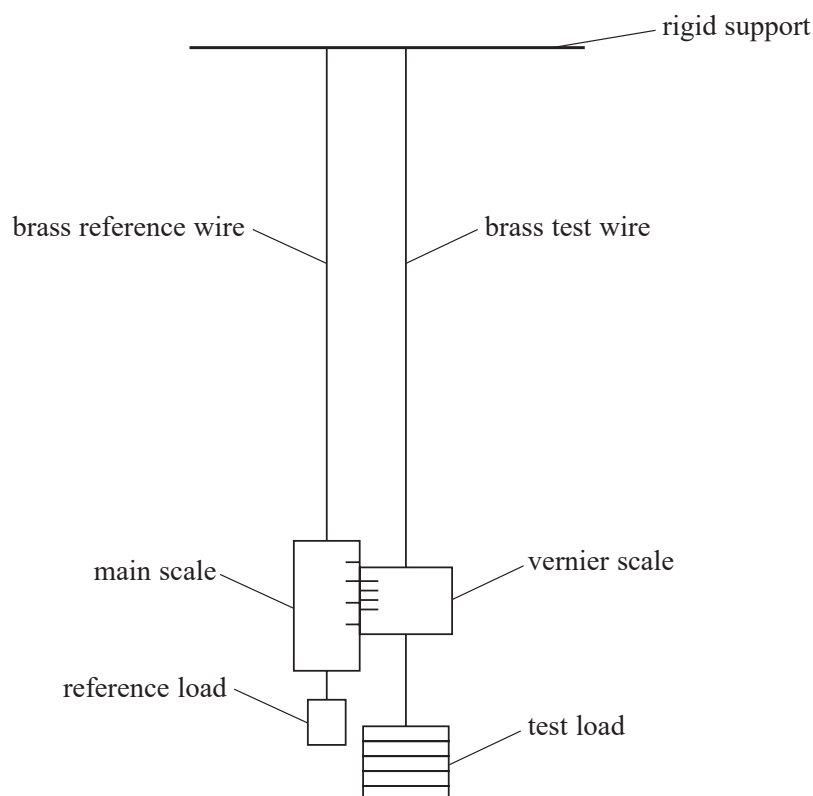
.....

.....

.....

(Total for Question 17 = 10 marks)

- 5 A student used the apparatus shown to determine the Young modulus of brass. Loads were added to the test wire and corresponding readings taken from the vernier scale. The test wire and the reference wire were identical.



- (a) (i) Give one advantage of using a reference wire as well as a test wire.

(1)

.....

.....

.....

- (ii) State why a reference load was applied to the reference wire.

(1)

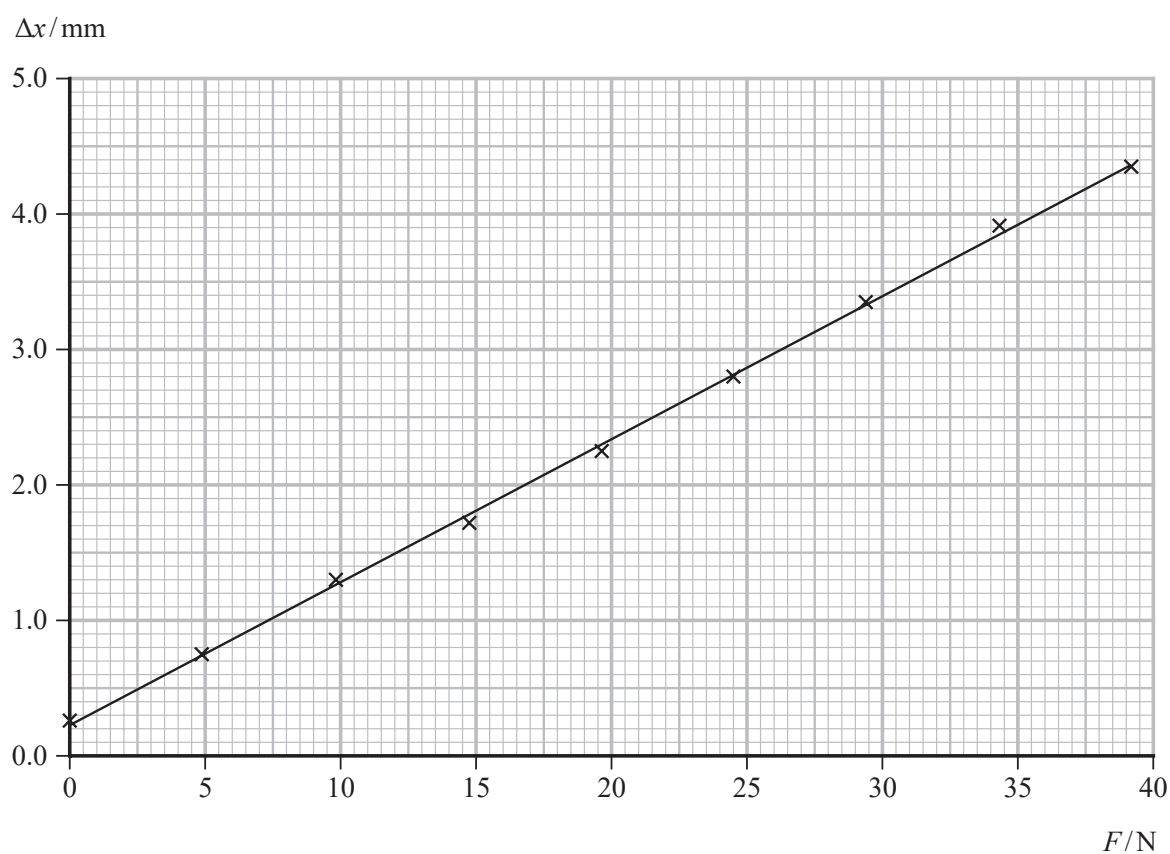
.....

.....

(b) Explain why the test wire should be both long and thin.

(3)

(c) The student varied the load F on the test wire and recorded the corresponding change in length Δx from the vernier scale. The results are shown on the graph.



Determine a value for the Young modulus of brass.

length of wire = 2.75 m

diameter of wire = 5.60×10^{-4} m

(5)

Young modulus of brass = ...

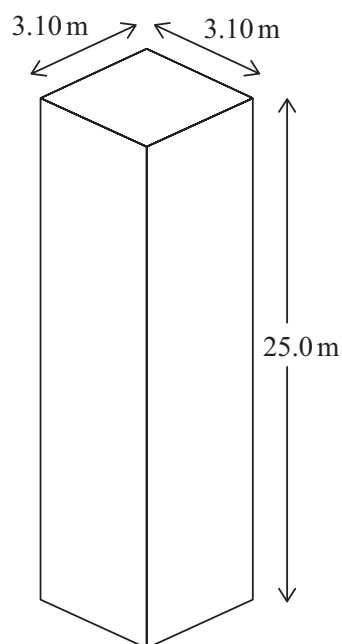
(Total for Question 5 = 10 marks)

- 19 The photograph shows a giant ice sculpture of the Elizabeth Tower (Big Ben). The ice sculpture was installed in St Pancras station in London in 2009.



(Source: © Skye Hohmann / Alamy Stock Photo)

The ice sculpture can be approximated as a regular cuboid, as shown below.



- (a) Show that the mass of the ice sculpture is about 2.2×10^5 kg.

density of ice = 920 kg m^{-3}

(2)

.....

.....

.....

.....

- 20 The photograph shows the Petronas Twin Towers in Kuala Lumpur, which are the world's tallest twin buildings.



(Source: © saiko3p/Shutterstock)

- (a) Each tower is supported by 16 cylindrical concrete columns.

Calculate the stress at the base of each cylindrical concrete column.

mass of each tower = $3.0 \times 10^8 \text{ kg}$

diameter of each column = 2.4 m

(5)

.....

.....

.....

.....

.....

.....

.....

Stress at the base of each column = ...

(b) Tall buildings sway in the wind. The design of the Petronas Towers permits safe movement of the towers.

- (i) The towers were designed to permit a maximum horizontal displacement of 0.90 m at the top of the towers. The natural frequency of each tower is 0.17 Hz.

Calculate the maximum velocity at the top of one of the towers when the tower is oscillating at its natural frequency.

(3)

.....

.....

.....

.....

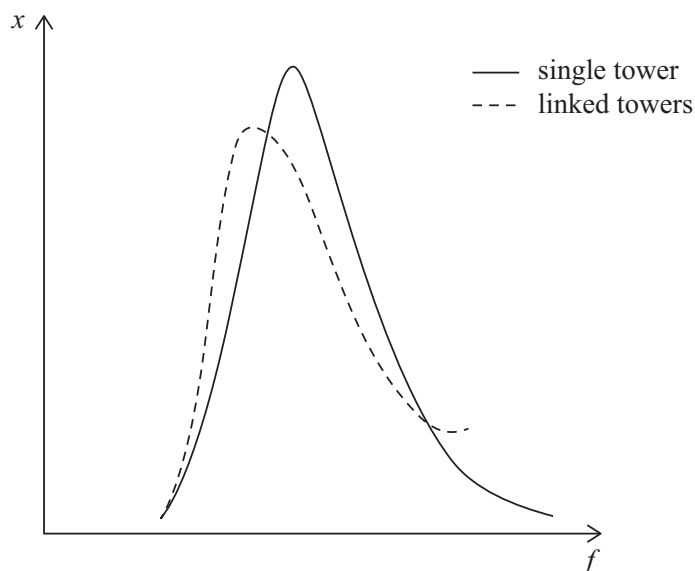
.....

Maximum velocity at the top of the tower = ...



- (ii) The twin towers were linked together to improve the response of the building to strong winds.

The graph below shows how the maximum displacement x varies with the frequency f for a single tower and for two linked towers.



Explain the behaviour of a single tower compared with the behaviour of the linked towers.

(3)

.....

.....

.....

.....

.....

.....

.....

.....

(Total for Question 20 = 11 marks)

- 17 An empty lift is positioned at the first floor of a building. It is suspended by 6 identical steel cables of length 50 m.

(a) Calculate the extension of each lift cable.

cross-sectional area of a cable = $3.1 \times 10^{-4} \text{ m}^2$

Young modulus of steel = 200 GPa

weight of lift = 12 kN

(3)

.....

.....

.....

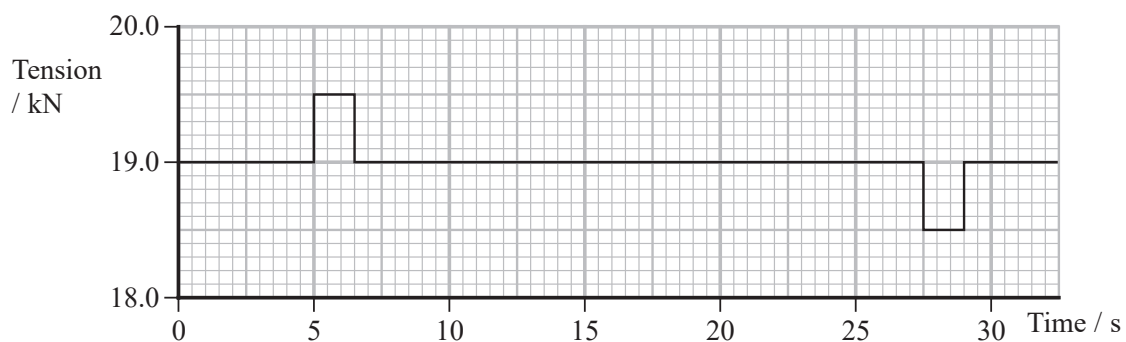
.....

.....

Extension = ...

- (b) Ten people enter the lift. After 5 seconds the lift starts to move upwards and stops at the top floor of the building.

The graph shows the total tension force in the cables during this time.



- (i) Calculate the total mass of the people in the lift.

weight of lift = 12 kN

(3)

.....

.....

.....

.....

.....

Mass of people = ...



(ii) Explain the motion of the lift between 5 s and 29 s.

(3)

(c) When the lift is empty, a technician removes one of the cables for maintenance.

Assess how removing one cable would affect the extension of the remaining cables.

(3)

(Total for Question 17 = 12 marks)



16 The photograph shows an example of a Foucault pendulum.



This is a pendulum that consists of a massive sphere, suspended by a long wire from a high ceiling. Over time the vertical plane through which the pendulum swings appears to rotate because of the rotation of the Earth.

mass of sphere = 28.0 kg

(a) The pendulum makes 8 complete oscillations in 52.2 s.

Show that the length of the wire supporting the sphere is about 10 m.

diameter of sphere = 60.0 cm

(4)

.....

.....

.....

.....

.....

.....

.....

.....

.....

(b) During refurbishment, the pendulum is taken down and the wire is replaced.

Steel wires of the following diameters are available:

0.71 mm 0.91 mm 1.22 mm 1.63 mm 2.03 mm

(i) Explain which of these wires is the thinnest that could be used to support the sphere safely.

breaking stress of steel = $3.10 \times 10^8 \text{ N m}^{-2}$

(3)

.....

.....

.....

.....

.....

.....



- (ii) The wire identified in part (i) is used for the pendulum, the unstretched length of the new wire is 11.2 m.

Calculate the extension of the new wire when the sphere is attached.

Young Modulus for steel = 200 GPa

(3)

Extension = ...

- (c) To show the rotation of the Earth, the pendulum needs to oscillate for several hours.

Explain how using a heavy sphere is better than using a light sphere of the same diameter.

(3)

(Total for Question 16 = 13 marks)



12 A student investigated the properties of metal wires.

(a) Describe how the student should determine the diameter of a wire.

(3)

.....

.....

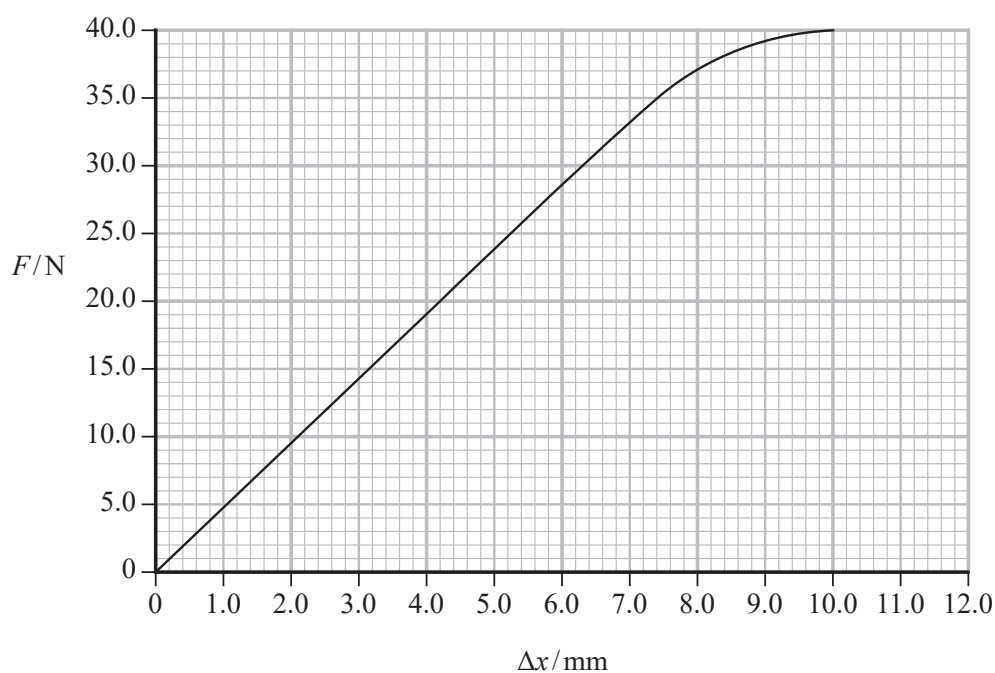
.....

.....

(b) The student applied increasing force F and determined the corresponding extensions Δx of the wire.

The force was applied in increments of 5 N, up to a maximum value of 40 N.

The student plotted a graph of F against Δx , as shown.



The Young modulus E of the material of the wire is given by the expression

$$E = \text{gradient} \times \frac{x}{A}$$

where A is the cross-sectional area of the wire and x is the original length of the wire.



- (iii) The student repeated measurements of force and extension using a thinner wire of the same metal and length. He changed the values of the force he applied to the wire.

Explain **two** changes that the student should make to the values of the force he applied to the wire.

(4)

(Total for Question 12 = 13 marks)



13 When designing a building, architects consider the properties of different materials.

- (a) A student made measurements to determine the Young modulus of a metal in the form of a wire. He measured the initial length of the wire as 1.960 m.

He applied a force of 90 N to the wire and measured the corresponding extension.

The student measured three values for the extension.

12.9 cm

12.1 cm

13.7 cm

- (i) Calculate a value for the mean strain and its absolute uncertainty from these values.

(4)

.....

.....

.....

.....

.....

.....

Mean strain = ...

Absolute uncertainty in value of strain = ...

- (ii) Calculate the elastic strain energy in the extended wire.

(2)

.....

.....

.....

.....

Elastic strain energy = ...

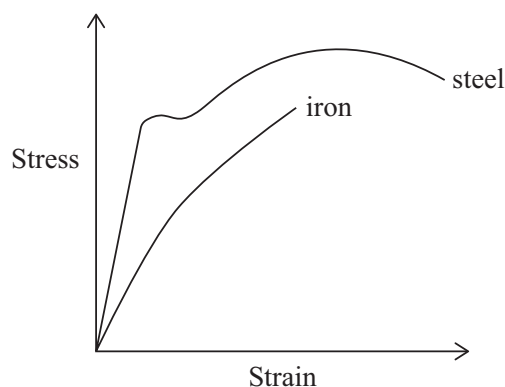


(iii) Describe how the student could determine the cross-sectional area of the wire.

(4)



- (b) The graph shows the stress-strain relationship of steel and iron up to the point of fracture.



Steel is used in the construction of buildings. Steel is made by adding different elements to iron to form an alloy.

Explain, using the properties shown in the graph, two reasons why steel might be preferred to iron in the construction of buildings.

(4)

.....

.....

.....

.....

.....

.....

.....

.....

(Total for Question 13 = 14 marks)

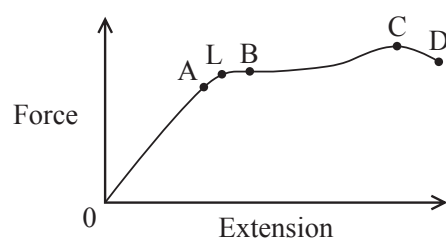
SUB-TOPIC 4.5

MATERIAL PROPERTIES AND STRESS-STRAIN GRAPHS

Sub-topic 4.5 · 8 questions · 47 marks · lowest tariff first



3 The diagram shows a force-extension graph for a wire.



L is the elastic limit.

