Name: ____

Topic 4: Materials

Date:

Time:

Total marks available:

Total marks achieved: ______

Questions

Q1.

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 = 8.0×10^{-6} m^3

mass of diver = 0.0059 kg

density of water = 1.0×10^3 kg m^{-3}

(3)

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(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 8.0×10^{-6} m^3.

Show that the volume now occupied by the air is about 6×10^{-6} m^3.

(3)

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(c) The pressure of the air in the empty pipette in part (a) was 1.01×10^5 Pa.

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

(2)

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Pressure = ...

(Total for question = 8 marks)

Q2.

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

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 = 3.10×10^8 N m^{-2}

(3)

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(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)

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Extension = ...

(Total for question = 6 marks)

Q3.

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.

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)

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(Total for question = 3 marks)

Q4.

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.

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)

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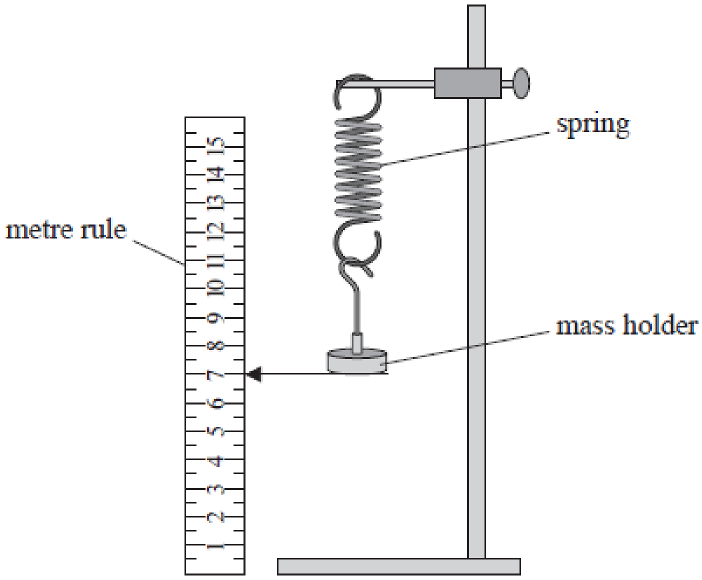
(Total for question = 6 marks)

Q5.

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

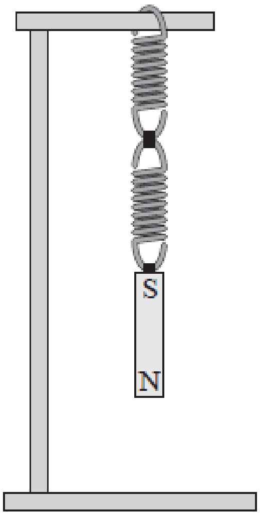


The position of the bottom of the mass holder was recorded. The spring was stretched by adding masses to the mass holder and the new positions were recorded. The extension of the spring each time was calculated.

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

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)

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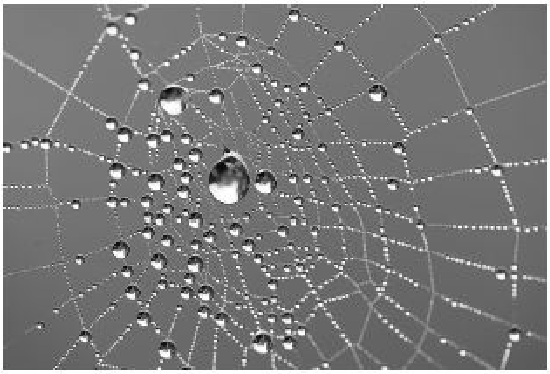
Frequency = ...

(Total for question = 4 marks)

Q6.

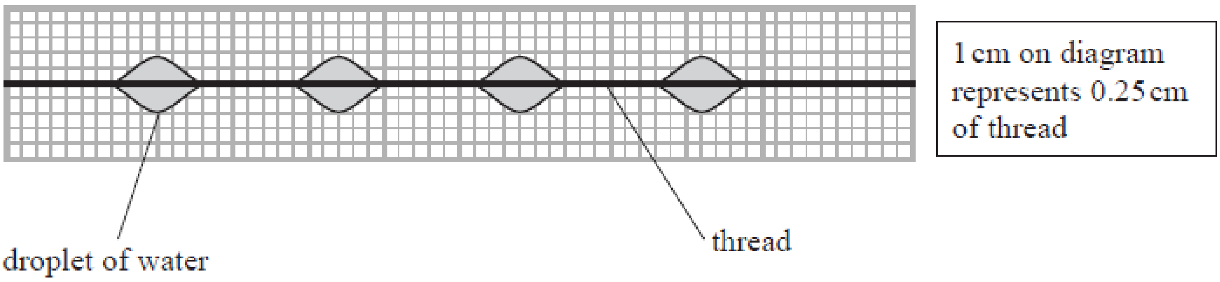
The photograph shows part of a spider's web where water droplets have collected at certain points. The web is made from spider silk which is made by the spider.



Spiders are almost completely dependent on vibrations transmitted through their web for receiving information about the location of trapped insects. When the threads are disturbed by the insects, progressive waves are transmitted along sections of the silk.

It has been suggested that the droplets of water collect at certain points on the web because stationary waves are formed.

The diagram shows water droplets on a single thread of spider silk when the frequency of waves is 7.9 Hz.



Further measurements are taken to test whether the observations are consistent with the presence of stationary waves in the threads.

diameter of the thread = 3.6×10^{-6} m

mass per unit length of the thread = 1.32×10^{-8} kg m^{-1}

Young modulus of spider silk = 1.2×10^{9} N m^{-2}

strain in the thread = 9.7×10^{-9}

Determine, by considering wave speed, whether the measurements are consistent with this suggestion.

(7)

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Q7.

Answer the question with a cross in the box you think is correct (☒). If you change your mind about an answer, put a line through the box (☒) and then mark your new answer with a cross (☒).

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*?

