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 = 4.5×10^{-4} m^2
tensile force applied to bar = 36 000 N
extension of bar = 2.0×10^{-4} m

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

☒ **A** $\dfrac{36000 \times 0.50}{4.5 \times 10^{-4} \times 2.0 \times 10^{-4}}$

☒ **B** $\dfrac{4.5 \times 10^{-4} \times 2.0 \times 10^{-4}}{36000 \times 0.50}$

☒ **C** $\dfrac{36000 \times 2.0 \times 10^{-4}}{4.5 \times 10^{-4} \times 0.50}$

☒ **D** $\dfrac{4.5 \times 10^{-4} \times 0.50}{36000 \times 2.0 \times 10^{-4}}$

(Total for Question 6 = 1 mark)

14 A seiche is a standing wave that can form on the surface of a lake in strong winds, causing flooding and erosion.

(a) Early in 2020, a single-node seiche was observed on Lake Erie in the USA. A node formed at the centre of the lake. Antinodes formed at the two ends of the lake.

The speed v of a seiche wave is given by

$$v = \sqrt{gh}$$

where h is the mean depth of the water.

Calculate the period of oscillation of the seiche.

length of Lake Erie = 400 km
mean depth of Lake Erie = 19 m

(3)

Period of oscillation = ...

(b) Erosion causes clay particles to be washed into the lake, making the lake cloudy. The lake can remain cloudy to a depth of about 4 m for more than 6 months.

One spherical clay particle has a radius of 2.5×10^{-7} m.

Deduce whether this particle takes more than 6 months to fall 4 m.
You should assume that the water in the lake remains still.

viscosity of water = 1.0×10^{-3} kg m^{-1} s^{-1}
density of water = 1000 kg m^{-3}
density of clay = 2650 kg m^{-3}

(6)

(c) The temperature of the lake decreases with depth.

Explain how this may affect the rate at which a particle falls.

(2)

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(d) In an investigation to determine the viscosity of water, a student drops a small sphere into a cylinder of water. The student uses a stopwatch to record the time it takes for the sphere to fall through the water.

Assess whether the stopwatch is suitable for measuring the time in this investigation.

(2)

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(Total for Question 14 = 13 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.

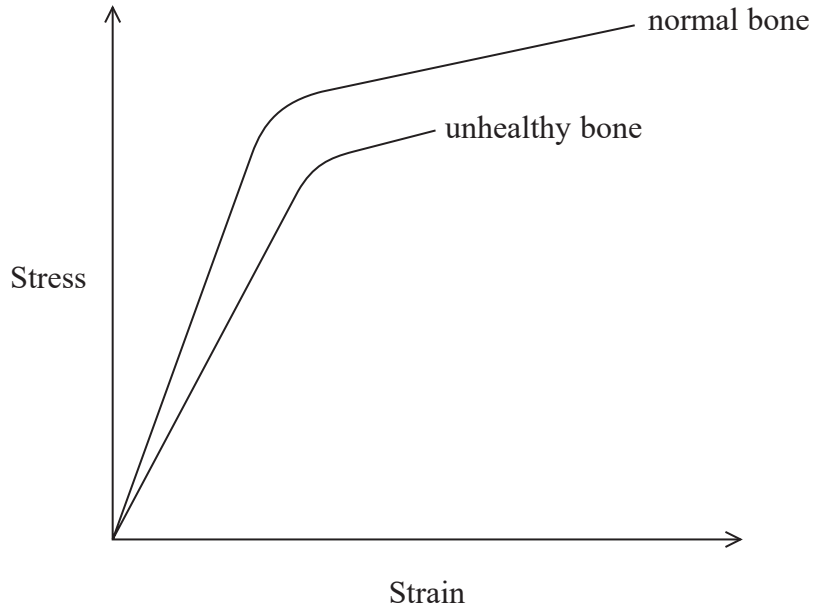
(4)

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)

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(Total for Question 17 = 10 marks)

TOTAL FOR SECTION B = 24 MARKS
TOTAL FOR PAPER = 80 MARKS

SECTION A

Answer ALL questions.

All multiple choice questions must be answered with a cross in the box ☒ for the correct answer from A to D. If you change your mind about an answer, put a line through the box ☒ and then mark your new answer with a cross ☒.