Which point represents the yield point?

- ☐ A
- ☐ B
- ☐ C
- ☐ D

(Total for Question 3 = 1 mark)

1 A sample of steel in the form of a wire is subjected to an increasing load.

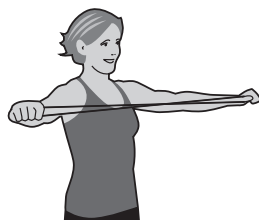
Which of the following is the best description of the elastic limit of the steel?

- ☐ **A** The stress at which the steel undergoes an increase in strain with no increase in stress.
- ☐ **B** The stress beyond which the stress and strain are no longer proportional.
- ☐ **C** The stress beyond which the steel becomes permanently deformed.
- ☐ **D** The stress at which the steel breaks.

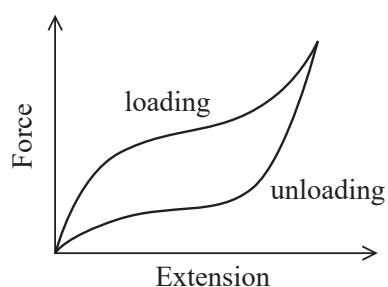
(Total for Question 1 = 1 mark)



- *9 A resistance band is a length of an elastic material that can be used for exercise. The user repeatedly applies an increasing tensile force (loading) and then releases the force (unloading).



The force-extension graph for the resistance band is shown.



The user finds that the band gets warm during use.

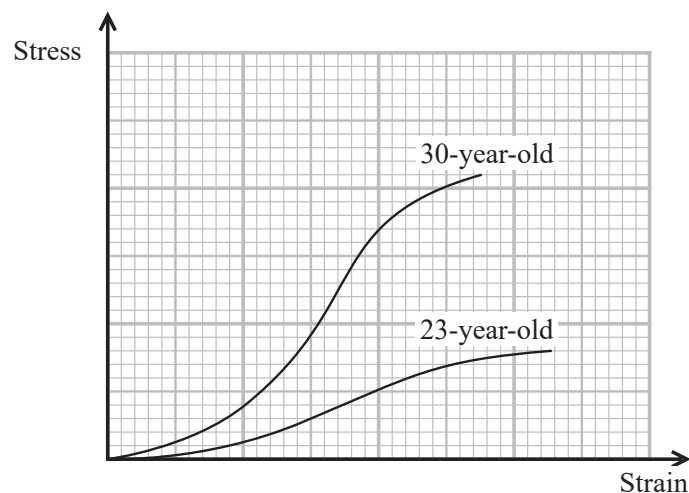
Describe, with reference to the graph, the behaviour of the resistance band when it is repeatedly loaded and unloaded.

(6)

(Total for Question 9 = 6 marks)

12 The power of the lens in the human eye changes as the lens changes shape. This enables a person to see objects at different distances clearly. To change the shape, muscles in the eye put the lens under stress.

(a) A stress-strain graph for the eye lens for people of different ages is shown.



(i) State one difference between the lens of a 23-year-old and the lens of a 30-year-old.

(1)

(ii) Give a reason for your answer, making reference to the graph.

(1)

- (b) A teacher was modelling the human eye. He placed an object 60 cm from a converging lens system. A real image of the object was observed with a magnification of 0.5

The converging lenses that were available to the teacher had powers of 2D, 3D and 4D.

Deduce which lens, or combination of lenses, the teacher used.

(4)

(Total for Question 12 = 6 marks)



- 10** Seat belts are being tested by a car manufacturer. In the test, a car moving at a steady speed of 28 m s^{-1} collides with a wall and stops.

A crash-test dummy in the driving seat is wearing a seat belt made from polyester webbing. The seat belt has a cross-sectional area of 0.85 cm^2 and a total length of 2.0 m . A student suggests that in the collision the seat belt absorbs all the kinetic energy of the dummy.

- (a) Show that the energy per unit volume that would have to be absorbed by the seat belt is about $2 \times 10^8 \text{ J m}^{-3}$.

mass of dummy = 75 kg

(3)

.....

.....

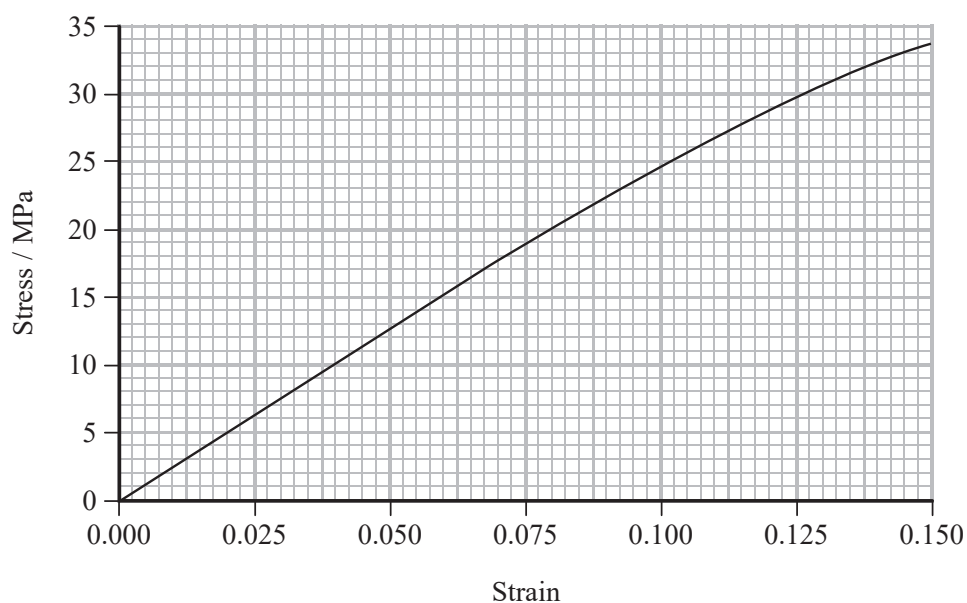
.....

.....

.....

.....

- (b) The graph shows how stress varies with strain for the seat belt.



- (i) Show that the area under the graph represents the energy stored per unit volume in the seat belt.

(2)

- (ii) Use the graph to determine whether the seat belt absorbs all the kinetic energy of the dummy from part (a).

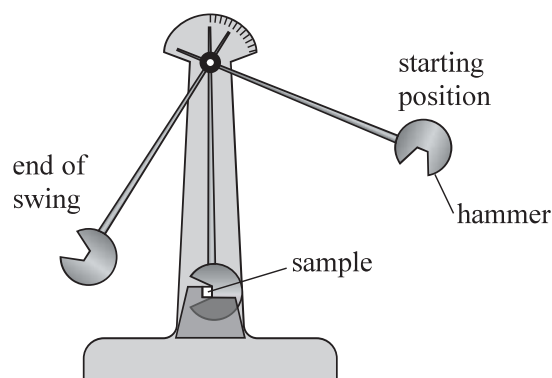
In this collision, the maximum strain of the seat belt is 0.075

(3)

(Total for Question 10 = 8 marks)



15 Read the passage and answer the questions below.



(ref: Physics Review April 2015 p22)

The Charpy test is used by scientists to measure the fracture toughness of a material. A simple pendulum, with a hammer on the end, is held high and released so that it swings down and strikes the sample. The height from which the hammer is released is increased until the sample fractures. Some energy is absorbed by the sample in the impact but the hammer continues to move until it comes to rest at the top of its swing. Due to the law of conservation of energy the hammer will not swing up as high as its starting position. The difference in height between the start and end is proportional to the energy absorbed in the impact – the fracture toughness.

- (a) “The difference in height between the start and end is proportional to the energy absorbed in the impact – the fracture toughness.”

Justify this statement.

(2)

.....

.....

.....

.....

(b) The hammer is released from a height of 13.0 cm above the lowest point of the swing.

Calculate the momentum of the hammer when it strikes the sample.

mass of hammer = 31 kg

(3)

.....

.....

.....

.....

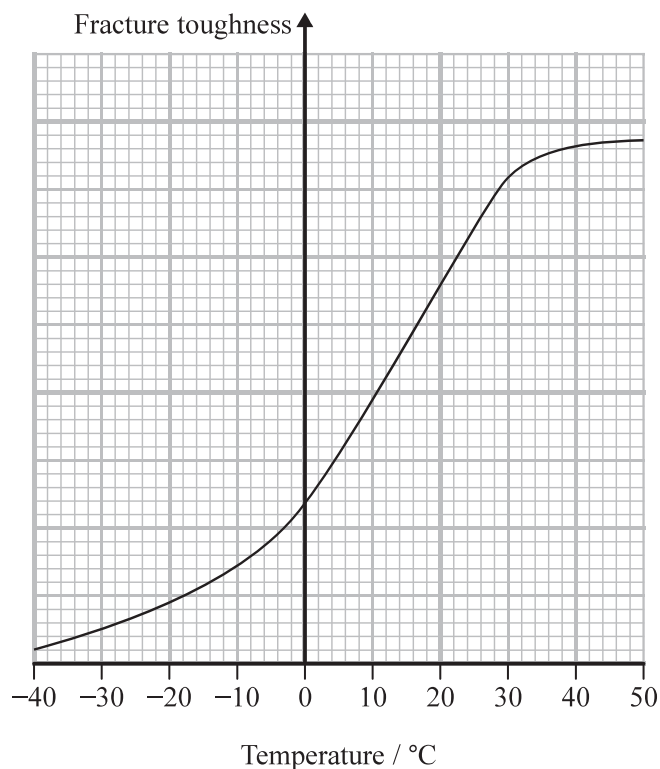
.....

.....

Momentum of hammer = ...



- (c) The sketch graph shows how the fracture toughness of a sample of steel varies with temperature.



A material with a low fracture toughness can absorb less energy before fracture than a material with high fracture toughness.

The ship *Titanic* sank in 1912 following a collision with an iceberg in the icy waters of the Atlantic. The steel hull of the ship was fractured by the impact.

Deduce why the steel was likely to have been fractured by the impact.

(3)

.....

.....

.....

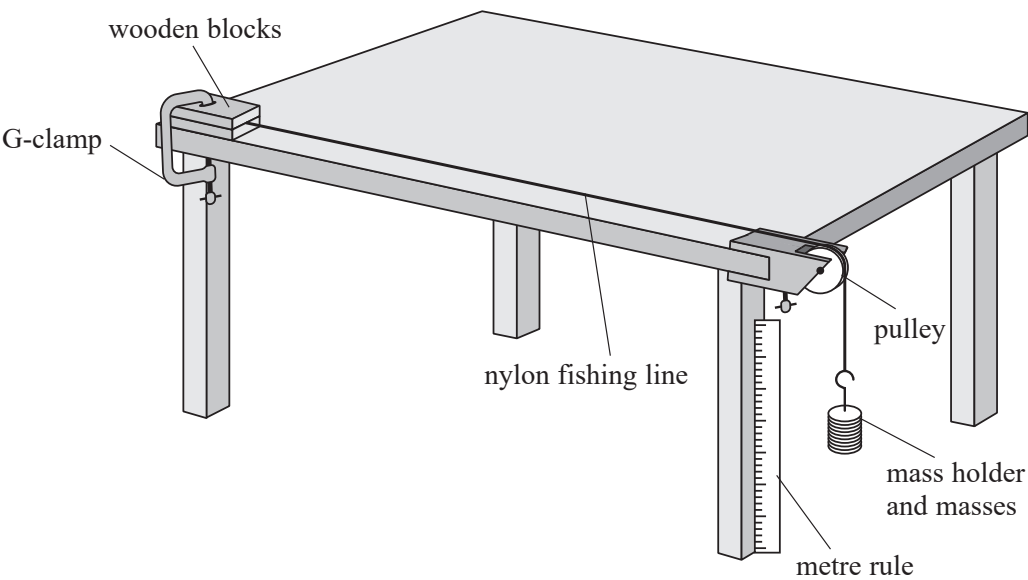
.....

.....

.....

(Total for Question 15 = 8 marks)

1 A student stretched a length of nylon fishing line using the apparatus shown below.



- (a) The nylon fishing line was stretched by adding masses to the mass holder. The positions of the bottom of the mass holder were measured as masses were added. For each mass, the extension of the nylon fishing line was calculated. The student recorded the results, as shown in the table.

Mass / kg	Extension / cm
0.05	0.4
0.1	0.8
0.25	2.1
0.5	3.9
0.75	6.0
1.0	7.2

Criticise the recording of these results.

(2)

- (b) Describe how the extension of the nylon fishing line could have been determined as accurately as possible.

(3)

- (c) The strain for the nylon fishing line at its yield point is 0.04

- (i) State what is meant by yield point.

(1)

- (ii) The original length of the nylon fishing line was 2.00 m.

Determine whether the fishing line was stretched beyond its yield point.

(2)

(Total for Question 1 = 8 marks)



- 16** In 2010, Andre Geim and Konstantin Novoselov were awarded the Nobel Prize in Physics for producing, identifying and studying graphene.

Graphene is a form of carbon which exists only as a single atomic layer of graphite. It has a breaking stress of 130 GPa compared to 0.5 GPa for steel. Some scientists claim that graphene is the strongest material ever measured.

- (a) Explain why graphene, despite its greater strength, is unlikely to replace steel in many applications.

(2)

.....

.....

.....

.....

.....

.....

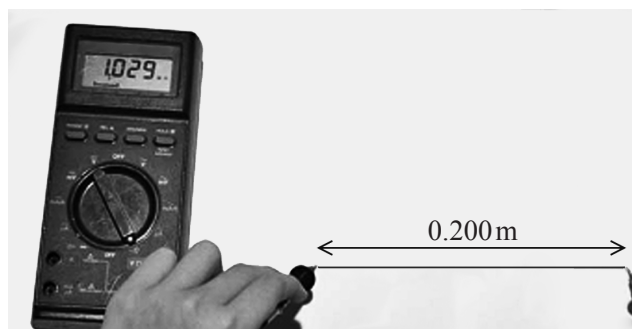
.....

.....

- (b) Graphite used in pencils consists of many layers of carbon. It can be assumed that a pencil deposits approximately 100 layers of carbon atoms when drawn across a piece of paper.

A student carried out an experiment to determine the resistivity of the graphite in a pencil.

A line of length 0.200 m and width 0.50 mm was drawn on a piece of paper. An ohmmeter was then used to measure the resistance of the graphite line.



Calculate the resistivity of graphite.

$$\text{resistance} = 1.029 \times 10^6 \, \Omega$$

$$\text{diameter of carbon atom} = 1.4 \times 10^{-10} \, \text{m}$$

(4)

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

Resistivity of graphite = ...

- (c) Photocells traditionally use silicon to generate electricity using visible light. Research demonstrates that unlike silicon, graphene is able to respond at all wavelengths and releases multiple electrons as it absorbs one photon.

Deduce why it would be an advantage to use graphene in photocells to generate electricity.

(3)

(Total for Question 16 = 9 marks)



MARK SCHEMES

official mark schemes



8	B	The only correct answer is B: Upthrust is density of fluid $\times$ volume of object $\times g$ A is not the correct answer because density of object has been used, so this is the gravitational force acting on the object C is not the correct answer because this is the resultant force D is not the correct answer because this is the mean of the magnitude of the forces in A and B	1
---	---	--	---



Question Number	Acceptable answers	Additional guidance	Mark
1	The only correct answer is C A is not correct as upthrust is equal to weight of fluid displaced B is not correct as upthrust is equal to weight of fluid displaced D is not correct as upthrust is equal to weight of fluid displaced		1



7	The only correct answer is B A <i>is not correct because</i> this is missing <i>g</i> C <i>is not correct because</i> this is an incorrect arrangement D <i>is not correct because</i> this is an incorrect arrangement	1
---	---	---



8	A $V\rho g$	1
	Incorrect Answers: B – incorrect C – incorrect D – incorrect	

(Total for Multiple Choice Questions = 8 marks)



Question Number	Acceptable Answer	Additional Guidance	Mark
2(a)	- Use a micrometer to measure y and/or z - Use Vernier/digital calipers to measure x and/or z - Mass of slide(s) measured using (top pan) balance/scales - Repeat and determine mean for at least one measurement	(Part (a) and (b) to be marked holistically) MP1 accept <u>digital</u> calipers for a single slide Accept Vernier calipers if it is clear that the thickness of a number of slides is being measured. To award both MP1 & 2, x, y & z must all be referred to. MP4 can be awarded for a reference to averaging any of the measurements.	4
2(b)	Check zero error on micrometer/calipers/balance Or measure $x/y/z$ of slide in different places Or measure thickness/mass of multiple slides	Accept 'tare' for zero error check on balance	1

(Total for Question 2 = 5 marks)



Question Number	Acceptable Answer	Additional Guidance	Mark
2(a)	An explanation that makes reference to the following points: - Measure the thickness of a stack of slides and divide by number of slides (1) - the uncertainty would be the same but the measurement would be larger (so the percentage uncertainty would be less) (1)		2
2(b)	- Precision refers to the spread of values (so the reference to precision is incorrect) (1) - Accuracy refers to how close the value is to the true value (1) - The resolution (of the balance) is 0.01 g Or the uncertainty (of the readings) is (half of) 0.01 g (1) - Repeating the measurement doesn't reduce the effect of random error Or Repeating the measurement and calculating a mean reduces the effect of random error (1)		4

(Total for Question 2 = 6 marks)



Question Number	Acceptable Answer	Additional guidance	Mark
14(a)(ii)	- Use of $F = 6\pi r\eta v$ (1) 1.1 m s^{-1} (ecf from (a)(i)) (1)	<u>Example of calculation</u> $1.73 \times 10^{-5} \text{ N} = 6\pi \times 0.0011 \times \left(\frac{1.5 \times 10^{-3}}{2}\right)v$ $v = 1.1 \text{ m s}^{-1}$	2
14(b)	- Use of $\Delta E_{\text{el}} = \frac{1}{2} F\Delta x$ and $\Delta F = k\Delta x$ (1) $2.2 \times 10^{-14} \text{ J}$ (1)	<u>Example of calculation</u> $E = 0.5 \times 1195 \text{ N m}^{-1} \times ((18 - 12) \times 10^{-9} \text{ m})^2$ $= 2.15 \times 10^{-14} \text{ J}$	2