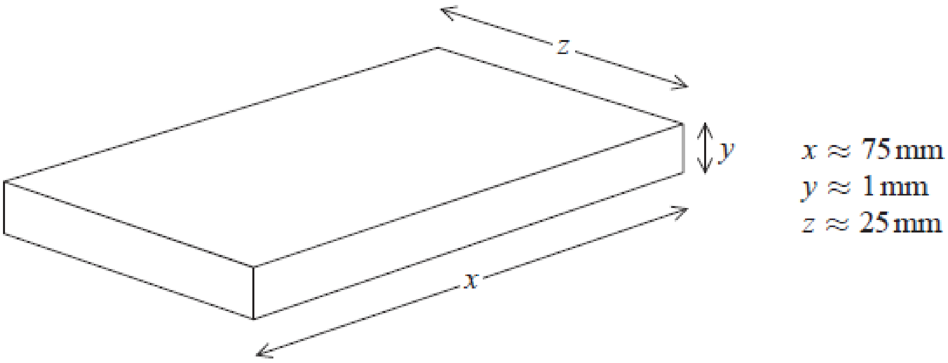
	y-axis	*x*-axis
☒ **A**	extension	force
☒ **B**	force	length
☒ **C**	stress	strain
☒ **D**	strain	length

(Total for question = 1 mark)

Q8.

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)

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

(1)

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(Total for question = 5 marks)

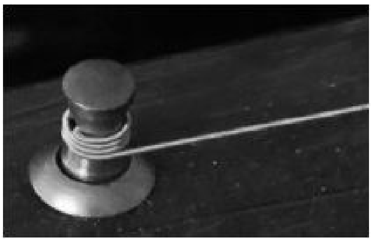
Q9.

The photograph shows a guitar.

When a guitar string is plucked, a standing wave is created.

One end of the guitar string is wrapped around a cylindrical tuning peg. Turning the peg changes the total length of the string and hence changes the tension in the string.

This changes the frequency of vibration of the string.



(i) The length of one string is 68 cm.

Calculate the extension required to produce a tension of 93.4 N in the string.

Young modulus of string material = $1.8 \times 10^{9}\ \mathrm{N\,m^{-2}}$

cross-sectional area of string = $6.6 \times 10^{-7}\ \mathrm{m^{2}}$

(4)

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Extension = ...

(ii) The vibrating length of string is unchanged by turning the tuning peg.

Explain the effect that tightening the string has on the frequency of the sound produced.

(2)

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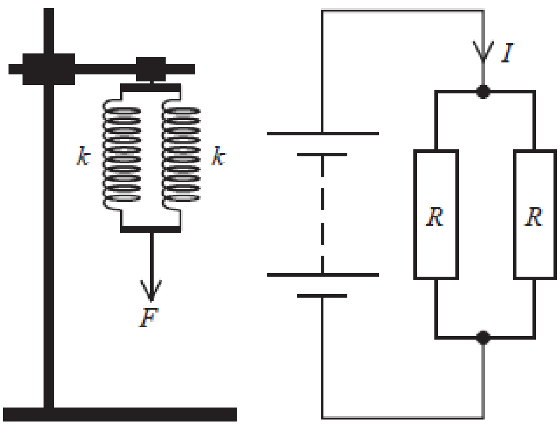
(Total for question = 6 marks)

Q10.

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.



Assess the validity of the student's suggestion by considering the effective stiffness of two identical springs in parallel.

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(Total for question = 6 marks)

Q11.

Answer the question with a cross in the box you think is correct ☒. If you change your mind about an answer, put a line through the box ☒ and then mark your new answer with a cross ☒.

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 2*F* is applied to a spring with stiffness 2*k*?

☐ **A** $\frac{E}{2}$

☐ **B** E

☐ **C** $2E$

☐ **D** $8E$

(Total for question = 1 mark)

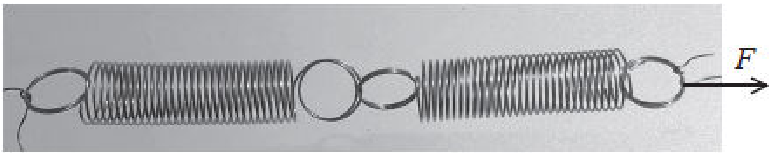
Q12.

Answer the question with a cross in the box you think is correct ☒. If you change your mind about an answer, put a line through the box ☒ and then mark your new answer with a cross ☒.

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.



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 = 1 mark)

Q13.

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 = 1.41×10^{-8} m^3
mass of steel sphere = 1.10×10^{-4} 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

Identify which type of oil the student used.

(4)

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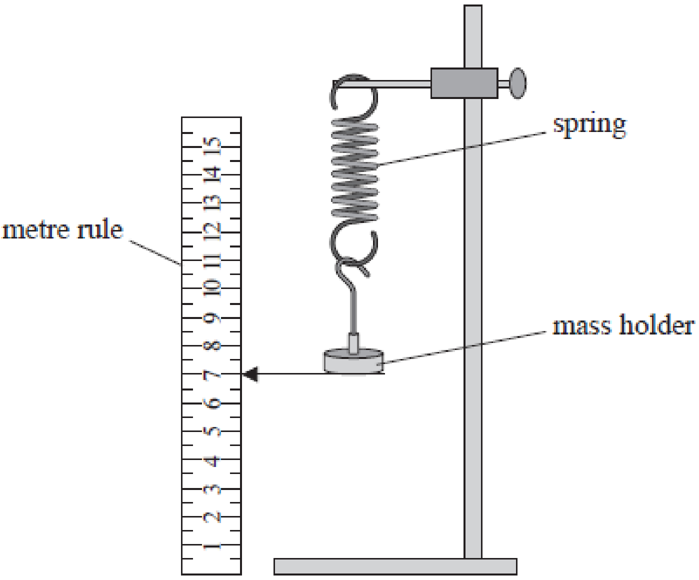
(Total for question = 4 marks)

Q14.