1 Which of the following provides evidence for the particle model of electromagnetic radiation?

☒ **A** diffraction

☒ **B** interference

☒ **C** polarisation

☒ **D** visible line spectra

(Total for Question 1 = 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)

3 Which of the following is the SI base unit for the Planck constant?

☒ **A** $\text{N m}^{-1}\text{ s}^{-1}$

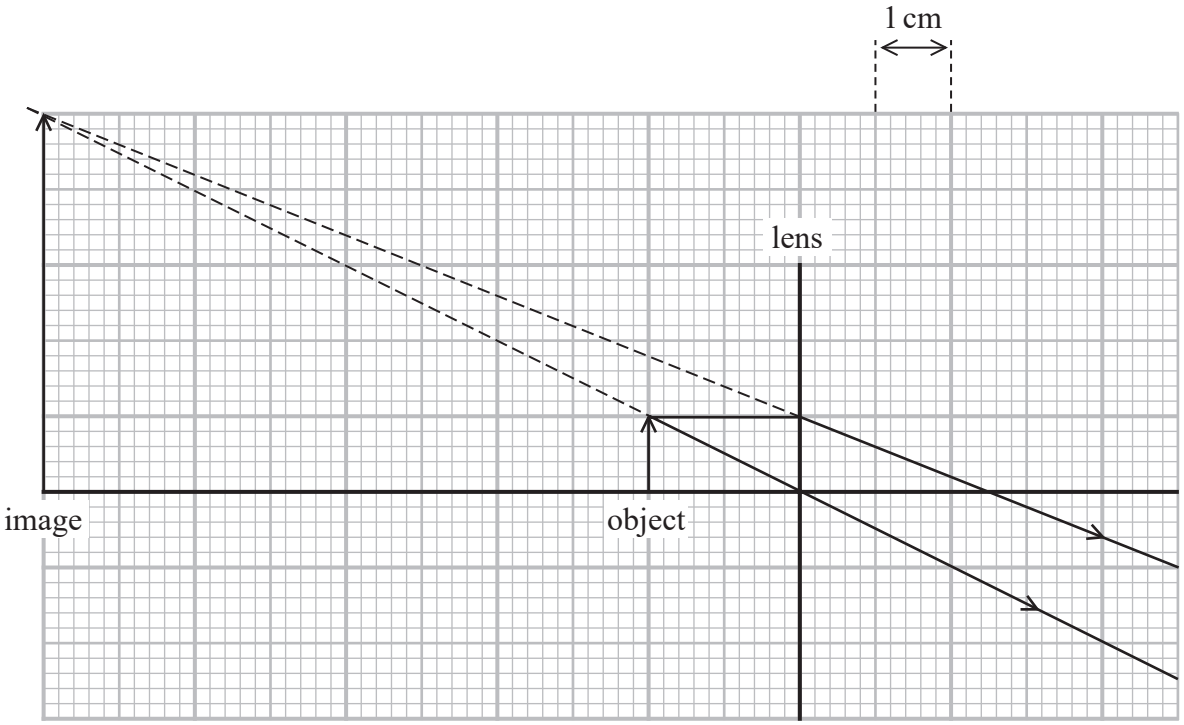
☒ **B** N m s

☒ **C** $\text{kg m}^{2}\text{ s}^{-1}$

☒ **D** $\text{kg m}^{-2}\text{ s}$

(Total for Question 3 = 1 mark)

4 A ray diagram, drawn to scale, is used to locate the size and position of an image formed by a lens as shown.



Which row in the table gives the focal length and the type of lens?

	Focal length / cm	Type of lens
☒ **A**	2.5	converging
☒ **B**	2.5	diverging
☒ **C**	10	converging
☒ **D**	10	diverging

(Total for Question 4 = 1 mark)

5 A student measures the diameter of a steel wire in order to determine the cross-sectional area of the wire. The percentage uncertainty in the measurement of the diameter was 1.8%.

Which of the following is the percentage uncertainty in the value for the cross-sectional area?

☒ **A** 1.8%

☒ **B** (1.8 + 1.8)%

☒ **C** (1.8 + 1.8 + 1.8)%

☒ **D** (1.8 × 1.8)%

(Total for Question 5 = 1 mark)