(Total for Question 14 = 7 marks)

Total for Section A = 57 marks



Question Number	Acceptable answers	Additional guidance	Mark
16(a)	• use of $\rho = m/V$ and $W = mg$ to calculate upthrust • use of downward force of lid = upthrust – weight of diver • downward force of lid = 0.021 (N)	(1) <u>Example of calculation</u> $m_{\text{displaced}} = 1.0 \times 10^3 \text{ kg m}^{-3} \times 8.0 \times 10^{-6} \text{ m}^3$ $= 8.0 \times 10^{-3} \text{ kg}$ $U = 8.0 \times 10^{-3} \text{ kg} \times 9.81 \text{ N kg}^{-1} = 0.0785 \text{ N}$ $W = 0.0059 \text{ kg} \times 9.81 \text{ N kg}^{-1} = 0.0579 \text{ N}$ Lid force = $0.0785 \text{ N} - 0.0579 \text{ N}$ $= 0.0206 \text{ N}$	3
16(b)	Either • use of force of lid = $V\rho g$ • volume of air = $8.0 \times 10^{-6} \text{ m}^3$ - their value • volume of air = $5.9 \times 10^{-6} \text{ (m}^3\text{)}$ Or • use of upthrust on diver = weight of diver • use of upthrust = $V\rho g$ • volume of air = $5.9 \times 10^{-6} \text{ (m}^3\text{)}$	(1) <u>Example of calculation</u> volume = $0.0206 \text{ N} \div 9.81 \text{ N kg}^{-1} \div 1.0 \times 10^3 \text{ kg m}^{-3}$ $= 2.1 \times 10^{-6} \text{ m}^3$ new volume of air = $8.0 \times 10^{-6} \text{ m}^3 - 2.1 \times 10^{-6} \text{ m}^3$ $= 5.9 \times 10^{-6} \text{ m}^3$	3
16(c)	• use of $pV = \text{constant}$ • $p = 1.4 \times 10^5 \text{ Pa}$	(1) <u>Example of calculation</u> $p_1 \times V_1 = p_2 \times V_2$ $p_2 = 1.01 \times 10^5 \text{ N m}^{-2} \times 8.0 \times 10^{-6} \text{ m}^3 / 5.9 \times 10^{-6} \text{ m}^3$ $p = 1.37 \times 10^5 \text{ Pa}$	2

(Total for Question 16 = 8 marks)



Question Number	Acceptable Answer	Additional Guidance	Mark
3(a)	Micrometer (screw gauge) (1)	Accept <u>digital</u> calipers	1
3(b)	Use of $V = \pi r^2 t$ (1) Use of $\rho = \frac{m}{V}$ to find m (1) Use of 0.5% to find total mass needed (1) Number of discs = 10 (1)	<u>Example of calculation</u> $V = \pi r^2 t = \pi \left(\frac{1.3 \times 10^{-2} \text{ m}}{2} \right)^2 \times 2 \times 10^{-3} \text{ m}$ $\therefore V = 2.65 \times 10^{-7} \text{ m}^3$ $m = \rho V = 7900 \text{ kg m}^{-3} \times 2.65 \times 10^{-7} \text{ m}^3$ $\therefore m = 2.10 \times 10^{-3} \text{ kg}$ $\frac{0.1 \text{ g}}{M} = 0.5\%$ $\therefore M = \frac{0.1 \text{ g}}{0.5/100} = 20 \text{ g}$ $\therefore \text{number of discs} = \frac{20 \text{ g}}{2.10 \text{ g}} = 9.5$	4
3(c)	% uncertainty calculated for d or t (1) % uncertainty calculated for cross sectional area (1) Uncertainty in volume = ($\pm$) 4% [accept 4.0%] (1)	<u>Example of calculation</u> uncertainty in $d = \frac{0.1 \text{ mm}}{13 \text{ mm}} \times 100\% = 0.77\%$ $\therefore \text{uncertainty in } A = 2 \times 0.77\% = 1.5\%$ uncertainty in $t = \frac{0.05 \text{ mm}}{2 \text{ mm}} \times 100\% = 2.5\%$ $\therefore \text{uncertainty in } V = 1.5\% + 2.5\% = 4.0\%$	3

(Total for Question 3 = 8 marks)



Question Number	Acceptable Answer	Additional Guidance	Mark
3(a)	- Use of $V = \frac{4}{3}\pi r^3$ (1) - Use of $\rho = \frac{m}{V}$ (1) $\rho = 2580 \text{ (kg m}^{-3}\text{)}$ (1)	<u>Example of calculation</u> $V = \frac{4}{3}\pi \left(\frac{5.06 \times 10^{-2} \text{ m}}{2} \right)^3 = 6.78 \times 10^{-5} \text{ m}^3$ $\rho = \frac{0.175 \text{ kg}}{6.78 \times 10^{-5} \text{ m}^3} = 2580 \text{ kg m}^{-3}$	3
3(b)	- Use of half resolution to calculate % uncertainty (1) % uncertainty in $V = 3 \times$ % uncertainty in r (1) % uncertainty in $\rho =$ (% uncertainty in $m +$ % uncertainty in V) (1) - Use of % uncertainty to calculate upper value of density (1) - Upper value of density 2596 (kg m⁻³) [2616 (kg m⁻³) if “show that” value used] (1) - Glass is in the range and Quartz isn’t, so it may not be genuine (1) ECF from (a)	% uncertainty in $r = \frac{0.005 \text{ cm}}{5.06 \text{ cm}} \times 100 \% = 0.10 \%$ % uncertainty in $m = \frac{0.5 \text{ g}}{175 \text{ g}} \times 100 \% = 0.29 \%$ % uncertainty in $\rho = (3 \times 0.1\%) + 0.29\% = 0.59\%$ Range = $\pm \frac{0.6}{100} \times 2580 \text{ kg m}^{-3} = \pm 15.5 \text{ kg m}^{-3}$ Density range = $2565 \rightarrow 2596 \text{ kg m}^{-3}$ Allow use of half resolution in either r or m to calculate minimum V and maximum m and then calculate maximum ρ for MP1 $\rightarrow$ MP4	6

(Total for Question 3 = 9 marks)



Question Number	Acceptable Answer	Additional Guidance	Mark
7(a)	- Measure the total thickness of a number of discs (stacked) together (1) - Divide by the number of discs (in the stack) to determine the average thickness of one disc (1) - Measure the total length of a number of discs lined up together Or Measure diameter of a number of discs using vernier calipers (1) - Divide by the number of discs to determine the average diameter of one disc (1)		4



7(b)	• Uses $V = \pi r^2 t$ • Use of $\rho = \frac{m}{V}$ • $\rho = 1.1 \times 10^4 \text{ kg m}^{-3}$ • Uses % uncertainty in mass or diameter or thickness • Uses $2 \times \% \text{ U in diameter}$ • $\% \text{ U in density} = 10 \%$	(1) <u>Example of calculation</u> (1) $V = \pi \left(\frac{5.2 \times 10^{-2} \text{ m}}{2} \right)^2 \times 1.9 \times 10^{-3} \text{ m} = 4.04 \times 10^{-6} \text{ m}^3$ (1) $\rho = \frac{42.5 \times 10^{-3} \text{ kg}}{4.04 \times 10^{-6} \text{ m}^3} = 1.05 \times 10^4 \text{ kg m}^{-3}$ (1) For mass % U = $\frac{0.5 \text{ g}}{42.5 \text{ g}} \times 100\% = 1.2 \%$ (1) For diameter % U = $\frac{0.1 \text{ cm}}{5.2 \text{ cm}} \times 100\% = 1.9 \%$ For thickness % U = $\frac{0.1 \text{ mm}}{1.9 \text{ mm}} \times 100\% = 5.3 \%$ % U in density = $1.2 \% + (2 \times 1.9 \%) + 5.3 \% = 10.3 \%$ <u>Alternative MP4 and MP5</u> • Uses absolute uncertainties to calculate upper or lower limit • Uses half range •	6
------	--	---	---

(Total for Question 7 = 10 marks)



Question Number	Acceptable answers	Additional guidance	Mark																		
15 (a)	- Processing of data to calculate $1/d$ - Axes with labels and units - Scales (can include (0, 0)) - Plots - Line of best fit	<table><thead><tr><th>Liquid</th><th>$\rho_L / \text{kg m}^{-3}$</th><th>$d^{-1} / \text{m}^{-1}$</th></tr></thead><tbody><tr><td>Honey</td><td>1420</td><td>29</td></tr><tr><td>Corn syrup</td><td>1330</td><td>25</td></tr><tr><td>Seawater</td><td>1030</td><td>20</td></tr><tr><td>Vegetable oil</td><td>920</td><td>18</td></tr><tr><td>Baby oil</td><td>830</td><td>17</td></tr></tbody></table> 	Liquid	$\rho_L / \text{kg m}^{-3}$	d^{-1} / m^{-1}	Honey	1420	29	Corn syrup	1330	25	Seawater	1030	20	Vegetable oil	920	18	Baby oil	830	17	5
Liquid	$\rho_L / \text{kg m}^{-3}$	d^{-1} / m^{-1}																			
Honey	1420	29																			
Corn syrup	1330	25																			
Seawater	1030	20																			
Vegetable oil	920	18																			
Baby oil	830	17																			

15 (b)	- Graph ($1/d$ against of ρ_L) is a straight line (1) - Through the origin (1)	For MP2 accept statement that line should go through the origin.	2
15 (c)	- Determine gradient from line of best fit (1) - Use of gradient = $\rho_s x$ (1) $\rho_s = 550 - 700 \text{ (kg m}^{-3}\text{)}$ (1) - Type of wood identified appropriately from their ρ_s (1)	<u>Example of calculation</u> Gradient = $\frac{1500 \text{ kg m}^{-3}}{30 \text{ m}^{-1}} = 50 \text{ kg m}^{-2}$ $50 \text{ kg m}^{-2} = 0.09\rho_s$ $\rho_s = 556 \text{ kg m}^{-3}$	4

(Total for Question 15 = 11 marks)



Question Number	Acceptable answers	Additional guidance	Mark
17(a)	- Use of $pV = NkT$ (1) - Conversion of T in K (1) - Use of $\rho = m/V$ to determine mass of air in the balloon (1) - Calculation of total mass = mass of air at 120 °C + passengers + balloon (1) - Use of $W = mg$ (1) $W = 31\,600\text{ N}$, which is less than $33\,000\text{ N}$, so the balloon can take off (1)	<u>Example of calculation</u> $p_1 V_1 = NkT_1$ $p_1 V_1 / T_1 = NkT_2 = p_2 V_2 / T_2$ $V_1 / 293\text{ K} = 2800\text{ m}^3 / 393\text{ K}$ Volume of gas before heating, $V_1 = 2087\text{ m}^3$ mass of air in balloon $= 1.2\text{ kg m}^{-3} \times 2087\text{ m}^3$ $= 2505\text{ kg}$ Total mass with 5 passengers $= (2505 + 340 + 380)\text{ kg} = 3225\text{ kg}$ $W = 3225\text{ kg} \times 9.81\text{ N kg}^{-1} = 31\,637\text{ N}$ $31\,600\text{ N} < 33\,000\text{ N}$	6
17(b)(i)	Any one from: - Point particles - Particles have negligible volume (compared to their container) - Negligible forces between particles (except during a collision) - Range of molecular forces small (in comparison to average separation) - Duration of collisions negligible (in comparison to time between them) - Newtonian mechanics applies - Particles moves with uniform velocity between collisions - Elastic collisions - Particles move with (constant) random motion (1)	Accept molecules for particles	1



17(b)(ii)	- States $pV = NkT$ or $pV = 1/3 Nm\langle c^2 \rangle$ (1) - Suitable algebra to show $\frac{1}{2} m\langle c^2 \rangle = 3/2 kT$ (1)		2
17(b)(iii)	- Use of a.m.u. to determine particle mass (1) - Use of $\frac{1}{2} m\langle c^2 \rangle = 3/2 kT$ with T in K (1) - rms speed = 590 m s^{-1} (1)	<u>Example of calculation</u> Mass = $28 \times 1.66 \times 10^{-27} \text{ kg} = 4.65 \times 10^{-26} \text{ kg}$ $\frac{1}{2} \times 4.65 \times 10^{-26} \text{ kg} \langle c^2 \rangle = 3/2 \times 1.38 \times 10^{-23} \text{ J K}^{-1} \times 393 \text{ K}$ $c = \sqrt{349900} = 590 \text{ m s}^{-1}$	3

(Total for Question 17 = 12 marks)



Question Number	Acceptable Answer	Additional Guidance	Mark
2(a)(i)	• Use of $V = \pi r^2 t$ (1) • Use of half resolution to calculate % uncertainty in d (1) • % uncertainty in area = $2 \times$ (% uncertainty in d) (1) • Calculation of % uncertainty in t (1) • % uncertainty in t added to % uncertainty in area (1) • $V = 5.94 \times 10^{-7} \text{ m}^3$ (1) • % $U = 0.4 \%$ (1)	Allow MP4 for use of full resolution if MP2 was withheld for not using half resolution <u>Example of calculation</u> $V = \pi \left(\frac{22.16 \times 10^{-3} \text{ m}}{2} \right)^2 \times 1.54 \times 10^{-3} \text{ m}$ $\therefore V = 5.94 \times 10^{-7} \text{ m}^3$ $\% U = \left(2 \times \frac{0.005 \text{ mm}}{22.16 \text{ mm}} + \frac{0.005 \text{ mm}}{1.54 \text{ mm}} \right) \times 100\%$ $\% U = 0.36 \%$	7



2(a)(ii)	EITHER • Use of $\rho = \frac{m}{V}$ (allow use of V from (a)(i)) (1) • Calculation of % U in ρ (1) • Max density = $1.9 \times 10^4 \text{ kg m}^{-3}$ (ecf from (a)(i)) • $1.9 \times 10^4 \text{ kg m}^{-3} < 1.93 \times 10^4 \text{ kg m}^{-3}$ so coin not pure gold (1) • Or comparison of calculated value of max density with density of gold and consistent conclusion (1) OR • Use of $\rho = \frac{m}{V}$ to calculate mass of pure gold coin (1) • Mass of pure gold coin = 11.5 g (ecf from (a)(i)) (1) • Use of half resolution to calculate max mass of coin being tested (1) • 11.25 g < 11.5 g, so coin is not pure gold • Or comparison of maximum value of mass of coin with mass pure gold coin and consistent conclusion. (1) OR • Use of $\rho = \frac{m}{V}$ to calculate volume of a pure gold coin with mass 11.2g (1) • Use of half resolution to calculate % U in mass ($0.05/11.2 \times 100\% = 0.44\%$), and hence calculated volume (1) • Find the <i>smallest</i> volume possible within uncertainty from part (i) (1) • $5.83 \times 10^{-7} \text{ m}^3 < 5.91 \times 10^{-7} \text{ m}^3$, so coin not pure gold • Or comparison of minimum value of volume of coin from part i with maximum volume of pure gold coin and consistent conclusion. (1)	For MP2, allow use of resolution if use of half resolution has already been penalised in (a)(i) Allow a conclusion that states the values are similar so it might be gold MP4, allow “density of pure gold” for $1.93 \times 10^4 \text{ kg m}^{-3}$ For MP3, allow use of resolution if use of half resolution has already been penalised in (a)(i) MP4: allow “density of pure gold” for $1.93 \times 10^4 \text{ kg m}^{-3}$ <u>Example of calculation</u> $\rho = \frac{m}{V} = \frac{11.2 \times 10^{-3} \text{ kg}}{5.94 \times 10^{-7} \text{ m}^3} = 1.89 \times 10^4 \text{ kg m}^{-3}$ $\% U = \frac{0.05 \text{ g}}{11.2 \text{ g}} \times 100\% + 0.36\% = 0.81\%$ $\therefore \text{range} = \pm 1.89 \times 10^4 \text{ kg} \times 0.008 = \pm 152 \text{ kg m}^{-3}$ $\therefore \text{max density} = 18900 + 150 = 19050 \text{ kg m}^{-3}$	4
----------	--	--	---



2(b)	MAX 4 • Measure thickness of a stack of coins Or measure the mass of a stack of coins • (Uncertainty remains the same, so) % U is reduced [MP2 dependent on MP1] • Determine diameter/mass/thickness by repeating measurement and calculating a mean • This reduces the effect of random errors • Check and correct for zero error on calipers or balance • This reduced the effect of systematic error		MP1 accept measuring a number of coins side by side (1) MP1 accept using a balance with a higher resolution (1) MP2 as this would reduce the uncertainty (1) MP4 dependent on MP3 (1) MP6 dependent on MP5 (1)	4
------	---	--	---	---

(Total for Question 2 = 15 marks)



Question Number	Acceptable Answer	Additional Guidance	Mark
11(a)	MAX 3 - The rule has a resolution of 1 mm (1) - The rule is not suitable to measure t, as the % uncertainty would be too large (1) - She should use vernier/digital calipers instead (1) - Vernier calipers have a resolution of 0.1 mm (1) Or Digital calipers have a resolution of 0.01 mm	MP3L Accept micrometer for MP3 Then, MP4; micrometer has resolution of 0.01 mm	3
11(b)	- Stack the washers together (1) - This increases the distance being measured (1) - So the % uncertainty is reduced (1)	MP1: Accept measure t in multiple places on washer and calculate a mean	3