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

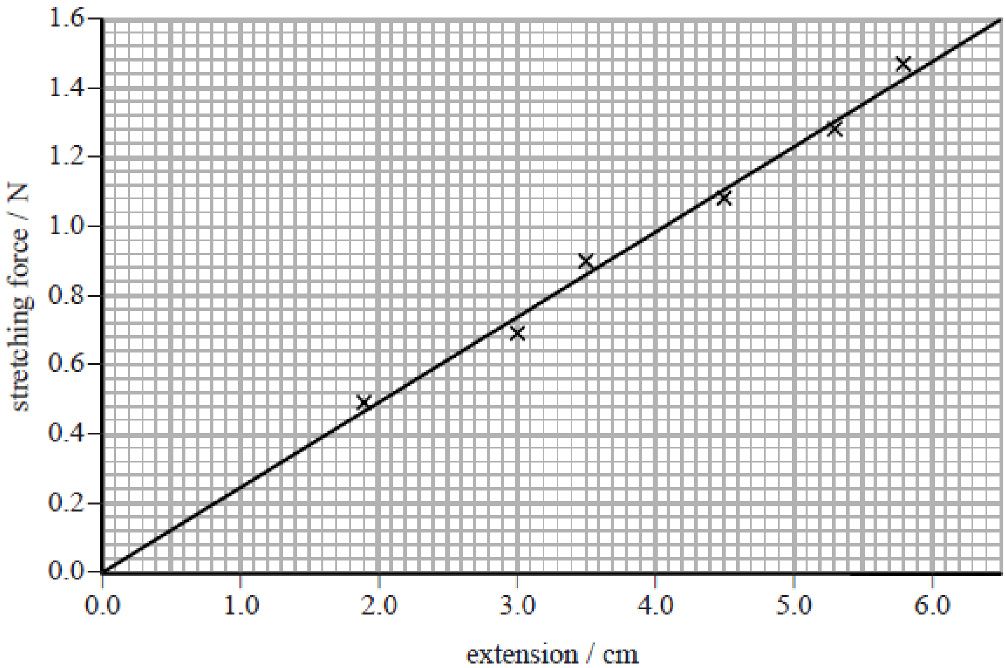


The position of the bottom of the mass holder was recorded. The spring was stretched by adding masses to the mass holder and the new positions were recorded. The extension of the spring each time was calculated.

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

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



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

(2)

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k = ...

(Total for question = 2 marks)

Q15.

In 2014 the Rosetta spacecraft reached the comet Churyumov-Gerasimenko.
Rosetta went into orbit around the comet.

The following table gives some data for the comet.

Mass / kg	1.0×10^{13}
Density / kg m^{-3}	470

The comet is irregular in shape but can be modelled as a spherical object.

(a) Show that a sphere with this mass and density has a radius of about 1700 m.

(3)

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(b) Calculate the gravitational field strength at the surface of the comet.

(2)

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Gravitational field strength = ...

(c) A probe was sent from the Rosetta spacecraft to land on the comet.
The probe bounced off the surface of the comet and took 1 hour and 50 minutes to return to the surface again.

Calculate the height above the surface of the comet that the probe would have reached. Assume that the acceleration of the probe is constant with the magnitude calculated in (b).

(2)

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Height = ...

(d) Explain, using gravitational field theory, how the actual height reached would compare with the value calculated in part (c).

You may assume there are no resistive forces such as air resistance.

(3)

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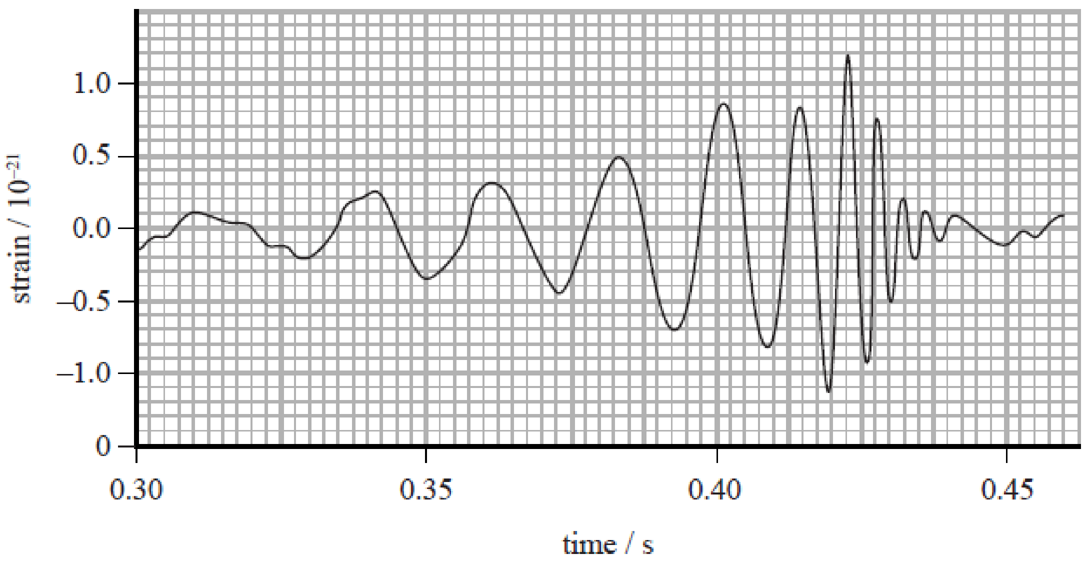
(Total for question = 10 marks)

Q16.

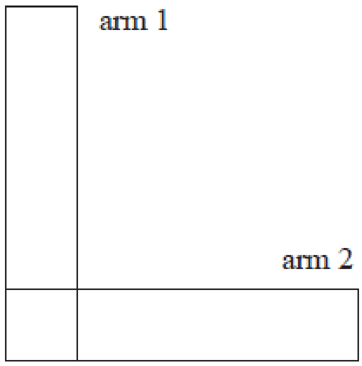
In 2016 scientists at the Laser Interferometer Gravitational-Wave Observatory (LIGO) announced that gravitational waves had been detected.

The signal they detected is shown on the graph.



Gravitational waves alternately compress and stretch matter by very small amounts as they pass through.

The LIGO detector has two arms, at 90° to each other, each 4 km long. As a gravitational wave passes the detector, the arms change length. The detector continuously compares the lengths of the two arms.



(i) An article states that 'the maximum change in the 4 km length of the arm is about 0.001 times the diameter of a proton'.