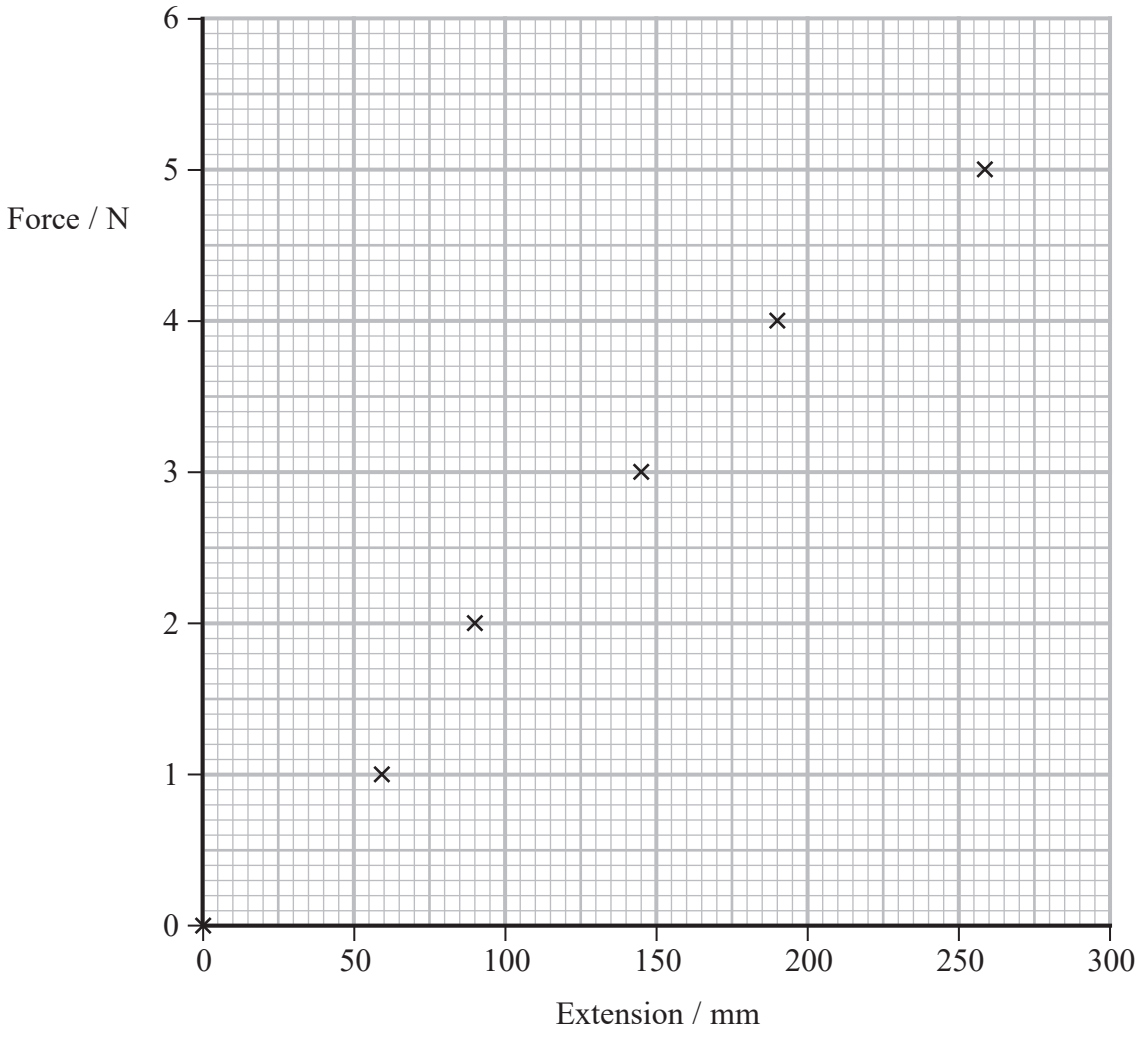
13 A manufacturer gives the following information about a spring.

1. Follows Hooke's law up to loads of 5 N
2. Maximum extension without permanent deformation 0.4 m
3. Stiffness 21 N m^{-1} ±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.



(a) Determine the stiffness of the spring.

(3)

Stiffness = ...

(b) Discuss the extent to which the student's results are consistent with the information given by the manufacturer.

(6)

(Total for Question 13 = 9 marks)

SECTION B

Answer ALL questions in the spaces provided.

16 Read the extract and answer the questions that follow.

Gravitricity is developing a new technology to capture and store the excess power generated by renewable energy resources. A large load is suspended by cables in a disused mineshaft. During periods of low power demand, excess generated power is used to winch the load upwards. During periods of high demand, the load is lowered down the shaft, causing electricity to be generated. The system can produce electricity at low power for several hours, or a short burst of electricity at high power.

(Source based on: https://gravitricity.com/)

(a) One such system is planned to use a load of mass 2500 tonnes. The load will be at the top of a shaft. The load will be lowered down the shaft at a steady speed. A useful power output of 15 MW will be generated. The system will have an efficiency of 80%.

Calculate the speed of the load.

1 tonne = 1000 kg

(3)

Speed = ...

(b) The system can generate "a short burst of electricity at high power".

Explain why high power can be generated for only a short time.

(2)

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(c) A load of 5.0×10^3 tonnes is held stationary by several vertical steel cables. The strain on the cables is 5.0×10^{-3}.

Calculate the total cross-sectional area of the cables holding the load.

Young modulus of steel = 180 GPa
1 tonne = 1.0×10^3 kg

(2)

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Cross-sectional area = ...

(d) The speed of the load in the shaft will depend on the variation of the electricity supply and demand throughout the day.