11(c)(i)	- Uncertainty added for sums and difference (1) % uncertainty calculated for sum and difference (1) % uncertainties added for product (1) % uncertainty in $A = 2.6$ (%) (1)	<u>Example of calculation</u> % uncertainty in $(d_1 + d_2) = \frac{2 \times 0.02 \text{ cm}}{(4.52 + 2.53) \text{ cm}} \times 100\% = 0.57\%$ % uncertainty in $(d_1 - d_2) = \frac{2 \times 0.02 \text{ cm}}{(4.52 - 2.53) \text{ cm}} \times 100\% = 2.0\%$ % uncertainty in $(d_1 + d_2)(d_1 - d_2) = 0.6\% + 2.0\% = 2.6\%$	4
11(c)(ii)	- Mean $t = 4.1$ (mm) (1) - Use of half range value to calculate % U in t (1) - Calculates volume from area and thickness (1) - Use of $\rho = \frac{m}{V}$ (1) - Calculates % U in density (ecf from (c)(i)) (1) - Range of density is from 6.6 g cm^{-3} to 7.6 g cm^{-3}, so washer is made of iron. (1)	<u>Example of calculation</u> $\bar{t} = \frac{(4.3 + 4.2 + 4.1 + 3.9 + 4.0) \text{ mm}}{5} = 4.1 \text{ mm}$ % U in $t = \frac{(4.3 - 3.9) \text{ mm}/2}{4.1 \text{ mm}} \times 100\% = 4.9\%$ $V = \frac{\pi}{4} (4.52 + 2.53) \text{ cm} \times (4.52 - 2.53) \text{ cm} \times 0.41 \text{ cm} = 4.52 \text{ cm}^3$ $\rho = \frac{32.0 \text{ g}}{4.52 \text{ cm}^3} = 7.08 \text{ g cm}^{-3}$ % U in $\rho = 2.6\% + 4.9\% = 7.5\%$ Maximum value of $\rho = 1.075 \times 7.08 \text{ g cm}^{-3} = 7.61 \text{ g cm}^{-3}$ Minimum value of $\rho = 0.925 \times 7.08 \text{ g cm}^{-3} = 6.55 \text{ g cm}^{-3}$ Only iron has a density within range, so the washers are made from iron	6

(Total for Question 11 = 16 marks)



Question Number	Acceptable answers	Additional guidance	Mark
4	B The bubble has a constant velocity because upthrust is equal to viscous drag.		1



Question Number	Answer	Mark
3	C 	1
	Incorrect Answers: A – this is the diagram for a bead moving downwards with a constant velocity B – this is the diagram for a bead moving upwards with a decreasing velocity D – this is the diagram for a bead moving downwards with a decreasing velocity	

Question Number	Answer	Mark
2	D larger ball bearing in liquid with lower viscosity	1
	Incorrect Answers: A smaller ball bearing in higher viscosity will fall most slowly B ball bearing in higher viscosity will fall the more slowly than in lower viscosity C smaller ball bearing will fall more slowly than a larger ball bearing	



Question Number	Answers	Mark
1	The only correct answer is A <i>B is incorrect because the drag force increases as the skydiver falls through the air</i> <i>C is incorrect because the drag force increases as the skydiver falls through the air</i> <i>D is incorrect because the drag force increases as the skydiver falls through the air</i>	1



Question Number	Acceptable answers	Additional guidance	Mark
5	The only correct answer is D A is not correct as there must be a resultant force downwards B is not correct as there must be a resultant force downwards C is not correct as there must be a resultant force downwards		1



Question Number	Answer	Mark
3	B Incorrect Answers: A – this answer is incorrect C – this answer is incorrect D – this answer is incorrect	1



7	The only correct answer is C, viscosity of liquid decreases and terminal velocity of ball bearing increases A is not correct because viscosity decreases with increasing temperature B is not correct because viscosity decreases with increasing temperature D is not correct because terminal velocity increases when the viscosity decreases	1
---	---	---



Question Number	Answer	Mark
1	A – The resultant force decreases as the ball-bearing falls.	1
	Incorrect Answers: B – resultant force = weight – drag force, drag force increases with speed, so the resultant force decreases C – resultant force = weight – drag force, drag force increases with speed, so the resultant force decreases D – resultant force = weight – drag force, drag force increases with speed, so the resultant force decreases	



7	D small slow	1
	Incorrect Answers: A – both incorrect B – diameter incorrect C – speed incorrect	



Question Number	Acceptable Answers	Additional guidance	Mark
16(a)	- Recognises that $F=0$ Or Uses $D = U - W$ (1) - Use of $W = mg$ with $m = 5.2$ g (1) - Use of $U =$ weight of air displaced by balloon Or $U = \frac{4}{3}\rho_a\pi r^3 g$ Or $U = \rho_a V g$ and $V = \frac{4}{3}\pi r^3$ Or $U = mg$ and $\rho = \frac{m}{V}$ and $V = \frac{4}{3}\pi r^3$ (1) 0.034 N (1)	<u>Example of calculation</u> $D = \left(\frac{4}{3}\pi \times (0.12 \text{ m})^3 \times 1.2 \text{ kg m}^{-3} \times 9.81 \text{ m s}^{-2}\right) - ((4+1.2) \text{ kg} \times 9.81 \text{ m s}^{-2})$ $= 0.034 \text{ N}$	4
16(b)	<u>Viscosity</u> of air increases as temperature increases (1) Or <u>Density</u> of air is lower so upthrust is smaller (1)		1
	Total for question 16		5



Question Number	Acceptable answers	Additional guidance	Mark
14 (a)	- Use of $\rho = m/V$ (1) - Use of relationship upthrust = weight of liquid (1) - Use of $F = 6\pi\eta r v$ (1) $\eta = 3.97 \times 10^{-2}$ (Pa s) so it is sunflower oil (1)	<u>Example of calculation</u> mass of oil displaced $= 9.20 \times 10^2 \text{ kg m}^{-3} \times 1.41 \times 10^{-8} \text{ m}^3$ $= 1.30 \times 10^{-5} \text{ kg}$ upthrust $= 1.30 \times 10^{-5} \text{ kg} \times 9.81 \text{ m s}^{-2}$ $= 1.27 \times 10^{-4} \text{ N}$ weight of sphere $= 1.10 \times 10^{-4} \text{ kg} \times 9.81 \text{ m s}^{-2}$ $= 1.08 \times 10^{-3} \text{ N}$ weight = upthrust + drag $1.08 \times 10^{-3} \text{ N} = (6\pi \times \eta \times 1.5 \times 10^{-3} \text{ m} \times 0.849 \text{ m s}^{-1}) + 1.27 \times 10^{-4} \text{ N}$ $\eta = 3.97 \times 10^{-2} \text{ Pa s}$	4
14 (b)	An explanation that makes reference to the following points: - at a lower temperature viscosity is increased (1) - there would be a lower maximum speed Or one of the other oils could have been identified (1)		2



Question Number	Acceptable answers	Additional guidance	Mark
13(a)	- Weight and drag force are equal for terminal velocity stated or implied (1) - Quotes $F = 6\pi\eta rv$ and $mg = 4(\pi r^3)\rho g/3$ and suitable working to obtain $v = \frac{2g\rho r^2}{9\eta}$ (1)		2
13(b)	- Use of $v = \frac{2g\rho r^2}{9\eta}$ (1) $v = 760 \text{ (m s}^{-1}\text{)}$ (1)	<u>Example of calculation</u> $v = 2 \times 9.81 \text{ N kg}^{-1} \times 1.0 \times 10^3 \text{ kg m}^{-3} \times (2.5 \times 10^{-3} \text{ m})^2 / 9 \times 1.8 \times 10^{-5} \text{ Pa s}$ $v = 757 \text{ m s}^{-1}$	2
13(c)	- Measured value much less than calculated value (1) Max 2 from - The raindrop is moving very fast so Stokes' law does not apply (1) - Flow is not laminar so Stokes' law does not apply (1) - Raindrops not small so Stokes' law does not apply (1) - Raindrops not spherical so Stokes' law does not apply (1) - Argument based on increased upward force if upthrust taken into account so it doesn't apply (1)		3

(Total for Question 13 = 7 marks)



Question Number	Acceptable Answer	Additional Guidance	
10(a)	- The first rubber band is too near the surface of the honey (so the ball won't be at its terminal velocity) (1) - There is no method for checking that the ball is falling at terminal velocity (when he times) (1)	Accept statements for how procedure could be improved consistent with MP1 and MP2 e.g. there should be multiple bands for timing e.g. they haven't videoed the falling ball	2
10(b)(i)	- Mean time calculated (1) - Use of $s = ut$ (1) $u = 0.039 \text{ (m s}^{-1}\text{)}$ (1)	Credit individual velocities and then mean velocity being calculated <u>Example of calculation</u> $t_{\text{av}} = \frac{6.40 + 6.35 + 6.36 + 6.38}{4} \text{ s} = 6.37 \text{ s}$ $u = \frac{0.25 \text{ m}}{6.37 \text{ s}} = 3.92 \times 10^{-2} \text{ m s}^{-1}$	3
10(b)(ii)	- Use of $\eta = \frac{2r^2 g(\rho_B - \rho_H)}{9v}$ (1) $\eta = 10.8 \text{ (Pa s)}$, so it is honey A (1)	Show that value gives 10.5 Pa s 10.7 Pa s if 0.0392 m s^{-1} used Allow ecf from (b)(i) <u>Example of calculation</u> $\eta = \frac{2 \times (5.50 \times 10^{-3})^2 \times 9.81 \text{ m s}^{-2} \times (7750 - 1360) \text{ kg m}^3}{9 \times 3.9 \times 10^{-2} \text{ m s}^{-1}}$ $\therefore \eta = 10.8 \text{ Pa s}$	2

(Total for Question 10 = 7 marks)



Question Number	Acceptable Answers	Additional guidance	Mark
13(a)	- See drag = $6\pi r\eta v$ (1) - see Upthrust = $\rho_l Vg$ (1) - see weight of sphere = $\rho_s Vg$ (1)	Accept F or D for drag Do not accept $U = \rho_s Vg$ for MP2 Accept ρ_f for ρ_l <u>Example of Calculation</u> At terminal velocity: Weight = Drag + Upthrust Therefore $m_s g = 6\pi r\eta v + m_l g$ $\rho_s Vg = 6\pi r\eta v + \rho_l Vg$ Rearranging $v = \frac{\rho_s Vg - \rho_l Vg}{6\pi r\eta}$ $v = \frac{Vg(\rho_s - \rho_l)}{6\pi r\eta}$	3
13(b)(i)	- Use of $v = \frac{s}{t}$ (1) - Use of $V = \frac{4}{3}\pi r^3$ (1) - Use of $v = \frac{Vg(\rho_s - \rho_l)}{6\pi r\eta}$ (1) $\eta = 1.8 \text{ Pa s}$ (1)	<u>Example of Calculation</u> $v = \frac{0.5}{3.9} = 0.13 \text{ (m s}^{-1}\text{)}$ $\eta = \frac{\frac{4}{3}\pi(4 \times 10^{-3})^3 \times 9.81 \times (7800 - 1300)}{6\pi \times 4 \times 10^{-3} \times 0.13} = 1.8 \text{ Pa s}$ Accept $\text{kg m}^{-1}\text{s}^{-1} / \text{N s m}^{-2}$	4
13(b)(ii)	5cm (no mark) - Laminar flow Or less/no turbulent flow (1) - So Stoke's law applies Or sphere falls at a more constant rate (1)	Accept wider for 5.0 cm	2

(Total for Question 13 = 9 marks)



Question Number	Acceptable Answers	Additional guidance	Mark
12(a)	- experiment shows the liquid flows faster at higher temperature (1) (if lava behaves similarly) lava will flow a long way (covering a large area) in a given time Or (since) at a higher temperature the liquid has a lower viscosity (1)	MP1 Must be an indication of speed. MP2 Accept solidifying as an indication of in a given time	2
12(b)(i)	- Use of $v = \frac{s}{t}$ (1) - Use of $V = \frac{4}{3}\pi r^3$ (1) - Use of $v = \frac{Vg(\rho_s - \rho_l)}{6\pi r\eta}$ (1) $\eta = 1.1 \text{ (Pa s)}$ (1)	<u>Example of Calculation</u> $\eta = \frac{\frac{4}{3}\pi\left(\frac{7.0 \times 10^{-3} \text{ m}}{2}\right)^3 \times 9.81 \text{ m s}^{-2} \times (7800 - 1430) \text{ kg m}^{-3}}{6\pi \times \frac{7.0 \times 10^{-3} \text{ m}}{2} \times \frac{0.8 \text{ m}}{5.3 \text{ s}}}$ $\eta = 1.13 \text{ Pa s}$	4
12(b)(ii)	- With the large sphere the speed will be greater so Stokes' law won't apply (1) - The flow is turbulent or not laminar (1)		2
12(b)(iii)	Any one - Can eliminate human reaction time - Can playback to measure <u>time</u> more accurately - Can check that terminal velocity is reached (1)		1

(Total for Question 12 = 9 marks)



Question Number	Answers	Additional guidance	Mark
11(a)	- Use a micrometer Or vernier callipers Or digital callipers (1) - Measure diameter/width of ball at more than one orientation/position (1) - Calculate the mean of the diameter and divide by 2 (1)		3
(b)i	- Use of $V = \frac{4}{3}\pi r^3$ (1) - Use of $\rho = \frac{m}{V}$ and $W = mg$ (1) $W = 4.1 \times 10^{-2}$ (N) (1)	<u>Example of Calculation</u> $W = 8.0 \times 10^3 \text{ kg m}^{-3} \times \frac{4}{3} \pi (0.005 \text{ m})^3 \times 9.81 \text{ m s}^{-2}$ $W = 4.11 \times 10^{-2} \text{ N}$	3
(b)ii	- Use of $F = 6\pi r \eta v$ (1) $v = 0.24 \text{ m s}^{-1}$ (1)	<u>Example of Calculation</u> $4.1 \times 10^{-2} \text{ N} = 6\pi \times 0.005 \text{ m} \times 1.78 \text{ N s m}^{-2} \times v$ $v = \frac{4.1 \times 10^{-2} \text{ N}}{6\pi \times 0.005 \text{ m} \times 1.78 \text{ N s m}^{-2}}$ $v = 0.24 \text{ m s}^{-1}$	2
(c)	- Ensure the velocity is low Or use small (radius) spheres Or use a wide cylinder (1) - To prevent turbulence Or to ensure laminar flow (1)		2

(Total for Question 11 = 10 marks)



Question Number	Acceptable Answer	Additional Guidance	Mark
15(a)	- Comparison to $y = mx + c$ (1) - Identify that η, ρ_s, ρ_f and g are constants (1) $c = 0$ so the graph passes through the origin Or when $d^2 = 0$, $v = 0$ so would pass through the origin (1)	MP1 e.g. $y = mx + c$ so $v = \left(\frac{g(\rho_b - \rho_f)}{18\eta} \right) \times d^2 (+ 0)$	3



15(b)	• Axes labelled with quantities and units (1) • Suitable scale (1) • Correct plotting (1) • Line of best fit (judged by eye) (1)	MP1: $v / 10^{-3} \text{ m s}^{-1}$ on y-axis and $d^2 / 10^{-6} \text{ m}^2$ on x-axis <table><tr><th>$d^2 / 10^{-6} \text{ m}^2$</th><th>$v / 10^{-3} \text{ m s}^{-1}$</th></tr><tr><td>1.0</td><td>2.3</td></tr><tr><td>4.0</td><td>11</td></tr><tr><td>9.0</td><td>23</td></tr><tr><td>16.0</td><td>39</td></tr><tr><td>25.0</td><td>64</td></tr></table>	$d^2 / 10^{-6} \text{ m}^2$	$v / 10^{-3} \text{ m s}^{-1}$	1.0	2.3	4.0	11	9.0	23	16.0	39	25.0	64	4
$d^2 / 10^{-6} \text{ m}^2$	$v / 10^{-3} \text{ m s}^{-1}$														
1.0	2.3														
4.0	11														
9.0	23														
16.0	39														
25.0	64														
15(c)	• Attempt to find gradient, at least half drawn line used (1) • Use of $\eta = \frac{g(\rho_s - \rho_f)}{18} \times \frac{1}{\text{gradient}}$ (1) • $\eta = 1.4 - 1.5 \text{ (Pa s)}$ (1) • Corn syrup identified as the fluid (1)	MP4 to be consistent with calculated value for η <u>Example of calculation</u> $\eta = \frac{9.81 \text{ N kg}^{-1} \times (8000 \text{ kg m}^{-3} - 1260 \text{ kg m}^{-3})}{18 \times 2.52 \times 10^3 \text{ m}^{-1} \text{ s}^{-1}}$ $\eta = 1.46 \text{ Pa s}$	4												

(Total for Question 15 = 11 marks)

Question Number	Acceptable Answer	Additional Guidance	Mark
12(a)(i)	EITHER - Calculation of mean t (1) - Use of $s = ut$ (1) - Use of $v = \frac{2r^2 g(\rho_B - \rho_C)}{9\eta}$ (1) - Cocoa content = 30% Or viscosity at 35% = 4.5 (Pa s) (1) - Conclusion consistent with their graph value (1) OR - Viscosity at 35% = 4.5 (Pa s) (1) - Use of $v = \frac{2r^2 g(\rho_B - \rho_C)}{9\eta}$ (1) - Use of $s = ut$ to calculate time to fall T_{fall} (1) - Calculation of mean t (1) - Conclusion consistent with calculated value of T_{fall} (1)	<u>Example of calculation</u> $t = \frac{(9.6 + 9.9 + 9.6) \text{ s}}{3} = 9.7 \text{ s}$ $v = \frac{0.225 \text{ m}}{9.7 \text{ s}} = 0.0232 \text{ m s}^{-1}$ $\eta = \frac{2 \times (4.25 \times 10^{-3} \text{ m})^2 \times 9.81 \text{ m s}^{-2} \times (7750 - 1330) \text{ kg m}^{-3}}{9 \times 0.0232 \text{ m s}^{-1}}$ $\eta = 10.9 \text{ Pa s, so cocoa content is 30% (from graph)}$ Cocoa content is 30% so not consistent Or viscosity value is 4.5 Pa s so not consistent Time taken would be 4.0 s so not consistent with mean time	5

(Total for Question 12 = 13 marks)



Question Number	Acceptable answers	Additional guidance	Mark
13(a)	Any two from • Small object (1) • spherical object (1) • (Moving at a) slow speed (1) • In laminar flow or not turbulent flow (1)		2



*13(b)

This question assesses a student’s ability to show a coherent and logically structured answer with linkages and fully-sustained reasoning.

Marks are awarded for indicative content and for how the answer is structured and shows lines of reasoning.

The following table shows how the marks should be awarded for structure and lines of reasoning

Number of indicative points seen in answer	Number of marks awarded for indicative points
6	4
5-4	3
3-2	2
1	1
0	0

Indicative content

IC1 (Initially) there is a downward resultant force on the ball bearing

Or

(Initially) weight is greater than upthrust

IC2 (so) the ball bearing accelerates downwards

IC3 The (viscous) drag force increases with speed

IC4 The (viscous) drag force (at any given velocity) is greater in the more viscous fluid

IC5 Eventually resultant force is zero so ball reaches terminal velocity

Or

When weight = upthrust + drag the ball falls at a constant speed

IC6 In the higher viscosity fluid the terminal velocity is lower.