Determine whether this statement applies to the gravitational wave shown in the graph.

diameter of proton = 8.8×10^{-16} m

(3)

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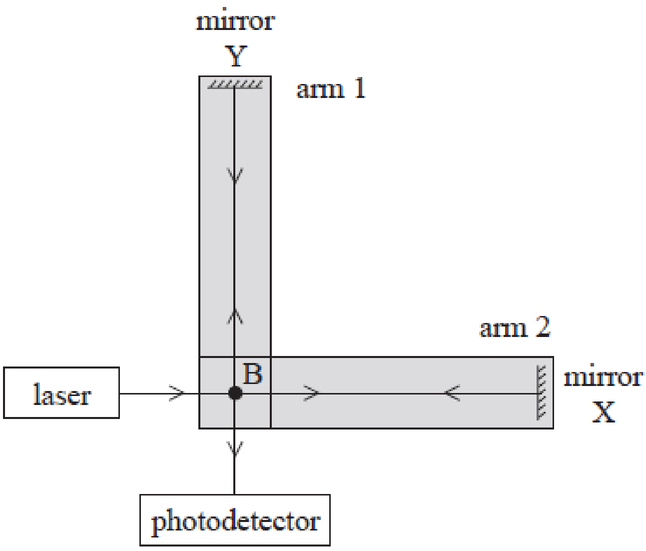
(ii) In the LIGO detector, any change in the lengths of the arms is detected using a laser beam and photodetector.



The laser beam is split into two at B, one beam travelling to one mirror and the other beam travelling to the other mirror. After reflection at the mirrors, the beams are recombined at B and reach the photodetector. The photodetector measures the intensity of the incident light.

The system is arranged so that when no gravitational waves are present, the beams have a path difference of half a wavelength at the photodetector.

Explain how the photodetector detects very small changes in the length of one arm, when the other arm stays the same length.

(4)

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(iii) The system could be arranged so that when no gravitational waves are present, the beams have zero path difference at the photodetector.

Explain whether using an initial path difference of half a wavelength is a more sensitive way of detecting changes in length than having an initial path difference of zero.

(2)

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(Total for question = 9 marks)

Q17.

A metal wire is stretched elastically. The area under the force-extension graph for this process is equal to the

☒ **A** breaking stress of the wire.

☒ **B** elastic limit of the wire.

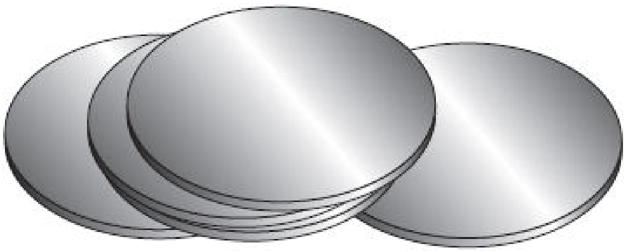
☒ **C** elastic strain energy in the wire.

☒ **D** Young modulus of the metal.

(Total for question = 1 mark)

Q18.

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 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}

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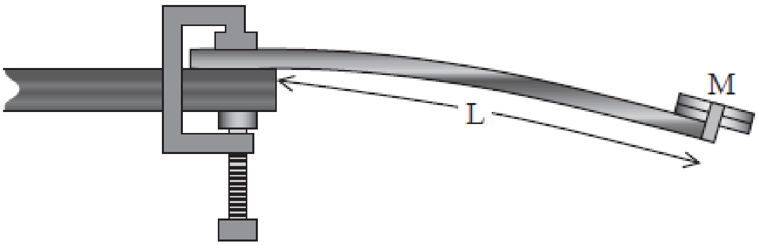
Minimum number of discs = ...

(Total for question = 4 marks)

Q19.

A metre rule clamped at one end is an example of a cantilever. The diagram shows an arrangement of a cantilever where a mass *M* is attached to the end of a metre rule and the rule clamped with a free length *L*.



When *M* is displaced, the period of oscillation *T* of the cantilever is related to *L* and the Young modulus *E* of the material of the metre rule by the following equation:

$$T^2 = \frac{KML^3}{E}$$

where *K* is a constant.

A student uses this arrangement to compare the Young modulus values for two metre rules. The metre rules have identical dimensions, but are made from different types of wood.

(a) One of the metre rules is set into oscillation, and the time for 20 oscillations is measured with an electronic stopwatch. This is repeated twice with the same metre rule. The same procedure is carried out for the second metre rule, using an identical mass and free length.

(i) Explain why a pointer placed at the equilibrium position of the end of the metre rule would help the student to obtain repeatable data.

(2)

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(ii) The student collects the following data.

	Time for 20 oscillations t_1 / s	Time for 20 oscillations t_2 / s	Time for 20 oscillations t_3 / s
Metre rule 1	19.3	19.1	19.3
Metre rule 2	21.3	21.5	21.5

Use this data to calculate a value for the ratio E_2/E_1 of the Young modulus values of the two metre rules.

(3)

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E_2/E_1 = ...

(b) The student intends to use a graphical method to determine a value for the Young modulus of one of the metre rules. She decides that she will vary the free length *L* and measure the time period for each length.

(i) State what variables she should plot.

(1)

y-axis

....

x-axis

....

(ii) Explain how the student can use her graph to determine the Young modulus of the rule. You may assume that she has been provided with the value of *K*.

(2)

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(c) Explain what the student could do to reduce the uncertainty in her measurement of the time period.

(2)

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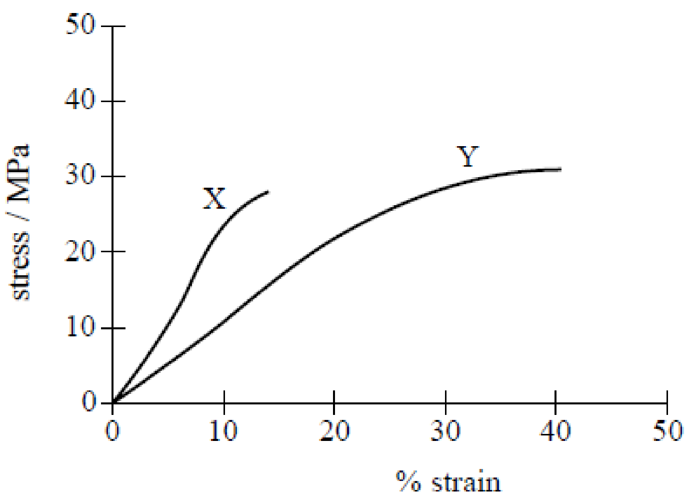
(Total for question = 10 marks)

Q20.

The graph shows the behaviour of two materials when placed under stress.



We can conclude from the graph that

☐ **A** material X is stiffer and stronger than material Y.

☐ **B** material Y is stiffer and stronger than material X.

☐ **C** material X is stiffer but weaker than material Y.

☐ **D** material Y is stiffer but weaker than material X.

(Total for question = 1 mark)

Q21.

The picture shows a toy hanging from a spring.

(Source: m4.sourcingmap.com/photo_new/20120821/g/ux_a12082100ux0119_ux_g03.jpg)

The toy has a mass of 0.066 kg. When it is hanging freely on the spring, the spring extends by 4.5cm.

When the toy is pulled downwards and released, it undergoes simple harmonic motion.

Calculate the frequency of the oscillations.

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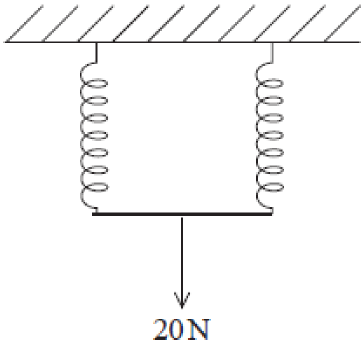
Frequency = ...

(Total for question = 5 marks)

Q22.

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?

(1)

☒ **A** 2 cm

☒ **B** 4 cm

☒ **C** 8 cm

☒ **D** 16 cm

(Total for question = 1 mark)

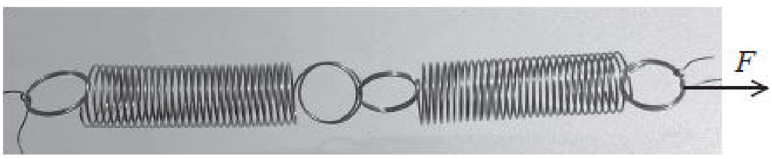
Q23.

Answer the question with a cross in the box you think is correct ☒. If you change your mind about an answer, put a line through the box ☒ and then mark your new answer with a cross ☒.

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.



What is the stiffness of the combination of springs?

☒ **A** $\frac{k}{2}$

☒ **B** k

☒ **C** $2k$

☒ **D** $4k$

(Total for question = 1 mark)

Q24.

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)

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(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)

$\rho = 1.0 \times 10^3$ kg m^{-3}
$\eta = 1.8 \times 10^{-5}$ Pa s

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

(3)

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(Total for question = 7 marks)

Q25.

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 = 1.41×10^{-8} m^3
mass of steel sphere = 1.10×10^{-4} 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

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)

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(Total for question = 2 marks)

Q26.

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** ¼ *E*

☒ **B** ½ *E*

☒ **C** *E*

☒ **D** 2*E*

(Total for question = 1 mark)

Q27.

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** $\rho 1\ V\ g$

☒ **B** $\rho 2\ V\ g$

☒ **C** $(\rho_2 - \rho_1)\ V\ g$

☒ **D** $\frac{(\rho_2 + \rho_1)}{2} Vg$

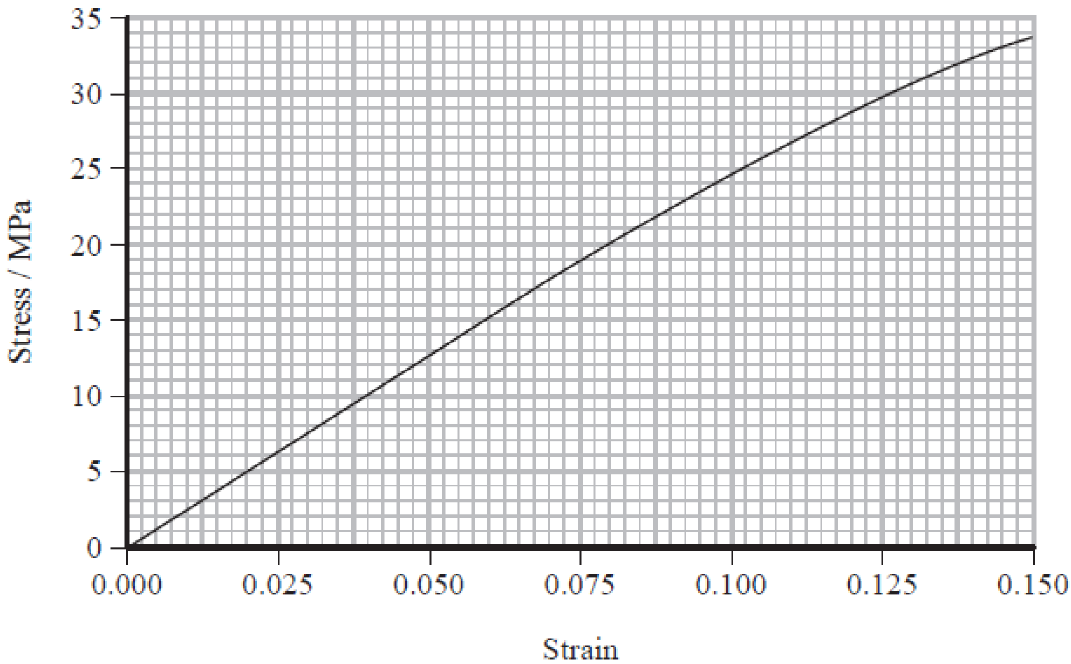
(Total for question = 1 mark)

Q28.

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.

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)

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(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)

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(Total for question = 5 marks)

Q29.

A small sphere is falling through a liquid. The viscous drag force acting on the sphere will increase if the

☐ **A** density of the liquid decreases.

☐ **B** radius of the sphere decreases.

☐ **C** temperature of the liquid decreases.

☐ **D** viscosity of the liquid decreases.

(Total for question = 1 mark)

Q30.

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

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)

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(Total for question = 3 marks)

Q31.

Answer the question with a cross in the box you think is correct ☒. If you change your mind about an answer, put a line through the box ☒ and then mark your new answer with a cross ☒.

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

The Young modulus of steel is 1.8×10^{11} Pa.

Which of the following gives the extension of the wire?

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

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

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

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

(Total for question = 1 mark)

Mark Scheme

Q1.