The following table shows how the marks should be awarded for structure and lines of reasoning

	Number of marks awarded for structure and lines of reasoning
Answer shows a coherent and logical structure with linkage and fully sustained lines of reasoning demonstrated throughout	2
Answer is partially structured with some linkages and lines of reasoning	1
Answer has no linkage between points and is unstructured	0

Linkage marks

Number of indicative content points awarded	Possible linkage marks
0, 1, 2	0
3, 4	1
5, 6	2

6



13(c)(i)	• Use of $s = ut + \frac{1}{2}at^2$ with $a = 0$ (1) • Use of $F = 6\pi\eta rv$ (1) • 0.037 N (1)	<u>Example of calculation</u> $v = \frac{0.75 \text{ m}}{3.4 \text{ s}} = 0.22 \text{ m s}^{-1}$ $F = 6\pi \times 1.8 \text{ Pa s} \times 5 \times 10^{-3} \text{ m} \times 0.22 \text{ m s}^{-1} = 0.037 \text{ N}$	3
13(c)(ii)	• Viscous drag force + upthrust = weight (1) • Upthrust and weight are unchanged (with temperature) (1) • (So at terminal velocity) viscous drag force is unchanged so the student is incorrect Or For viscous drag to be constant, if the viscosity decreases then the terminal velocity will increase so the student is incorrect ($F = 6\pi\eta rv$) (1)		3

(Total for Question 13 = 14 marks)

(Total for Section A = 56 marks)

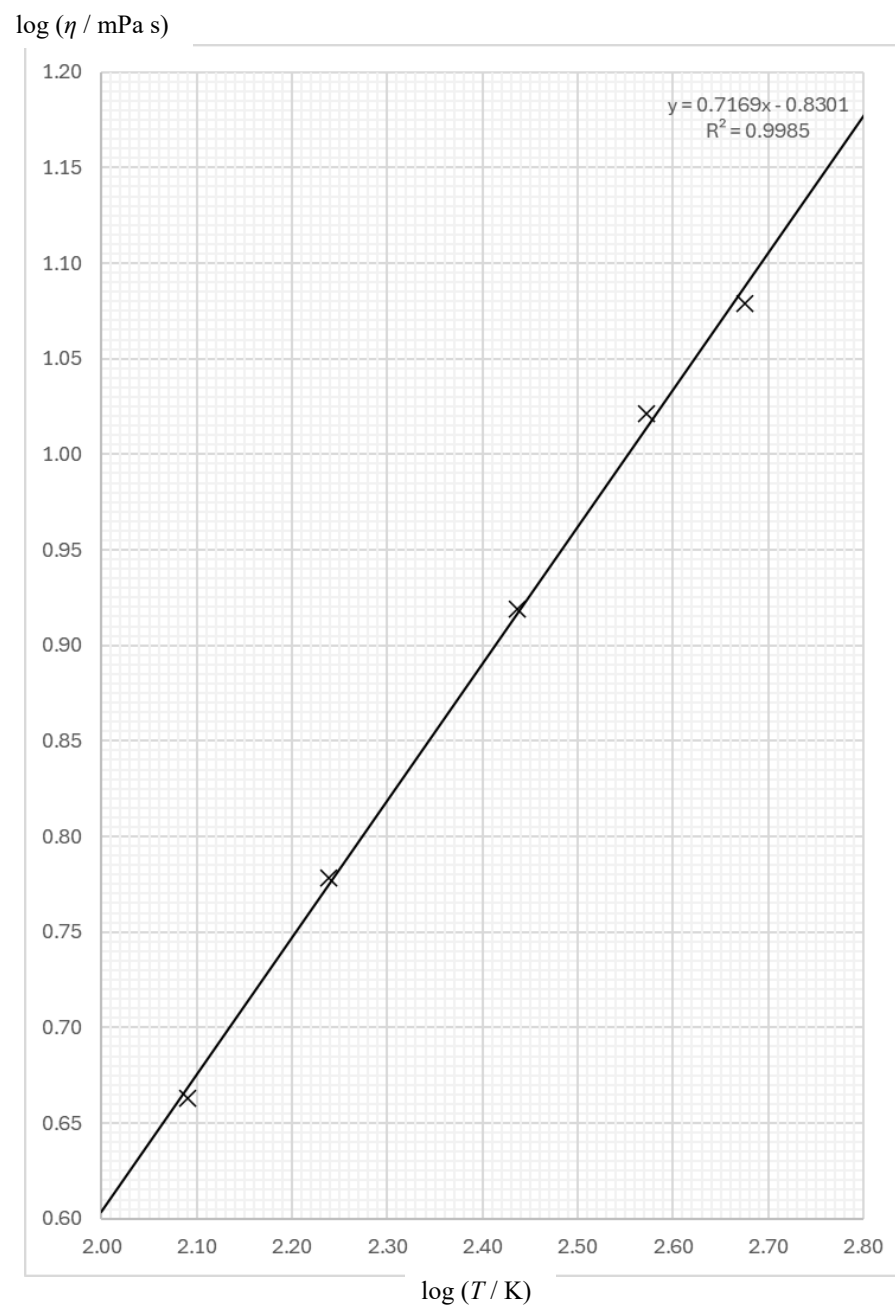


Question Number	Acceptable Answer	Additional Guidance	Mark
8(a)	- Uses $V = \frac{4}{3}\pi r^3$ (1) - Use of $\rho = \frac{m}{V}$ (1) - Use of $W = mg$ to calculate upthrust (1) - Use of $F = 6\pi\eta r v$ (1) $v = 1.8 \times 10^{-3} \text{ m s}^{-1}$ (1)	<u>Example of calculation</u> $V = \frac{4}{3}\pi \times (6.8 \times 10^{-3} \text{ m})^3 = 1.32 \times 10^{-6} \text{ m}^3$ $m = \rho V = 925 \text{ kg m}^{-3} \times 1.32 \times 10^{-6} \text{ m}^3 = 1.22 \times 10^{-3} \text{ kg}$ $\text{upthrust} = 1.22 \times 10^{-3} \text{ kg} \times 9.81 \text{ N kg}^{-1} = 1.20 \times 10^{-2} \text{ N}$ $v = \frac{1.20 \times 10^{-2} \text{ N}}{6\pi \times 52.6 \text{ Pa s} \times 0.68 \times 10^{-2} \text{ m}} = 1.77 \times 10^{-3} \text{ m s}^{-1}$	5
8(b)(i)	An explanation that makes reference to the following points: EITHER - Shows expansion $\log \eta = B \log T + \log A$ (1) - Compares with $y = mx + c$ and states that gradient is B (which is a constant) (1) OR - Shows expansion $\log \eta = \log A + B \log T$ (1) - Compares with $y = c + mx$ and states that gradient is B (which is a constant) (1)	Do not accept m for gradient MP2 dependent on MP1 Do not accept m for gradient MP2 dependent on MP1	2

8(b)(ii)	- Log values correct and consistent to 3 decimal places - Axis labels y as $\log (\eta / \text{mPa s})$, x as $\log (T / \text{K})$ - Scales - Plots - Line of best fit	(1) (1) (1) (1) (1)	Accept correct and consistent to 2 decimal places [Each column is internally consistent]	5																																				
			<table><tr><th>T / K</th><th>$\eta / \text{mPa s}$</th><th>$\log T$</th><th>$\log T$</th><th>$\log \eta$</th><th>$\log \eta$</th></tr><tr><td>123</td><td>4.60</td><td>2.090</td><td>2.09</td><td>0.663</td><td>0.66</td></tr><tr><td>173</td><td>6.00</td><td>2.238</td><td>2.24</td><td>0.778</td><td>0.78</td></tr><tr><td>273</td><td>8.30</td><td>2.436</td><td>2.44</td><td>0.919</td><td>0.92</td></tr><tr><td>373</td><td>10.4</td><td>2.572</td><td>2.57</td><td>1.017</td><td>1.02</td></tr><tr><td>473</td><td>12.0</td><td>2.675</td><td>2.67</td><td>1.079</td><td>1.08</td></tr></table>		T / K	$\eta / \text{mPa s}$	$\log T$	$\log T$	$\log \eta$	$\log \eta$	123	4.60	2.090	2.09	0.663	0.66	173	6.00	2.238	2.24	0.778	0.78	273	8.30	2.436	2.44	0.919	0.92	373	10.4	2.572	2.57	1.017	1.02	473	12.0	2.675	2.67	1.079	1.08
T / K	$\eta / \text{mPa s}$	$\log T$	$\log T$		$\log \eta$	$\log \eta$																																		
123	4.60	2.090	2.09		0.663	0.66																																		
173	6.00	2.238	2.24		0.778	0.78																																		
273	8.30	2.436	2.44	0.919	0.92																																			
373	10.4	2.572	2.57	1.017	1.02																																			
473	12.0	2.675	2.67	1.079	1.08																																			
8(b)(iii)	- Gradient determined using large triangle $B = 0.68 \rightarrow 0.75$ to 2 or 3 sf - Inverse log of intercept determined $A = 0.12 \rightarrow 0.18$ ignore unit	(1) (1) (1) (1)	<u>Example of calculation</u> Gradient = $B = \frac{1.105-0.675}{2.70-2.10} = 0.717$ $\log A = \log \eta - B \log T = 1.105-0.717 \times 2.7 = -0.831$ $A = 10^{-0.831} = 0.148$ MP3: Allow intercept from false origin	4																																				

(Total for Question 8 = 16 marks)





Question Number	Answer	Mark
2	B – 4 cm Incorrect Answers: Correct method: 1. force on one spring is $20 \text{ N} \div 2 = 10 \text{ N}$, 2. spring constant $k = 10 \text{ N} \div 8 \text{ cm} = 1.25 \text{ N cm}^{-1}$, 3. extension = $5 \text{ N} \div 1.25 \text{ N cm}^{-1} = 4 \text{ cm}$ A – 2 cm, omits step 1 C – 8 cm, applies 10 N in step 3 D – 16 cm, applies 20 N in step 3	1



Question Number	Answer	Mark
1	C $\frac{1}{2}mg\Delta x$	1
	Incorrect Answers: A – no factor of $\frac{1}{2}$ B – incorrect equation and no factor of $\frac{1}{2}$ D – incorrect equation	



Question Number	Acceptable answers	Additional guidance	Mark
3	The only correct answer is B because the gradient of this graph is change in length $\div$ change in force and the change in length is the same as the change in extension, so the gradient is equal to stiffness A is not correct because a graph of extension against force will have a gradient of $1/k$ C is not correct because a graph of stress against strain will have a gradient equal to the Young modulus for the sample D is not correct because a graph of strain versus length is equivalent to a graph of extension versus $(\text{length})^2$, so it does not have a gradient equal to k		1



Question Number	Acceptable answer	Additional guidance	Mark
2	B	The only correct answer is B : for each spring, $\frac{1}{2}$ force, so $\frac{1}{2}$ extension, so $\frac{1}{2}Fx$ gives $\frac{1}{4}E$, so total is $\frac{1}{2}E$ A is not correct because it is the energy for one spring with this extension C is not correct because it only applies the factor of $\frac{1}{2}$ once D is not correct because it is the energy for two springs, each with the original extension	1



Question Number	Answer	Mark
4	A kg s^{-2}	1
	Incorrect Answers: B – base units for N C – incorrect units and not base units D – correct units but not base units	



Question Number	Acceptable answer	Additional guidance	Mark
3	C	The only correct answer is C because for the original spring $F = kx$ so $x = F/k$, so $E = \frac{1}{2}Fx = \frac{1}{2}F^2/k$. For $2F$ and $2k$ the epe is $E \times 2^2 / 2 = 2E$ A is not correct because it is $E/2$ B is not correct because it is E A is not correct because it is $8E$	1



Question Number	Answer	Mark
3	The only correct answer is A because the extension is doubled and the force for each spring is the same and $k = F/x$	1



Question Number	Answer	Mark
4	The only correct answer is C because each spring is extended by the same amount so each stores the same energy so the total is doubled	1



8	B $0.5 \times 0.15 \times 2.5$ $E = \frac{1}{2} F \Delta x$	1
	A - incorrect calculation C – incorrect calculation D – incorrect calculation	

(Total for Multiple Choice Questions = 8 marks)



8	The only correct answer is D <i>A is not correct because elastic strain energy is equal to $\frac{1}{2}F^2/k$</i> <i>B is not correct because elastic strain energy is equal to $\frac{1}{2}F^2/k$</i> <i>C is not correct because elastic strain energy is equal to $\frac{1}{2}F^2/k$</i>	1
---	--	---



Question Number	Answer	Mark
3	B $0.5x$	1
	Incorrect Answers: A – Incorrect for parallel springs C – Incorrect for parallel springs D – Incorrect for parallel springs	



Question Number	Acceptable Answers	Additional guidance	Mark
10(a)	- Use of $\Delta E_{el} = \frac{1}{2} F \Delta x$ (1) 4.6 J (1)	<u>Example of Calculation</u> $\Delta E_{el} = \frac{1}{2} \times 29 \text{ N} \times 0.32 \text{ m} = 4.6 \text{ J}$	2
10(b)	- Use of $F = k \Delta x$ (1) 0.30 m (1)	<u>Example of Calculation</u> $\frac{29 \text{ N}}{0.32 \text{ m}} = \frac{27 \text{ N}}{\Delta x}$ $\Delta x = 0.30 \text{ m}$	2
	Total for question 10		4



Question Number	Acceptable Answer	Additional Guidance	Mark
1(a)	- Data not recorded to the same s.f./d.p. (1) - Position of mass holder not recorded (1)		2
1(b)	- Calculate mean value of position of mass (holder) by taking loading and unloading positions of mass (holder) Or calculate mean value by taking repeat readings/measurements (for each mass) (1) - Use a pointer on mass (holder to ensure that position of mass holder is read correctly) Or take readings at eye level (to ensure that position of mass holder is read correctly) Or use a set square to take readings from metre rule (to ensure that position of mass holder is read correctly) Or bring metre rule as close as possible to mass (holder) (1) - Check that metre rule is vertical (1) Or fix metre rule in position		3

(Total for Question 1 = 5 marks)



Question Number	Acceptable Answers	Additional Guidance	Mark
12(a)	- Uses $\Delta F = k\Delta x$ with corresponding points up to $F = 60\text{N}$ (1) Or calculates the gradient between $F = 0$ and $F = 60\text{N}$ 1000 N m^{-1} [range to be determined from final copy of graph] (1)	<u>Example of calculation</u> $\Delta F = k\Delta x$ $k = \frac{\Delta F}{\Delta x} = \frac{60\text{ N}}{0.06\text{ m}} = 1000\text{ N m}^{-1}$ [accept answers in N mm^{-1} or N cm^{-1}]	2
12(b)	- Attempt to determine an area under the graph (1) Or use of $\Delta E_{el} = \frac{1}{2}F\Delta x$ (1) - Between $F = 60$ and $F = 220$ (1) - Ans 4.2 [range to be decided from final copy of graph] (1)	For example: trapezium calculation or counting squares	3
12(c)	- Uses graph to find full compression of spring at $F=700\text{ (N)}$ (1) - Ans = $6 \times 10^{-3}\text{ m}$ [range to be determined from final copy of graph] (1)	<u>Example of calculation</u> $d = 0.126 - 0.120 = 6 \times 10^{-3}\text{ m}$	2
	Total for question 12		7



Question Number	Acceptable Answer	Additional Guidance	Mark
6(a)	- See $I = I_1 + I_2$ (1) - Use of $I = \frac{V}{R}$ with the same V for every term (1) - Algebra to show $\frac{1}{R_{\text{eff}}} = \frac{1}{R_1} + \frac{1}{R_2}$ (1)	If student assumes that $R_1 = R_2 = R \rightarrow R_{\text{eff}} = \frac{R}{2}$, then MP1 and MP2 only For MP3, can assume algebra if equation seen <u>Example of derivation</u> $I = I_1 + I_2 \quad I = \frac{V}{R}$ $\therefore \frac{V}{R_{\text{eff}}} = \frac{V}{R_1} + \frac{V}{R_2}$	3
6(b)	- If two springs are added in parallel the stretching force is shared between the springs (1) - Hence the extension for a given force is half of what it would be for a single spring (1) - So parallel combination has twice the stiffness of a single spring (1) - For two identical resistors in parallel $\frac{1}{R_{\text{eff}}} = \frac{1}{R} + \frac{1}{R}$ (1) - So, adding two equal resistors in parallel halves the effective resistance of the combination (1) - This is in contrast to the springs and so the student's suggestion is invalid (dependent upon MP3 and MP5) (1)	MP3: Allow parallel combination has a greater stiffness than a single spring MP5: Allow adding two resistors in parallel decreases the effective resistance of the combination Equivalent points for MP4 – MP6 - For two identical resistors in series, $R_{\text{eff}} = R + R$ - So adding two equal resistors in series doubles/increases the effective resistance - This is equivalent to parallel springs, so the student's statement is invalid (dependent upon MP3 and MP5)	6

(Total for Question 6 = 9 marks)