Question Number	Acceptable answers		Additional guidance	Mark
(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) (1) (1)	Example of calculation $m_{displaced} = 1.0 \times 10^3$ kg m^{-3} $\times 8.0 \times 10^{-6}$ m^{-3} $= 8.0 \times 10^{-3}$ kg $U = 8.0 \times 10^{-3}$ kg $\times$ 9.81 N kg^{-1} = 0.0785 N W = 0.0059 kg $\times$ 9.81 N kg^{-1} = 0.0579 N Lid force = 0.0785 N - 0.0579 N = 0.0206 N	3

Question Number	Acceptable answers	Additional guidance	Mark
(b)	**Either** • use of force of lid = $V\rho g$ **(1)** • volume of air = 8.0×10^{-6} m^{-3} - their value **(1)** • volume of air = 5.9×10^{-6} (m^3) **(1)** **Or** • use of upthrust on diver = weight of diver **(1)** • use of upthrust = $V\rho g$ **(1)** • volume of air = 5.9×10^{-6} (m^3) **(1)**	Example of calculation volume = 0.0206 N ÷ 9.81 N kg^{-1} ÷ 1.0 × 10^3 kg m^{-3} = 2.1×10^{-6} m^{-3} new volume of air = 8.0×10^{-6} m^{-3} - 2.1×10^{-6} m^{-3} = 5.9×10^{-6} m^3	**3**

Question Number	Acceptable answers	Additional guidance	Mark
(c)	• use of pV = constant **(1)** • $p = 1.4 \times 10^5$ Pa **(1)**	Example of calculation $p_1 \times V_1 = p_2 \times V_2$ $p_2 = 1.01 \times 10^5$ N m^{-2} × 8.0×10^{-6} m^{-3} / 5.9×10^{-6} m^3 $p = 1.37 \times 10^5$ Pa	**2**

Q2.

Question Number	Acceptable answers	Additional guidance	Mark
(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)**	Example of calculation For max stress, 3.10×10^8 N m^{-2} = 28 kg × 9.81 N kg^{-1}/A $A = 8.86 \times 10^{-7}$ m^2 8.86×10^{-7} m^2 = πr^2 $r = 5.3 \times 10^{-4}$ m diameter = 1.06 mm	**3**
(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 Example of calculation stress = 28 kg × 9.81 N kg^{-1}/ π (1.22 × 10^{-3} m / 2)^2 strain = 2.34×10^8 Pa / 200 GPa = 0.00117 extension = 0.00117 × 11.2 m = 0.0132 m	**3**

Q3.

Question Number	Acceptable Answer	Additional Guidance	Mark
	• Use of $V = \frac{4}{3}\pi r^3$ **(1)** • Use of $\rho = \frac{m}{V}$ **(1)** • $\rho = 2580$ (kg m^{-3}) **(1)**	Example of calculation $V = \frac{4}{3}\pi\left(\frac{5.06 \times 10^{-2}\ \text{m}}{2}\right)^3 = 6.78 \times 10^{-5}\ \text{m}^3$ $\rho = \frac{0.175\ \text{kg}}{6.78 \times 10^{-5}\ \text{m}^3} = 2580\ \text{kg m}^{-3}$	**3**

Q4.

Question Number	Acceptable Answer	Additional Guidance	Mark
	• Use of half resolution to calculate % uncertainty **(1)** • % uncertainty in V = 3 × % uncertainty in r **(1)** • % uncertainty in ρ = (% 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)** Allow use of half resolution in either r or m to calculate minimum V and maximum m and then calculate maximum ρ for MP1 → MP4 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 ρ = (3 × 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 → 2596 kg m^{-3}	**6**

Q5.

Question Number	Acceptable Answer		Additional Guidance	Mark
	• new spring constant = 11 N m^{-1} • Use of $T = 2\pi\sqrt{\frac{m}{k}}$ • Use of $f = 1/T$ • f = 1.5 Hz	(1) (1) (1) (1)	Example of calculation: k = 22/2 = 11 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 s = 1.5 Hz	4

Q6.

Question Number	Acceptable answers		Additional guidance	Mark
	• states wavelength = 1.2 cm • use of E = stress / strain • use of $A = \pi d^2/4$ • use of stress = F/A • use of $v = \sqrt{(T/\mu)}$ • use of $v = f\lambda$ with any two of the stated / measured / calculated values of v, f or λ to calculate the other • comparison of this calculated value of v, f or λ with the value obtained another way	(1) (1) (1) (1) (1) (1) (1)	Example of calculation: λ = 4.8 × 0.25 cm = 1.2 cm $A = \pi d^2 / 4$ = $\pi(3.6 \times 10^{-6}$ m$)^2$ / 4 = 1.012 × 10^{-11} m^2 stress = strain × E = 9.7 × 10^{-9} × 1.2 × 10^9 N m^{-2} = 11.64 N m^{-2} $T = F$ = stress × A = 11.64 N m^{-2} × 1.012 × 10^{-11} m^2 = 1.18 × 10^{-10} N $v = \sqrt{(\ \div\ )} = \sqrt{8.92 \times 10^{-3}}$ = 0.094 m s^{-1} Using $v = f\lambda$, v = 7.9 Hz × 0.012 m = 0.0912 m s^{-1} Agree to within 3%, so suggests consistent	7

Q7.

Question Number	Acceptable answers	Additional guidance	Mark
	The only correct answer is B because the gradient of this graph is change in length ÷ 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 (length)^2, so it does not have a gradient equal to k		1

Q8.

Question Number	Acceptable Answer	Additional Guidance	Mark
(a)	• Use a micrometer to measure y and/or z (1) • Use Vernier/digital calipers to measure x and/or (1) • Mass of slide(s) measured using (top pan) balance/scales (1) • Repeat and determine mean for at least one measurement (1)	**(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**

Question Number	Acceptable Answer	Additional Guidance	Mark
(b)	Check zero error on micrometer/callipers/balance **Or** measure *x*/*y*/*z* of slide in different places **Or** measure thickness/mass of multiple slides (1)	Accept 'tare' for zero error check on balance	**1**

Q9.

Question Number	Acceptable answers	Additional guidance	Mark
(i)	• Use of stress = F/A (1) • Use of Young modulus = stress / strain (1) • Use of strain = $\Delta x/x$ (1) • Extension = 0.053 m (1)	Example of calculation stress = 93.4 N / 6.6 ×10^{-7} m^2 = 1.42 ×10^8 N m^{-2} strain = 1.42 ×10^8 N m^{-2} / 1.8 ×10^9 N m^{-2} = 0.0786 extension = 0.0786 × 0.68 m = 0.053 m	4
(ii)	• Increase tension so increase wavespeed since $v = \sqrt{\frac{T}{\mu}}$ **Or** decrease μ so increase wavespeed since $v = \sqrt{\frac{T}{\mu}}$ (1) • Since $v = f\lambda$ and wavelength unchanged, this increases frequency (1)		2

Q10.

Question Number	Acceptable Answer	Additional Guidance	Mark
	• 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 $\frac{1}{R_{eff}} = \frac{1}{R} + \frac{1}{R}$ (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, $R_{eff} = R + R$ • 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

Q11.

Question Number	Acceptable answer	Additional guidance	Mark
	C	The only correct answer is C because for the original spring $F = kx$ so $x = F/k$, so $E = ½ Fx = ½ F^2/k$. 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

Q12.

Question Number	Answer	Mark
	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

Q13.

Question Number	Acceptable answers	Additional guidance	Mark
	• Use of $\rho = m/V$ (1) • Use of relationship upthrust = weight of liquid (1) • Use of $F = 6\pi\eta rv$ (1) • $\eta = 3.97 \times 10^{-2}$ (Pa s) so it is sunflower oil (1)	Example of calculation mass of oil displaced $= 9.20 \times 10^2$ kg m^{-3} $\times 1.41 \times 10^{-8}$ m^3 $= 1.30 \times 10^{-5}$ kg upthrust $= 1.30 \times 10^{-5}$ kg $\times$ 9.81 m s^{-2} $= 1.27 \times 10^{-4}$ N weight of sphere $= 1.10 \times 10^{-4}$ kg $\times$ 9.81 m s^{-2} $= 1.08 \times 10^{-3}$ N weight = upthrust + drag 1.08×10^{-3} N $= (6\pi \times \eta \times 1.5 \times 10^{-3}$ m $\times$ 0.849 m s$^{-1}) + 1.27 \times 10^{-4}$ N $\eta = 3.97 \times 10^{-2}$ Pa s	4

Q14.

Question Number	Acceptable Answer	Additional Guidance	Mark
	• Attempt to calculate gradient (1) • $k = (24.0 \rightarrow 25.0)$ N m^{-1} (1)	Accept $k = (0.24 \rightarrow 0.25)$ N cm^{-1} Example of calculation: gradient$= \frac{(1.6\text{-}0)\text{ N}}{(6.5\text{-}0)\times10^{-2}\text{m}} = 24.6$ N m^{-1}	2

Q15.

Question Number	Acceptable answers	Additional guidance	Mark
(a)	• use of density = mass / volume (1) • use of $V = 4/3\ \pi r^3$ (1) • $r = 1720$ m (1)	Example of calculation: $V = 1.0 \times 10^{13}$ kg ÷ 470 kg m^{-3} = 2.13×10^{10} m^3 = $4/3\ \pi r^3$ $r = \sqrt[3]{(2.13 \times 10^{10}\ \text{m}^3 \times 3) \div 4\pi}$ = 1720 m	**(3)**

Question Number	Acceptable answers	Additional guidance	Mark
(b)	• use of $g = GM/r^2$ (1) • $g = 2.3 \times 10^{-4}$ N kg^{-1} (1)	Example of calculation: $g = 6.67 \times 10^{-11}$ N m^2 kg^{-2} × 1.0×10^{13} kg / (1720 m)^2 $g = 2.25 \times 10^{-4}$ N kg^{-1}	**(2)**

Question Number	Acceptable answers	Additional guidance	Mark
(c)	• use of $s = ½\ gt^2$ (1) • $s = 1.2 \times 10^3$ m (1)	Example of calculation: $s = 0.5 \times 2.25 \times 10^{-4}$ m s^{-2} × (3300 s)^2 = 1.2×10^3 m	**(2)**

Question Number	Acceptable answers	Additional guidance	Mark
(d)	An explanation that makes reference to the following: • the calculated height is comparable with the radius (of asteroid) (1) • the field should be considered as radial rather than parallel, so the gravitational field strength is decreasing significantly for the probe (1) OR $g = GM/r^2$ the change in r is comparable with the radius, so there will be a significant change in g (1) • acceleration is less, so the actual height would be less (1)		**(3)**

Q16.

Question Number	Acceptable answers		Additional guidance	Mark
(i)	• use of strain = extension / length • change in length = 4.8×10^{-18} (m) **Or** max strain for 0.001× proton size = 2.2×10^{-22} • comparison of their change in length to 8.8×10^{-19}(m) **Or** comparison of their max strain to 1.2×10^{-21}	(1) (1) (1)	Example of calculation Change in length = $1.2 \times 10^{-21} \times 4000$ m = 4.8×10^{-18} m Fraction of proton diameter = 4.8×10^{-18} m ÷ 8.8×10^{-16} m = 0.0055	3

Question Number	Acceptable answers		Additional guidance	Mark
(ii)	• half wavelength path difference means waves in antiphase • so destructive interference takes place • this results in zero amplitude, (so no signal detected) • a change in length will result in a change in path difference, so signal detected **Or** a change in length will result in a change in phase difference, so signal detected	(1) (1) (1) (1)	Do not accept 'out of phase' for MP1 Accept reference to being 'not out of phase' for MP4	4

Question Number	Acceptable answers		Additional guidance	Mark
(iii)	• if initially the path difference is zero there will be a maximum signal • a change from max amplitude would represent a much smaller percentage (therefore less sensitive)	(1) (1)	MP2 alternative: a change from minimum amplitude would represent a much larger percentage (therefore more sensitive) MP2 Accept 'it is easier to detect the change from no light to light' MP2 Accept suitable reference to uncertainty	2

Q17.

Question Number	Answer	Additional guidance	Mark
	C	(elastic strain energy in the wire.)	**(1)**

Q18.