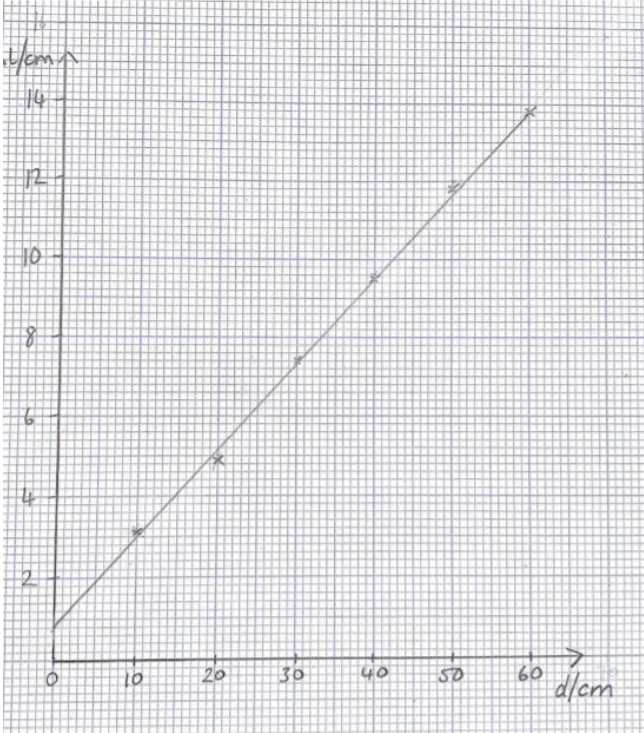
Question Number	Acceptable Answers	Additional guidance	Mark
13(a)	- Draws a line of best fit (1) - Calculates a gradient using at least half the graph (1) 19.4 – 20.6 N m⁻¹ (1)	<u>Example of calculation</u> Gradient = $\frac{5 \text{ N}}{0.25 \text{ m}} = 20 \text{ N m}^{-1}$	3
(b)	- Comment that a straight line graph through the origin (up to 5 N) is consistent with Hooke's law / $F \propto x$ (1) - Comment that indicates that the max extended length 400 mm is not covered by the student's results (1) - Use of $\Delta E_{el} = \frac{1}{2} F \Delta x$ and $F = k \Delta x$ with $\Delta x = 0.4 \text{ m}$ (1) - Or Use of $\Delta E_{el} = \frac{1}{2} F \Delta x$ using extrapolated readings from graph (1) - Candidate's calculated energy value compared with 1.6 J and valid conclusion given (1) Either - Use of %U to determine the range in k (manufacturer's) (1) - Comparison of values for k with conclusion consistent with candidates calculated value in (a) (1) Or - Calculates % difference between candidate's calculated value for k and 21 N m⁻¹ (1) - Comparison of calculated % difference with 5% and conclusion made (1)	<u>Example of calculation</u> $k = 21 \pm 1.05 = 19.95 - 22.05 \text{ N m}^{-1}$ $F = k \Delta x = 20 \text{ N m}^{-1} \times 0.4 \text{ m} = 8.0 \text{ N}$ $\Delta E_{el} (\text{max}) = \frac{1}{2} \times 8.0 \text{ N} \times 0.4 \text{ m} = 1.6 \text{ J}$	6

(Total for Question 13 = 9 marks)



Question Number	Acceptable answers	Additional guidance	Mark
16(a)	- Check that the top of the spring is aligned with zero on the ruler (1) - Move the rule close to the spring Or Ensure that rule is parallel to the spring Or Ensure the metre rule is vertical using a set square (1) - View (the rule) perpendicularly Or Use a set square to take the measurement from the rule (1)		Max 2



16(b)(i)	- Processing of data to calculate extension - Axes with labels & units - Scales - Plots - Line of best fit <table><thead><tr><th>d / cm</th><th>l / cm</th><th>$\Delta l / \text{cm}$</th></tr></thead><tbody><tr><td>10.0</td><td>6.6</td><td>3.1</td></tr><tr><td>20.0</td><td>8.4</td><td>4.9</td></tr><tr><td>30.0</td><td>10.9</td><td>7.4</td></tr><tr><td>40.0</td><td>13.0</td><td>9.5</td></tr><tr><td>50.0</td><td>15.3</td><td>11.8</td></tr><tr><td>60.0</td><td>17.3</td><td>13.8</td></tr></tbody></table>	d / cm	l / cm	$\Delta l / \text{cm}$	10.0	6.6	3.1	20.0	8.4	4.9	30.0	10.9	7.4	40.0	13.0	9.5	50.0	15.3	11.8	60.0	17.3	13.8	(1) (1) (1) (1) (1)  MP3: scales only in 1,2,5 and must cover at least half of paper MP4: a 1 mm square tolerance, check all points	5
d / cm	l / cm	$\Delta l / \text{cm}$																						
10.0	6.6	3.1																						
20.0	8.4	4.9																						
30.0	10.9	7.4																						
40.0	13.0	9.5																						
50.0	15.3	11.8																						
60.0	17.3	13.8																						
16(b)(ii)	- Determine gradient using a large triangle - Use of $gradient = \frac{W}{kD}$ k in range 25.6 – 27.2 3 significant figures and unit given	(1) (1) (1) (1) Example Calculation $gradient = \frac{0.138 - 0.008}{0.600 - 0.000}$ Gradient = 0.217 $0.217 = \frac{5.0 \text{ N}}{k \times 0.875 \text{ m}}$ $k = 26.4 \text{ N m}^{-1}$	4																					

(Total for Question 16 = 11 marks)

Question Number	Acceptable answers	Additional guidance	Mark																																
15(a)(i)	- Use of $\Delta F = k\Delta x$ (1) 45 (N m⁻¹) [accept 0.45 N cm⁻¹] (1)	<u>Example of calculation</u> $k = \frac{2.5 \text{ N}}{5.5 \times 10^{-2} \text{ m}} = 45.45 \text{ N m}^{-1}$	2																																
15(a)(ii)	- Use of $w = mg$ (1) - Use of vertical component of spring forces (1) - Use of $\Delta F = k\Delta x$ (1) $\Delta x = 0.050 \text{ m}$ [accept 5.0 cm] (ECF from (a)(i)) (1)	<u>Example of calculation</u> $w = 0.400 \text{ kg} \times 9.8 \text{ N kg}^{-1} = 3.92 \text{ N}$ $2T \cos 30^\circ = 3.92 \text{ N} \therefore F = \frac{3.92 \text{ N}}{2 \cos 30^\circ} = 2.26 \text{ N}$ $\Delta x = \frac{2.26 \text{ N}}{45.45 \text{ N m}^{-1}} = 0.0498 \text{ m}$	4																																
*15(b)	This question assesses a student's ability to show a coherent and logically structured answer with linkages and fully-sustained reasoning. Marks are awarded for indicative content and for how the answer is structured and shows lines of reasoning. The following table shows how the marks should be awarded for indicative content. - There is an upthrust on the rock (as the rock displaces water) - Hence the net downward force on the rock is reduced F decreases to a minimum once the rock is fully submerged - The rock pushes downwards on the water - So there is an extra force on the balance - Hence R increases to a maximum once the rock is fully submerged	<table border="1"> <thead> <tr> <th>IC points</th><th>IC mark</th><th>Max linkage mark available</th><th>Max final mark</th></tr> </thead> <tbody> <tr> <td>6</td><td>4</td><td>2</td><td>6</td></tr> <tr> <td>5</td><td>3</td><td>2</td><td>5</td></tr> <tr> <td>4</td><td>3</td><td>1</td><td>4</td></tr> <tr> <td>3</td><td>2</td><td>1</td><td>3</td></tr> <tr> <td>2</td><td>2</td><td>0</td><td>2</td></tr> <tr> <td>1</td><td>1</td><td>0</td><td>1</td></tr> <tr> <td>0</td><td>0</td><td>0</td><td>0</td></tr> </tbody> </table>	IC points	IC mark	Max linkage mark available	Max final mark	6	4	2	6	5	3	2	5	4	3	1	4	3	2	1	3	2	2	0	2	1	1	0	1	0	0	0	0	6
IC points	IC mark	Max linkage mark available	Max final mark																																
6	4	2	6																																
5	3	2	5																																
4	3	1	4																																
3	2	1	3																																
2	2	0	2																																
1	1	0	1																																
0	0	0	0																																

(Total for Question 15 = 12 marks)

Question Number	Acceptable answers	Additional guidance	Mark
20 (a)	- Use of $W = mg$ (1) - Use of $\Delta F = k\Delta x$ (1) - Use of $T = 2\pi\sqrt{\frac{m}{k}}$ (1) - Use of $f = \frac{1}{T}$ (1) $f = 1.7$ (Hz), so claim is incorrect. (1)	Example of calculation: $k = \frac{65 \times 10^{-3} \text{ kg} \times 9.81 \text{ N kg}^{-1}}{0.085 \text{ m}} = 7.50 \text{ N m}^{-1}$ $T = 2\pi\sqrt{\frac{65 \times 10^{-3} \text{ kg}}{7.50 \text{ N m}^{-1}}} = 0.585 \text{ s}$ $f = \frac{1}{T} = \frac{1}{0.585 \text{ s}} = 1.71 \text{ Hz}$	5
20 (b)	- There is damping Or resistive forces act on the flamingo (1) - Energy is removed from the oscillating system (and the amplitude decreases) (1)		2
20 (c)(i)	- Use of $T = 2\pi\sqrt{\frac{\ell}{g}}$ (1) $T = 2.24$ (s) (at least 3 sf) (1)	Example of calculation: $T = 2\pi\sqrt{\frac{1.25 \text{ m}}{9.81 \text{ m s}^{-2}}} = 2.24 \text{ s}$	2
20 (c)(ii)	- Use of $\omega = \frac{2\pi}{T}$ (1) - Use of $v = -A\omega \sin \omega t$ (1) $v = 0.21 \text{ m s}^{-1}$ (ecf from (i)) (1)	Example of calculation: $\omega = \frac{2\pi}{2.24 \text{ s}} = 2.80 \text{ rad s}^{-1}$ $v = -7.5 \times 10^{-2} \text{ m} \times 2.80 \text{ s}^{-1} \times 1 = 0.210 \text{ m s}^{-1}$	3

(Total for Question 20 = 12 marks)

Question Number	Acceptable answers	Additional guidance	Mark
16(a)	(Within the elastic limit,) if the load is removed the specimen/spring will return to its original shape / length Or above the elastic limit the specimen remains permanently deformed if the load is removed	Or the converse for each	1
16(b)(i)	- Use of $W = mg$ - Use of $F = kx$ $k = 17700 \text{ (N m}^{-1}\text{)}$	Example of calculation: $275 \text{ kg} \times 9.81 \text{ N kg}^{-1} = 2700 \text{ N}$ $2700 \text{ N} = k \times 0.152 \text{ m}$ $k = 17\,748 \text{ N m}^{-1}$	3
16(b)(ii)	- Use of $T = 2\pi\sqrt{\frac{m}{k}}$ - Use of $f = 1/T$ $f = 1.3 \text{ Hz}$ (ecf from (b)(i))	Example of calculation: $T = 2\pi\sqrt{\frac{1100 \text{ kg}}{4 \times 17\,700 \text{ N m}^{-1}}}$ $f = 1 / 0.783 \text{ s}$ $f = 1.28 \text{ Hz}$	3
16(c)	(Resultant) force/acceleration is proportional to the displacement from the equilibrium position (Resultant) force/acceleration is in the opposite direction to the displacement Or (resultant) force/acceleration is always directed towards the equilibrium position		2
16(d)	An explanation that makes reference to the following points: - High viscosity oil will mean a large resistive force applied to the oscillations (When piston moves) a large amount of work will be done (Heavy damping so) energy of oscillation is quickly dissipated to the oil	May refer to to $F = 6\pi\eta r v$ Mar refer to $\Delta W = F\Delta s$	3

(Total for Question 16 = 12 marks)



Question Number	Acceptable Answer	Additional Guidance	Mark
11(a)	- Data not recorded to the same sf/dp - Positions of mass holder not recorded		2
11(b)	- Attempt to calculate gradient $k = (24.0 \rightarrow 25.0) \text{ N m}^{-1}$	Accept $k = (0.24 \rightarrow 0.25) \text{ N cm}^{-1}$ <u>Example of calculation:</u> $\text{gradient} = \frac{(1.6-0) \text{ N}}{(6.5-0) \times 10^{-2} \text{ m}} = 24.6 \text{ N m}^{-1}$	2
11(c)	- new spring constant = 11 N m^{-1} - Use of $T = 2\pi\sqrt{\frac{m}{k}}$ - Use of $f = 1/T$ $f = 1.5 \text{ Hz}$	<u>Example of calculation:</u> $k = 22/2 = 11 \text{ N m}^{-1}$ $T = 2\pi\sqrt{\frac{0.12 \text{ kg}}{11 \text{ N m}^{-1}}} = 0.66 \text{ s}$ $f = 1/0.66 \text{ s} = 1.5 \text{ Hz}$	4

*11(d)

This question assesses a student’s ability to show a coherent and logical structured answer with linkage and fully-sustained reasoning. Marks are awarded for indicative content and for how the answer is structured and shows lines of reasoning. The following table shows how the marks should be awarded for indicative content.

Number of indicative points seen in answer	Number of marks awarded for indicative points
6	4
5-4	3
3-2	2
1	1
0	0

Indicative content:

- As magnet A moves, its coil experiences a change of magnetic flux (linkage)
- The change in magnetic flux linkage induces an emf in the coil
- The (induced) emf causes a current in both coils
- The current in the second coil causes a force to act on magnet B, driving magnet B into oscillation
- Because both mass-spring systems have the same period/frequency
- Resonance occurs (and magnet B oscillates with increasing amplitude)

The following table shows how the marks should be awarded for structure and lines of reasoning

	Number of marks awarded for structure and lines of reasoning
Answer shows a coherent and logical structure with linkage and fully sustained lines of reasoning demonstrated throughout	2
Answer is partially structured with some linkages and lines of reasoning	1
Answer has no linkage between points and is unstructured	0

Linkage Marks

IC points 1 – 4

Three of these points could score one linkage mark

IC points 5 & 6 could score one linkage mark

6

(Total for Question 11 = 14 marks)

Question Number	Acceptable Answer	Additional Guidance	Mark
-----------------	-------------------	---------------------	------

Question Number	Acceptable Answer	Additional Guidance Whole question to be clipped together to allow full ECF	Mark
10(a)(i)	- Calculation of mean value (1) - Use of $l = \pi w$ (1) $l = 48.1$ mm (3 sf) (1)	<u>Example of calculation:</u> $w = \frac{(15.3+15.2+15.4+15.3)}{4} = 15.3$ mm $l = \pi \times 15.3$ mm = 48.1 mm	3
10(a)(ii)	- Calculation of half range Or greatest deviation from mean (1) % uncertainty = 0.7 % (1) Allow ECF from (a)(i)	<u>Example of calculation:</u> Half range value = $\frac{15.4 \text{ mm} - 15.2 \text{ mm}}{2} = 0.1$ mm $\therefore$ % uncertainty = $\frac{0.1 \text{ mm}}{15.3 \text{ mm}} \times 100 \% = 0.65 \%$	2
10(a)(iii)	- Use of $L = Nl$ with $N = 16$ or 18 (1) $L = 866$ mm [0.866 m] (1) Allow ECF from (a)(i)	<u>Example of calculation:</u> $L = 18 \times 48.1$ mm = 866 mm	2
10(b)(i)	- Micrometer (screw gauge) Or <u>digital</u> calipers (1) - Because the measured value indicates a resolution of 0.01 mm (1)		2
10(b)(ii)	% uncertainty = 0.2 % (1)	<u>Example of calculation:</u> % uncertainty = $\frac{0.005 \text{ mm}}{2.52 \text{ mm}} \times 100 \% = 0.20 \%$	1
10(b)(iii)	% uncertainty = 1.6 % (1)	<u>Example of calculation:</u> % uncertainty = $\frac{0.5 \text{ g}}{32.0 \text{ g}} \times 100 \% = 1.56 \%$	1
10(b)(iv)	% uncertainty = 2.7 % [1 or 2 sf] (1) Allow ECF from (a)(ii), (bii) and (b)(iii)	<u>Example of calculation:</u> % uncertainty = 0.7 % + 1.6 % + (2 × 0.2 %) = 2.7 %	1

10(b)(v)	• Use of $V = L \times \frac{\pi d^2}{4}$ (1) • Use of $\rho = \frac{m}{V}$ (1) • Uncertainty in density = 200 kg m^{-3} (1) • So maximum density is 7600 kg m^{-3} which is lower than the standard value Or comment consistent with their calculated value (1) Allow ECF from (a)(iii) and (b)(iv)	<u>Example of calculation:</u> $V = 0.866 \text{ m} \times \frac{\pi(2.52 \times 10^{-3})^2}{4} = 4.32 \times 10^{-6} \text{ m}^3$ $\rho = \frac{3.20 \times 10^{-2} \text{ kg}}{4.32 \times 10^{-6} \text{ m}^3} = 7400 \text{ kg m}^{-3}$ Uncertainty in $\rho = \pm(7400 \text{ kg m}^{-3} \times \frac{2.7}{100}) = 200 \text{ kg m}^{-3}$	4
----------	---	---	---

(Total for Question 10 = 16 marks)



Question Number	Acceptable Answer	Additional Guidance	Mark
10(a)(i)	MAX 4 - It's difficult to measure from the same position on the spring each time (1) - Ruler may move between readings (1) - There may be parallax error in reading positions (1) - The student has only taken one measurement for each added mass (1) - Hence this method would not produce accurate values (dependent upon at least one from MP1 – MP4) (1)	Mark (i) and (ii) holistically	5
10(a)(ii)	MAX 5 - Attach a pointer to the bottom of the spring Or take measurements from bottom of mass holder (1) - Bring metre rule closer to the spring (1) - Take measurements from the metre rule as masses are added and as masses are removed (1) - Calculate a mean extension for each mass (1) - Method to ensure metre rule is vertical (1) - Method to reduce parallax error (1)	Mark (i) and (ii) holistically e.g. use of a set square, lining up against a vertical, use of spirit level e.g. take reading at eye level	5
10(b)(i)	Ignoring mass of holder / spring when determining the oscillating mass (1)		1



10(b)(ii)	- Using a data logger (and light gate) would eliminate reaction time (1) - So the uncertainty in the measurement (of the time) would be reduced (1) - Not easy to measure timings for multiple swings/oscillations with a data logger (1)	MP2 (dependent upon MP1)	3
10(b)(iii)	- Identify gradient as $\frac{4\pi^2}{k}$ (1) - Determine gradient of graph (1) $k = 17.8 \text{ N m}^{-1}$ [17.5 → 18.5] (1)	<u>Example of calculation</u> Gradient = $2.21 \text{ s}^2 \text{ kg}^{-1}$ $k = \frac{4\pi^2}{2.21 \text{ s}^2 \text{ kg}^{-1}} = 17.8 \text{ N m}^{-1}$	3
10(c)	- Timing a large number of oscillations minimised the percentage uncertainty in the measurement (1) - Repeating each timing measurement and calculating a mean minimised the effect of random errors (1) - Taking a repeat measurement allowed a check for gross timing errors. (1)		3

(Total for Question 10 = 20 marks)



Question Number	Answer	Mark
1	C $\frac{F/A}{\Delta x/x}$ (stress/strain)	1
	Incorrect Answers: A incorrect arrangement B incorrect arrangement D incorrect arrangement for strain	



Question Number	Answer	Mark
5	The only correct answer is B because $x = Fl/EA$ where $F = mg$ so $x = mgl/EA = \frac{24 \times 9.81 \times 1.5}{1.8 \times 10^{11} \times 3.1 \times 10^{-6}}$	1



Question Number	Answer	Mark
6	A $\frac{36000 \times 0.5}{4.5 \times 10^{-4} \times 2.0 \times 10^{-4}}$	1
	Incorrect Answers: B – incorrect arrangement of equation C – incorrect arrangement of equation D – incorrect arrangement of equation	