Question Number	Acceptable Answer	Additional Guidance	Mark
	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)	Example of calculation $V = \pi r^2 t = \pi \left(\frac{1.3\times10^{-2}\ \text{m}}{2}\right)^2 \times 2\times10^{-3}\text{m}$ $\therefore V = 2.65\times10^{-7}\text{m}^3$ $m = \rho V = 7900\ \text{kg m}^{-3} \times 2.65\times10^{-7}\text{m}^3$ $\therefore m = 2.10\times10^{-3}\text{kg}$ $\frac{0.1\ \text{g}}{M} = 0.5\%$ $\therefore M = \frac{0.1\ \text{g}}{0.5/100} = 20\ \text{g}$ $\therefore$ number of discs$= \frac{20\ \text{g}}{2.10\ \text{g}} = 9.5$	4

Q19.

Question Number	Acceptable Answer	Additional Guidance	Mark
(a)(i)	• reference point so that reliable timings can be made (1) • end of metre rule will be travelling fastest at its equilibrium position (so uncertainty is determining when rule is at this position is least) (1)		**(2)**
(a)(ii)	• calculate average time period for each ruler [T_1 = 0.962 s, T_2 = 1.072 s] (1) • use of $T^2 \propto \frac{ML^3}{E}$ (1) • $\frac{E_2}{E_1} = 0.80$ (1)	Example of calculation: $T_1 = \frac{19.3\text{s} + 19.1\text{s} + 19.3\text{s}}{60} = 0.962\text{s}$ $T_2 = \frac{21.3\text{s} + 21.5\text{s} + 21.5\text{s}}{60} = 1.07\text{s}$ $T^2 \propto \frac{ML^3}{E} \therefore \frac{E_1}{E_2} = \frac{T_2^2}{T_1^2}$ $\frac{E_2}{E_1} = \frac{T_1^2}{T_2^2} = \left(\frac{0.962\text{s}}{1.07\text{s}}\right)^2 = 0.804$	**(3)**

Question Number	Acceptable Answer	Additional Guidance	Mark
(b)(i)	T^2 on y-axis and L^3 on x-axis (or vice versa)		**(1)**
(b)(ii)	An explanation that makes reference to the following: • $T^2 = \frac{KML^3}{E}$, so gradient will be $\frac{KM}{E}$ (if T^2 plotted against L^3) (1) • $\therefore E = \frac{KM}{\text{gradient}}$, if K is known E can be determined (1)	If axes reversed in (b)(i), gradient = E/KM for full credit	**(2)**

Question Number	Acceptable Answer	Additional Guidance	Mark
(c)	An explanation that makes reference to the following: • time a larger number of oscillations (1) • as the greater the total time the smaller the % uncertainty (1)		**(2)**

Q20.

Question Number	Acceptable answers	Additional guidance	Mark
	C		1

Q21.

Question Number	Acceptable answers	Additional guidance	Mark
	• Use of $F = k\,\Delta x$ **(1)** • $k = 14.4\ \text{N m}^{-1}$ **(1)** • Use of $T = 2\pi\sqrt{\frac{m}{k}}$ **(1)** • Use of $f = 1/T$ **(1)** • $f = 2.4$ Hz **(1)**	Example of calculation: $k = mg/\Delta x = 66\times 10^{-3}\ \text{kg} \times 9.81\text{m s}^{-2})/4.5 \times 10^{-2}\ \text{m} = 14.4\ \text{N m}^{-1}$ $T = 2\pi(0.066/14.4.0)^{1/2} = 0.425$ s $f=1/T = 1/0.425 = 2.35$ Hz	**5**

Q22.

Question Number	Answer	Mark
	B – 4 cm	**1**
	Incorrect Answers: Correct method: 1. force on one spring is 20 N ÷ 2 = 10 N, 2. spring constant k = 10 N ÷ 8 cm = 1.25 N cm^{-1}, 3. extension = 5 N ÷ 1.25 N cm^{-1} = 4 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	

Q23.

Question Number	Answer	Mark
	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**

Q24.

Question Number	Acceptable answers		Additional guidance	Mark
(a)	• Weight and drag force are equal for terminal velocity stated or implied	(1)		2
	• 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)		

Question Number	Acceptable answers		Additional guidance	Mark
(b)	• Use of $v = \frac{2g\rho r^2}{9\eta}$	(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
	• $v = 760\ (\text{m s}^{-1})$	(1)		

Question Number	Acceptable answers		Additional guidance	Mark
(c)	• Measured value much less than calculated value	(1)		3
	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)		

Q25.

Question Number	Acceptable answers	Additional guidance	Mark
	An explanation that makes reference to the following points: • at a lower temperature viscosity is increased (1) • there would be a lower maximum speed (1) Or one of the other oils could have been identified		2

Q26.

Question Number	Acceptable answer	Additional guidance	Mark
	B	The only correct answer is **B**: for each spring, ½ force, so ½ extension, so ½ *Fx* gives ¼ *E*, so total is ½ *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 ½ once D is not correct because it is the energy for two springs, each with the original extension	1

Q27.

Question Number	Acceptable answer	Additional guidance	Mark
	B	The only correct answer is **B**: Upthrust is density of fluid × volume of object × *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

Q28.

Question Number	Acceptable Answer		Additional Guidance	Mark
(i)	• (For linear section of graph) area under graph = $\frac{1}{2}$ stress × strain • 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) (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
(ii)	• Area under graph up to 0.075 calculated • Energy per unit volume = 7.1×10^5 J m^{-3} • This is much less than the value given in (a), and so belt does not absorb all the KE. **OR** • Graph used to determine stress when strain is 0.075 and $\sigma = \frac{F}{A}$ used to calculate force • $\epsilon = \frac{\Delta x}{x}$ used to calculate extension and $W = \frac{1}{2}F\Delta x$ used to calculate energy • Statement that this energy is much less than the value in (a), and so belt does not absorb all the kinetic energy	(1) (1) (1) (1) (1) (1)	Example of calculation: When strain is 0.075 Area = $\frac{1}{2}\times19\times10^6\text{Pa}\times0.075=7.13\times10^5$ J m^{-3}	3

Q29.

Question Number	Acceptable answers	Additional guidance	Mark
	C		1

Q30.

Question Number	Acceptable answers		Additional guidance	Mark
	• 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) • For large mass the force due to air resistance produces a smaller negative acceleration since $a = F/m$ • 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 **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 • 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) (1) (1) (1) (1) (1)		3

	OR There is air resistance and this force is the same for both • For both masses the change in momentum per swing is the same	(1) (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)		

Q31.

Question Number	Answer	Mark
	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**