Question Number	Answer	Mark
2	B stress v strain	1
	Incorrect Answers: A – gradient $\neq$ Young modulus C – gradient $\neq$ Young modulus D – gradient $\neq$ Young modulus	



Question Number	Acceptable answers	Additional guidance	Mark
4	The only correct answer is C A is not correct as when Z is twice as long then the extension is doubled. When Z has twice the area then it will have half the extension. So overall the extension will be the same. B is not correct as when Z is twice as long then the extension is doubled. When Z has twice the area then it will have half the extension. So overall the extension will be the same. D is not correct as when Z is twice as long then the extension is doubled. When Z has twice the area then it will have half the extension. So overall the extension will be the same. displaced		1



Question Number	Answer	Mark
2	B metre rule and micrometer	1
	A - stopwatch incorrect C - stopwatch incorrect D- stopwatch incorrect	



10	The only correct answer is D <i>A is not correct because doubling the force and the length whilst halving the diameter leads to an increase by a factor of 16</i> <i>B is not correct because doubling the force and the length whilst halving the diameter leads to an increase by a factor of 16</i> <i>C is not correct because doubling the force and the length whilst halving the diameter leads to an increase by a factor of 16</i>	1
----	---	---

(Total for Multiple Choice Questions = 10 marks)



6	The only correct answer is D A is not correct because this is not a base unit B is not correct because this is not a unit for breaking stress C is not correct because this is not a base unit	1
---	--	---



Question Number	Answer	Mark
1	The only correct answer is B, kg m s^{-2} A is not correct because these are the base units of force C is not correct because N is not a base unit D is not correct because Pa is not a base unit	1



Question Number	Acceptable Answers	Additional Guidance	Mark
10	- Calculate force = mg (1) - calculate the cross-sectional area $A = \pi \frac{d^2}{4}$ (1) - x- and y- variables to produce a suitable straight-line graph (1) - correct use of the gradient from their graph to determine E (1)	Accept $A = \pi r^2$ and $r = \frac{d}{2}$ Accept stress and strain only if definition of each is given	4
	Total for question 10		4

Question Number	Acceptable Answers	Additional guidance	Mark
10(a)	- Use of $v = \frac{s}{t}$ with a factor of 2 (1) Either $t = 125 \mu\text{s}$ (1) - Comparison of their calculated value with $160 \mu\text{s}$ to reach a conclusion consistent with their answer (1) Or $s = 0.256 \text{ m}$ (1) - Comparison of their calculated value with 0.2 m to reach a conclusion consistent with their answer (1)	<u>Example of calculation</u> $s = \frac{3200 \text{ m s}^{-1} \times 1.25 \times 10^{-4} \text{ s}}{2} = 0.2 \text{ m}$ $t = \frac{2 \times 0.2 \text{ m}}{3200 \text{ m s}^{-1}} = 250 \mu\text{s}$ $125 \mu\text{s} < 160 \mu\text{s}$ so detected	3
10(b)	- Use of $\Delta E_{el} = \frac{1}{2} F \Delta x$ (1) 0.026 J (1)	<u>Example of calculation</u> $\Delta E_{el} = \frac{1}{2} \times 130 \text{ N} \times 4.0 \times 10^{-4} \text{ m} = 0.026 \text{ J}$	2

(Total for Question 10 = 5 marks)



Question Number	Acceptable Answers	Additional guidance	Mark
9(a)	- Use of $\sigma = \frac{F}{A}$ and $A = \frac{\pi d^2}{4}$ (1) - Use of $E = \frac{\text{stress}}{\text{strain}}$ with strain = 0.2 % (1) $E = 1.4 \times 10^9 \text{ Pa}$ (1)	<u>Example of Calculation</u> $\text{Stress} = \frac{14 \text{ N}}{\pi \times \left(\frac{2.5 \times 10^{-3} \text{ m}}{2}\right)^2} = 2.85 \times 10^6 \text{ N m}^{-2}$ $E = \frac{2.85 \times 10^6 \text{ N m}^{-2}}{0.2/100} = 1.4 \times 10^9 \text{ N m}^{-2}$	3
9(b)	- Use of $\Delta E_{el} = \frac{1}{2} F \Delta x$ Or Use of $F = kx$ and $\Delta E_{el} = \frac{1}{2} k \Delta x^2$ (1) 0.028 J (1)	<u>Example of Calculation</u> $\Delta E_{el} = \frac{1}{2} \times 14 \text{ N} \times (0.002 \times 2.0 \text{ m}) = 0.028 \text{ J}$	2
9(c)	(The longer the wire) the larger the extension (for a given force) (1) (So) smaller <u>percentage uncertainty</u> (in measurement of extension) (1)		2
	Total for Question 9		7

Question Number	Acceptable answers	Additional guidance	Mark
10(a)(i)	$\sigma = 54\text{--}56$ (MPa) (1) - Use of $\sigma = \frac{F}{A}$ with their value of σ (1) $F = 64.5\text{ N} - 67.5\text{ N}$ (1)	do not penalise powers of 10 <u>Example of calculation</u> $F = 56 \times 10^6 \text{ Nm}^{-2} \times 1.2 \times 10^{-6} \text{ m}^2$ $F = 67\text{ N}$	3
10(a)(ii)	- Use of $\epsilon = \frac{\Delta x}{x}$ (1) - Extension = 1.0 cm (1)	<u>Example of calculation</u> $0.04 = \Delta x / 25\text{ cm}$ $\Delta x = 0.04 \times 25\text{ cm} = 1.0\text{ cm}$ Allow 1 cm, 0.01 m, 10 mm	2
10(b)	An answer that makes reference to the following: - Shrilk has less strain for same stress Or Shrilk is stiffer (1) - Shrilk breaks at a higher stress (compared to polythene) Or Shrilk can withstand a greater stress/force/load/weight Or Shrilk is stronger (1) - Shrilk doesn't stretch as much (for a given force) (1)	It should be clear from the student's answer that shrilk is the better material Ignore references to Young modulus, renewable, biodegradable, cost Accept converse arguments for polythene	3

(Total for Question 10 = 8 marks)

Question Number	Acceptable answers	Additional guidance	Mark
10(a)	- SI units for v, ρ and d (1) $\text{Pa} = \text{N m}^{-2}$ (1) - SI units for Newton = kg m s^{-2} (1)		3
10(b)(i)	- Determines the gradient up to stress of $7.0 \times 10^7 \text{ N m}^{-2}$ (1) $1.2 - 1.3 \times 10^9 \text{ N m}^{-2}$ (1)	<u>Example of calculation</u> $E = \frac{5.0 \times 10^7 \text{ N m}^2}{0.04} = 1.25 \times 10^9 \text{ N m}^{-2}$	2
10(b)(ii)	MAX THREE <u>Stress</u> and <u>strain</u> are no longer proportional Or Fibre no longer obeys Hooke's law (1) - Fibres are stretched irreversibly (1) - Smaller change in stress to strain Or Larger change in strain to stress Or Collagen fibres becomes less stiff (1) - Collagen fibres break when stress = 8.0 N m^{-2} Or Collagen fibres break when strain = 0.08 (1)		3

(Total for Question 10 = 8 marks)



Question Number	Acceptable Answers	Additional Guidance	Mark
16(a)	A description that makes reference to two of the following: - No need for further calculation Or gives a value for resistance without calculation (1) - No need for an additional power supply (1) - Uncertainties caused by two devices is (possibly) greater than that caused by one device (1)	Do not accept more precise or no parallax or quicker	2
16(b)(i)	(As applied force increases) the length (l) (of wire) increases/stretches Or the wire is longer (1) - the resistance increases with reference to $R = \frac{\rho l}{A}$ (1)	Reference to formula may be in terms of proportionality or direct quote of equation Do not accept change in resistivity	2
16(b)(ii)	- Use of $GF = \frac{\Delta R}{\epsilon R}$ (1) - Substitution of $\epsilon = \frac{\Delta w}{w}$ into GF equation (1) $\Delta w = 2.5 \times 10^{-5} \text{ m}$ (1)	(x may seen in place of w) <u>Example of calculation:</u> $GF = \frac{\Delta R}{\epsilon R}$ $2 = \frac{0.001}{\Delta w / (5 \times 10^{-2})}$ $\Delta w = 2.5 \times 10^{-5} \text{ m}$ Accept $2.5 \times 10^{-3} \text{ cm}$ / $2.5 \times 10^{-2} \text{ mm}$	3
16(c)	An explanation that makes reference to the following: - As small changes (in w) are multiplied many times Or can use a longer wire (on a small gauge) Or to achieve a greater change in the length (1) (So) greater sensitivity Or larger changes in R (for a given change in width) (1)		2

(Total for Question 16 = 9 marks)



Question Number	Acceptable answers	Additional guidance	Mark
18 (a)(i)	- Use of $\rho = \frac{m}{V}$ with $V = \pi r^2 L$ (1) $\mu = 1.09 \times 10^{-3} \text{ (kg m}^{-1}\text{)}$ (to at least 3 sf) (1)	For MP1, accept use of ρA <u>Example of calculation:</u> $\mu = \frac{m}{L} = \frac{V\rho}{L} = \frac{\pi r^2 L \rho}{L} = \pi r^2 \rho$ $\therefore \mu = \pi \left(\frac{1.14 \times 10^{-3} \text{ m}}{2} \right)^2 \times 1070 \text{ kg m}^{-3}$ $\mu = 1.09 \times 10^{-3} \text{ kg m}^{-1}$	2
18 (a)(ii)	- Use of $L = \frac{\lambda}{2}$ (1) - Use of $v = f\lambda$ (1) - Use of $v = \sqrt{\frac{T}{\mu}}$ (1) $T = 140 \text{ N}$ (ecf from (a)(i)) (1)	<u>Example of calculation:</u> $\lambda = 2 \times 0.41 \text{ m} = 0.82 \text{ m}$ $v = 440 \text{ Hz} \times 0.82 \text{ m} = 361 \text{ m s}^{-1}$ $361 \text{ m s}^{-1} = \sqrt{\frac{T}{1.09 \times 10^{-3} \text{ kg m}^{-1}}}$ $\therefore T = (361 \text{ m s}^{-1})^2 \times 1.09 \times 10^{-3} \text{ kg m}^{-3}$ $T = 142 \text{ N}$	4
18 (b)	An explanation that makes reference to the following points: (As the temperature increases,) E decreases (1) - The tension in the string decreases (1) - The wave speed decreases and the frequency decreases (1) Or Wavelength is constant and the frequency decreases (1)	MP2 accept “the string slackens”, accept stress decreases	3

(Total for Question 18 = 9 marks)



Question Number	Acceptable Answers	Additional guidance	Mark
17 (a)(i)	- Use of $v^2 = u^2 + 2as$ (1) - Use of $a = \frac{\Delta v}{\Delta t}$ (1) - Use of $F = R - mg = ma$ (1) $R = 360 \text{ N}$ [accept total force = 721 N] (1)	<u>Example of calculation</u> $v^2 = 2 \times 9.81 \text{ m s}^{-1} \times 1.6 \text{ m} [v = 5.60 \text{ m s}^{-1}]$ $a = \frac{5.60 \text{ m s}^{-1}}{0.9} = 6.23 \text{ m s}^{-2}$ $F = 45 \text{ kg} \times 6.23 \text{ m s}^{-2} = 280 \text{ N}$ $R = 45 \text{ kg} \times 9.81 \text{ m s}^{-2} + 280 \text{ N} = 721 \text{ N}$	4
17(a)(ii)	- bending knees increases the time to come to rest (1) - decreasing rate of change of momentum or reducing the deceleration (1) - and (hence) force (1)	Accept converse argument	3
17(b)	Max three Elderly bone: - lower gradient showing the bone is under more strain for a given stress (1) - graph ends at a lower stress showing it has a lower breaking stress (1) - Area under graph is smaller as less energy is absorbed before fracture (1) - Graph is shorter showing less plasticity (1)	Accept answer with respect to healthy bone Accept more brittle	3

(Total for Question 17 = 10 marks)

Question Number	Acceptable Answer	Additional Guidance	Mark
5(a)(i)	- Changes (in recorded length) due to the support bending are minimised Or changes (in recorded length) due to temperature are minimised Or it allows use of a vernier scale (to determine extension)		1
5(a)(ii)	- To keep the reference wire taut/straight Or to keep the reference wire under tension		1
5(b)	An explanation that makes reference to the following points: - A thin wire has a large stress (for a given load) - A long/thin wire has a large extension (for a given stress) - Hence the percentage uncertainty in the length/extension is reduced		3
5(c)	- Calculates A - Determine gradient - Substitutes $\sigma = \frac{F}{A}$ and $\epsilon = \frac{\Delta x}{x}$ into $E = \frac{\sigma}{\epsilon}$ - Uses $E = \frac{1}{\text{gradient}} \times \frac{x}{A}$ $E = 1.1 \times 10^{11} \text{ N m}^{-2}$	<u>Example of calculation</u> $A = \frac{\pi \times (5.60 \times 10^{-4} \text{ m})^2}{4} = 2.46 \times 10^{-7} \text{ m}^2$ $E = \frac{F/A}{\Delta x/x} = \frac{F}{\Delta x} \times \frac{x}{A}$ $\text{Grad} = \frac{\Delta x}{F} \therefore E = \frac{1}{\text{gradient}} \times \frac{x}{A}$ $\text{Grad} = \frac{(3.6 - 0.75) \times 10^{-3} \text{ m}}{(32.0 - 5) \text{ N}} = 1.06 \times 10^{-4} \text{ m N}^{-1}$ $\therefore E = \frac{1}{1.06 \times 10^{-4} \text{ m N}^{-1}} \times \frac{2.75 \text{ m}}{2.46 \times 10^{-7} \text{ m}^2}$ $\therefore E = 1.057 \times 10^{11} \text{ N m}^{-2}$	5

(Total for Question 5 = 10 marks)



Question Number	Acceptable Answer	Additional Guidance	Mark
19(a)	- Use of $\rho = \frac{m}{V}$ and volume of a cuboid (1) $m = 2.21 \times 10^5$ (kg) (1)	<u>Example of calculation</u> $V = 25.0 \text{ m} \times 3.10 \text{ m} \times 3.10 \text{ m} = 240 \text{ m}^3$ $m = 920 \text{ kg m}^{-3} \times 240 \text{ m}^3 = 2.21 \times 10^5 \text{ kg}$	2
19(b)(i)	- Use of $I = \frac{P}{A}$ (1) - Use of $E = mL$ (1) - Use of $E = mc\Delta\theta$ (1) - Use of 1% (1) - Use of $P = \frac{W}{t}$ (1) - Energy needed ($8.3 \times 10^8 \text{ J}$) is greater than energy arriving ($5.6 \times 10^8 \text{ J}$), so claim is incorrect. (ecf for mass from (a)) (1) Or $t = 18 \text{ hours} > 12 \text{ hours}$, so claim is incorrect (1)	<u>Example of calculation</u> $P = 1350 \text{ W m}^{-2} \times (3.1 \text{ m})^2 = 13\,000 \text{ W}$ $E = 0.01 \times 2.21 \times 10^5 \times 2.09 \times 10^3 \text{ J kg}^{-1}\text{K}^{-1} \times 20\text{K} = 9.24 \times 10^7 \text{ J}$ $E = 0.01 \times 2.21 \times 10^5 \text{ kg} \times 3.34 \times 10^5 \text{ J kg}^{-1} = 7.38 \times 10^8 \text{ J}$ $E_{\text{total}} = 8.31 \times 10^8 \text{ J}$ $t = \frac{8.31 \times 10^8 \text{ J}}{13\,000 \text{ W}} = 6.39 \times 10^4 \text{ s}$ $t = \frac{6.39 \times 10^4 \text{ s}}{3600 \text{ s hour}^{-1}} = 18 \text{ hours}$ For MP6 allow their value compared to the reference value.	6
19(b)(ii)	MAX 2 - Energy will transfer to the ice sculpture from the surroundings (1) - Radiation from the sun is not continuously incident on the statue (1) - The Sun will not always be directly overhead (1) - Some incident radiation will be reflected (1)	Accept the model is idealised, as sculpture is not cuboid	2

(Total for Question 19 = 10 marks)

Question Number	Acceptable Answer	Additional Guidance	Mark
20(a)	- Use of $W = mg$ (1) - Use of $A = \pi r^2$ (1) - Use of $\sigma = \frac{F}{A}$ (1) - Use of 16 (1) $\sigma = 4.1 \times 10^7 \text{ Pa}$ (1)	<u>Example of calculation</u> $W = 3.0 \times 10^8 \text{ kg} \times 9.81 \text{ N kg}^{-1} = 2.94 \times 10^9 \text{ N}$ $F = \frac{2.94 \times 10^9 \text{ N}}{16} = 1.84 \times 10^8 \text{ N}$ $A = \pi \times (1.2 \text{ m})^2 = 4.52 \text{ m}^2$ $\sigma = \frac{1.84 \times 10^8 \text{ N}}{4.52 \text{ m}^2} = 4.07 \times 10^7 \text{ Pa}$	5
20(b)(i)	- Use of $\omega = 2\pi f$ (1) - Use of $v = (-)A\omega \sin \omega t$ (1) $v = (-)0.96 \text{ m s}^{-1}$ (1)	Allow $(-)0.48 \text{ m s}^{-1}$ if $A/2$ used <u>Example of calculation</u> Use of $\omega = 2\pi \times 0.17 \text{ Hz} = 1.07 \text{ rad s}^{-1}$ Use of $v = (-) 0.9 \text{ m} \times 1.07 \text{ rad s}^{-1} \times 1 = 0.961 \text{ m s}^{-1}$	3
20(b)(ii)	MAX 3 - There is a maximum displacement for each tower when forced into oscillation at its <u>natural</u> frequency (1) - This is an example of resonance (1) - The linked towers have a reduced displacement at (a lower) <u>natural</u> frequency (1) - There is (more) damping when the towers are linked (1)		3

(Total for Question 20 = 11 marks)



Question Number	Acceptable answers	Additional guidance	Mark
17(a)	- Use of $\sigma = F / A$ - Use of $E = \sigma / \varepsilon$ and $\varepsilon = \Delta x / x$ $\Delta x = 1.6 \times 10^{-3} \text{ m}$	(1) <u>Example of calculation</u> $\sigma = (12 \times 10^3 \text{ N}) / (6 \times 3.1 \times 10^{-4} \text{ m}^2)$ $\sigma = 6.45 \times 10^6 \text{ Pa}$ $\varepsilon = 6.45 \times 10^6 \text{ Pa} / 200 \times 10^9 \text{ Pa} = 3.23 \times 10^{-5}$ $\Delta x = 3.2 \times 10^{-5} \times 50 \text{ m} = 1.61 \times 10^{-3} \text{ m}$	3
17(b)(i)	- Weight of people = 19 kN – 12 kN - Use of $W = mg$ - Mass of people = 710 kg	(1) <u>Example of calculation</u> Weight of people = 19kN – 12 kN $7 \times 10^3 \text{ N} / 9.81 \text{ N kg}^{-1} = 714 \text{ kg}$	3
17(b)(ii)	An explanation that makes reference to the following points: - From 5 s to 6.5 s lift accelerates upwards and from 6.5 s to 27.5 s lift travels upwards at constant speed and from 27.5 s to 29 s lift decelerates to rest MAX 2 from: - From 5 s to 6.5 s there is resultant force upward Or From 5 s to 6.5 s the tension is greater than the weight - From 6.5 s to 27.5 s resultant force is zero Or From 6.5 s to 27.5 s tension is equal to weight - From 27.5 s to 29 s resultant force is downwards Or From 27.5 s to 29 s tension is less than weight		3
17(c)	- The tension in each of the remaining cables would increase Or Total force remains the same, but the total cable area decreases (The area of each cable doesn't change) so the stress in each cable would increase - With an increased stress, the strain of each cable would increase so the extension would be greater.		3

(Total for Question 17 = 12 marks)



Question Number	Acceptable answers	Additional guidance	Mark
16(a)	- Determine period, T (1) - Use of $T = 2\pi\sqrt{l/g}$ (1) - Subtracts radius of mass (1) - Length of wire = 10.3 (m) (1)	<u>Example of calculation</u> $T = 52.2 \text{ s} / 8$ $= 6.53 \text{ s}$ $6.53 \text{ s} = 2\pi\sqrt{l/9.81 \text{ N kg}^{-1}}$ Length of pendulum to centre of mass = 10.6 m Length of wire = 10.6 m – 0.3 m = 10.3 m	4
16 (b)(i)	- Use of (breaking) stress = F/A (1) - Use of $A = \pi r^2$ (1) - Diameter = 1.06 mm and choose 1.22 mm because it is the thinnest wire with stress lower than the breaking stress (1)	<u>Example of calculation</u> For max stress, $3.10 \times 10^8 \text{ N m}^{-2} = 28 \text{ kg} \times 9.81 \text{ N kg}^{-1}/A$ $A = 8.86 \times 10^{-7} \text{ m}^2$ $8.86 \times 10^{-7} \text{ m}^2 = \pi r^2$ $r = 5.3 \times 10^{-4} \text{ m}$ diameter = 1.06 mm	3
16 (b)(ii)	- Use of stress = F/A and $A = \pi r^2$ (ecf for radius from (b)(i)) (1) - Use of Young modulus = stress / strain and strain = $\Delta x/x$ (1) - Extension = 1.3 cm (1)	Allow ecf for radius of wire chosen in part (b)(i), but not for the calculated radius or area <u>Example of calculation</u> stress = $28 \text{ kg} \times 9.81 \text{ N kg}^{-1} / \pi (1.22 \times 10^{-3} \text{ m} / 2)^2$ strain = $2.34 \times 10^8 \text{ Pa} / 200 \text{ GPa} = 0.00117$ extension = $0.00117 \times 11.2 \text{ m} = 0.0132 \text{ m}$	3



16 (c)	• There is (damping due to) air resistance and this (damping) force is the same for both (since they have the same shape, area and speed initially) (1) • For large mass the force due to air resistance produces a smaller negative acceleration since $a = F/m$ (1) • The speed will decrease less for each swing, so there is less effect on the amplitude Or It will take longer for the (maximum) speed to decrease (to zero) so the pendulum will oscillate for a longer time (1) OR • There is air resistance and the force is the same for both • The work done by air resistance per swing is the same for both masses (1) • Initially the larger mass has greater quantity of energy shared between its kinetic and potential energy stores, so the proportion of KE transferred to the thermal energy store of the sphere and the surroundings is less per swing, so there is less effect on the amplitude Or Larger mass has greater total energy so fraction dissipated per swing is smaller so the pendulum will oscillate for a longer time (1)		3
--------	---	--	---



	OR There is air resistance and this force is the same for both (1) • For both masses the change in momentum per swing is the same (1) • The larger mass has greater initial momentum so it will take longer for the (maximum) momentum to decrease (to zero) so the pendulum will oscillate for a longer time (1)		
--	--	--	--

(Total for Question 17 = 13 marks)

Question Number	Acceptable answers	Additional guidance	Mark
12(a)	(Measure diameter) using micrometer / digital calipers (1) - Repeat measurements and calculate the mean (1) - Take measurements at different points (along the wire) or at different orientations (1)		3
12(b)(i)	- Substitutes stress = $\frac{F}{A}$ and strain = $\frac{\Delta x}{x}$ into $E = \frac{\text{stress}}{\text{strain}}$ (1) - Identifies gradient as $\frac{F}{\Delta x}$ (1)		2
12(b)(ii)	- Calculates gradient of straight section (1) - Use of $E = \text{gradient} \times \frac{x}{A}$ (1) $E = 1.2 \text{ to } 1.3 \times 10^{11} \text{ N m}^{-2}$ (1) - Wire is made from copper because 117 GPa is closest to the calculated value Or Correct conclusion of the metal consistent with candidate's calculated value (1)	<u>Example of calculation</u> Gradient = $\frac{33}{7 \times 10^{-3}} = 4600 - 4900$ $E = 1.24 \times 10^{11} \text{ N m}^{-1}$ $= 124 \text{ GPa copper}$	4
12(b)(iii)	- Use a smaller (maximum) force/load (1) - To avoid exceeding the limit of proportionality Or As the breaking force of a thinner wire is smaller (1) - Use small(er) increments in the force/load (1) - To obtain more readings (before the elastic limit is reached) Or to obtain enough readings (in the linear part of the graph) (1)		4

(Total for Question 12 = 13 marks)



Question Number	Acceptable answers	Additional guidance	Mark
13(a)(i)	- Uses $\varepsilon = \frac{\Delta x}{x}$ (1) - Strain = 0.07 or 7 % (1) - Uses uncertainty is half the range Or the difference between the mean and the furthest datum point (1) - Uncertainty = 0.008 m (1)	[mean $\Delta x = 12.9$ cm] <u>Example of calculation</u> Mean extension = $\frac{(1.29 + 1.21 + 1.37) \times 10^{-1} \text{ m}}{3} = 1.29 \times 10^{-1} \text{ m}$ $\varepsilon = \frac{1.29 \times 10^{-1} \text{ m}}{1.960 \text{ m}} = 0.07$ $\frac{(1.37 - 1.21) \times 10^{-1} \text{ m}}{2} = 0.008 \text{ m}$	4
13(a)(ii)	- Use of $\Delta E_{el} = \frac{1}{2} F \Delta x$ (1) 6 J (ecf for mean Δx from (a)(i)) (1)	<u>Example of calculation</u> $\Delta E_{el} = \frac{1}{2} \times 90 \text{ N} \times 0.129 \text{ m} = 5.8 \text{ J}$	2
13(a)(iii)	- Measure diameter with micrometer/screw gauge/calipers (1) - Take multiple readings at different locations / orientations (1) - Calculate a mean (1) - Calculate cross-sectional area of the wire using $A = \frac{\pi d^2}{4}$ (1)	Accept $A = \pi r^2$ and $r = \frac{\text{diameter}}{2}$	4



13(b)	An explanation that makes reference to the following points: Max 4 from any two of: (steel has a) greater Young Modulus Or (steel is) stiffer (1) - So less strain / deformation under a given stress/load (1) OR - Elastic limit (for steel) is at a greater stress (1) - So can return to its original size / length up to a greater stress (1) OR - Steel has a greater plastic region (1) - So can absorb more energy before fracture (1) OR - has a greater breaking stress (1) - more stress/force can be applied before it breaks (1)	[Accept answers wrt iron] [do not accept any properties not shown on the graph eg less likely to rust] [allow yield point is at a greater stress]]	4
-------	---	--	---

(Total for Question 13 = 14 marks)



Question Number	Acceptable answers	Additional guidance	Mark
3	B		1



Question Number	Answer	Mark
1	C The stress beyond which the steel becomes permanently deformed.	1
	Incorrect Answers: A – The stress at which the steel undergoes an increase in strain with no increase in stress. B – The stress beyond which the stress and strain are no longer proportional. D – The stress at which the steel breaks.	



Question Number	Acceptable Answers	Additional guidance	Mark								
9	This question assesses a student’s ability to show a coherent and logically structured answer with linkages and fully-sustained reasoning. Marks are awarded for indicative content and for how the answer is structured and shows lines of reasoning. Indicative Content - Band does not obey Hooke’s law Or there is a non-linear relationship between force and extension (1) (The band is elastic so) the extension returns to zero when the force is removed or size/shape is unchanged (1) - For a given force the extension when loading is less than when unloading or for the same extension more force required when loading (1) - Area under the loading curve is greater than the unloading curve Or Loading increases the elastic strain energy (of the band) (1) - The band absorbs more energy when being loaded than it releases when unloaded Or Unloading: some strain energy transferred by heating (1) - Energy released by heating represented by the area between the lines (1)	The following table shows how the marks should be awarded for structure and lines of reasoning <table><tr><td></td><td>Number of marks awarded for structure of answer and sustained line of reasoning</td></tr><tr><td>Answer shows a coherent and logical structure with linkages and fully sustained lines of reasoning demonstrated throughout</td><td>2</td></tr><tr><td>Answer is partially structured with some linkages and lines of reasoning</td><td>1</td></tr><tr><td>Answer has no linkages between points and is unstructured</td><td>0</td></tr></table>		Number of marks awarded for structure of answer and sustained line of reasoning	Answer shows a coherent and logical structure with linkages and fully sustained lines of reasoning demonstrated throughout	2	Answer is partially structured with some linkages and lines of reasoning	1	Answer has no linkages between points and is unstructured	0	6
	Number of marks awarded for structure of answer and sustained line of reasoning										
Answer shows a coherent and logical structure with linkages and fully sustained lines of reasoning demonstrated throughout	2										
Answer is partially structured with some linkages and lines of reasoning	1										
Answer has no linkages between points and is unstructured	0										
	Total for question 9		6								



Question Number	Acceptable Answers	Additional guidance	Mark
12(ai)	For the 30-year-old greater stress for a given strain Or greater Young Modulus Or stiffer Or max deformation of the 23-year-old lens is greater Or breaking stress of 30-year-old lens is greater (1)	Accept answers for the 23-year-old	1
12(aii)	Reference to the graph consistent with their answer to (ai) (1)		1
12(b)	- Use of $m = \frac{v}{u}$ (1) - Use of $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$ (1) - Use of $P = \frac{1}{f}$ (1) - Use of $P = P_1 + P_2 = 5D$ therefore use one lens with power of 2 (D) and one with power of 3 (D) (1)	<u>Example of Calculation</u> $v = 0.5 \times 0.6 \text{ m} = 0.3 \text{ m}$ $\frac{1}{f} = \frac{1}{0.6 \text{ m}} + \frac{1}{0.3 \text{ m}}$ $f = 0.2 \text{ m}$ $P = 1/0.2 \text{ m} = 5D$	4

(Total for Question 12 = 6 marks)



Question Number	Acceptable Answer	Additional Guidance	Mark
10(a)	- Cross sectional area $\times$ length used to calculate volume (1) - Use of $E_k = \frac{1}{2}mv^2$ (1) - Energy per unit volume = $1.7 \times 10^8 \text{ (J m}^{-3}\text{)}$ (1)	<u>Example of calculation:</u> Volume of seatbelt, $V = 0.85 \times 10^{-4} \text{ m}^2 \times 2 \text{ m}$ $V = 1.7 \times 10^{-4} \text{ m}^3$ $E_k = \frac{1}{2} \times 75 \text{ kg} \times (28 \text{ m s}^{-1})^2 = 2.9 \times 10^4 \text{ J}$ $\therefore \frac{E}{V} = \frac{2.9 \times 10^4 \text{ J}}{1.7 \times 10^{-4} \text{ m}^3} = 1.73 \times 10^8 \text{ J m}^{-3}$	3
10(b)(i)	(For linear section of graph) area under graph = $\frac{1}{2}$ stress $\times$ strain (1) - Use of stress = F/A and strain = $\Delta x/x$ to show that area = $\frac{1}{2} \times \frac{F}{A} \times \frac{\Delta x}{x} = \frac{F_{av} \Delta x}{V} = \frac{E}{V}$ (1)	Candidates who only use the graph to show that the area has units J m^{-3} can score a maximum 1 mark Accept F_{av} for $\frac{1}{2}F$	2
10(b)(ii)	- Area under graph up to 0.075 calculated (1) - Energy per unit volume = $7.1 \times 10^5 \text{ J m}^{-3}$ (1) - This is much less than the value given in (a), and so belt does not absorb all the KE. (1) OR - Graph used to determine stress when strain is 0.075 and $\sigma = \frac{F}{A}$ used to calculate force (1) $\epsilon = \frac{\Delta x}{x}$ used to calculate extension and $W = \frac{1}{2}F\Delta x$ used to calculate energy (1) - Statement that this energy is much less than the value in (a), and so belt does not absorb all the kinetic energy (1)	Example of calculation: When strain is 0.075 Area = $\frac{1}{2} \times 19 \times 10^6 \text{ Pa} \times 0.075 = 7.13 \times 10^5 \text{ J m}^{-3}$	3

(Total for Question 10 = 8 marks)



Question Number	Acceptable Answers	Additional guidance	Mark
15(a)	- Energy absorbed in the impact is equal to the change in GPE (between start and end) (1) $\Delta E = mg\Delta h$ and mg constant (so $E \propto \Delta h$) (1)		2
15(b)	- Equate $E = mg\Delta h$ and $E = \frac{1}{2}mv^2$ (1) - Use of $p = mv$ (1) $p = 50 \text{ kg m s}^{-1}$ (1)	Do not accept $v^2 = u^2 + 2as$ (because the hammer does not move in a straight line with constant acceleration) <u>Example of calculation</u> $mg\Delta h = \frac{1}{2}mv^2$ $31 \text{ kg} \times 9.81 \text{ ms}^{-2} \times 0.13 \text{ m} = \frac{1}{2} \times 31 \text{ kg} \times v^2$ $v = \sqrt{(2 \times 9.81 \text{ ms}^{-2} \times 0.13 \text{ m})} = 1.6 \text{ m s}^{-1}$ $p = 31 \text{ kg} \times 1.6 \text{ m s}^{-1} = 49.6 \text{ kg m s}^{-1}$	3
15(c)	- Steel had a lower fracture toughness due to the low temperature (1) - at low temperatures less energy is absorbed before fracture (1) - the (absorbed) energy was sufficient to cause fracture (1)		3

(Total for Question 15 = 8 marks)



Question Number	Acceptable Answer	Additional Guidance	Mark
1(a)	- Positions of mass holder not recorded (1) - Data not recorded to the same sf/dp (1)	Accept reference to not all raw data being recorded/shown	2
1(b)	MAX 3 from: - Read the metre rule at eye level (to avoid parallax) (1) - Bring the metre rule closer (to avoid parallax) (1) - Use set square to read position of bottom of mass holder (1) - Use plumb line to check that metre rule is vertical (1) - Record positions of mass holder when loading and unloading and calculate mean value (1)	A labelled diagram could score MP3 and MP4 Accept valid alternatives to set square e.g. reference to marker on mass holder or add marker to line and position metre rule underneath line Accept valid alternatives to plumb line Accept repeat readings of position and calculate a mean	3
1(c)(i)	- The value of stress at which the fishing line starts to deform permanently/plastically Or the value of stress at which the fishing line continues to extend with no additional force (1)	Accept point / strain for “value of stress” Accept line doesn’t return to original length when force is removed	1
1(c)(ii)	- Use of $\epsilon = \frac{\Delta x}{x}$ (1) (Maximum) extension (before yielding) is 8 cm, so line doesn’t yield Or strain (at max extension) = 0.036, so line doesn’t yield (1)	<u>Example of calculation</u> $\Delta x = 0.04 \times 2.0 \text{ m} = 0.08 \text{ m}$	2

(Total for Question 1 = 8 marks)



Question Number	Acceptable Answer	Additional Guidance	Mark
16(a)	- As graphene is only 1 atom thick so the CSA/thickness is far smaller than for a sample of steel Or most applications need a thickness greater than one atom Or if more than one layer of graphene is used it will be weaker or the bonds between the layers will not be strong Or Graphene is difficult to manufacture because it has only one atomic layer (1) - Although graphene has a greater breaking stress it will break at a lower force (1)	MP1: accept graphene can only be 1 atom thick but steel can be any thickness (MP1, treat references to cost/energy as neutral)	2
16(b)	- Use of depth of graphite = $100 \times \text{diameter of 1 carbon atom}$ (1) - Use of cross-sectional area = $\text{depth} \times (0.5 \times 10^{-3} \text{ m})$ (1) - Use of $\rho = \frac{RA}{l}$ (1) $\rho = 3.6 \times 10^{-5} \Omega \text{ m}$ Or $36 \mu\Omega \text{ m}$ (1)	<u>Example of calculation</u> Depth of graphite = $100 \times 1.4 \times 10^{-10} \text{ m} = 1.4 \times 10^{-8} \text{ m}$ CSA = $1.4 \times 10^{-8} \text{ m} \times 0.50 \times 10^{-3} \text{ m} = 7.0 \times 10^{-12} \text{ m}^2$ $\rho = \frac{1.029 \times 10^6 \Omega \times 7.0 \times 10^{-12} \text{ m}^2}{0.200 \text{ m}} = 3.6 \times 10^{-5} \Omega \text{ m}$	4
16(c)	Max 3 - Silicon will only release a (photo) electron for a limited range of frequencies/wavelengths (1) - Silicon releases only one (photo) <u>electron</u> per incident photon (1) - Greater current (for the same illumination) in graphene (1) - Graphene (cells are) more efficient Or graphene cells could be smaller / cheaper / thinner (1)	MP1: accept single frequency for limited range	3

(Total for Question 16 = 9 marks)