Explain why the total area of the cables will need to be greater than that calculated in (c) to limit the strain to no more than 0.005

(3)

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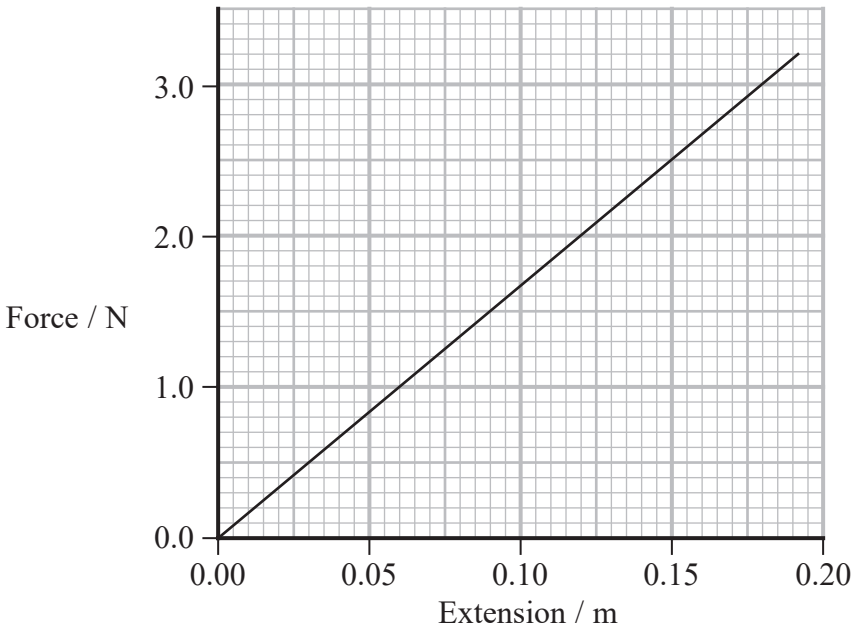
(Total for Question 16 = 10 marks)

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)

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.

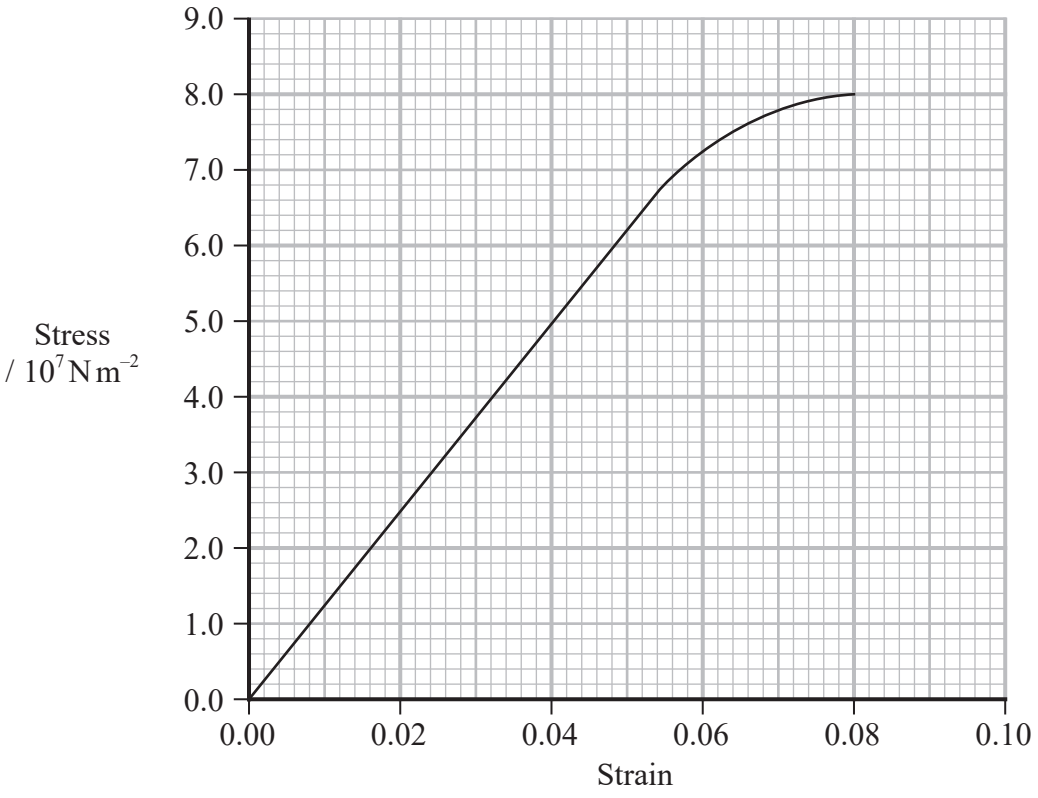
Show that the unit for η is Pa s.

(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 = ...

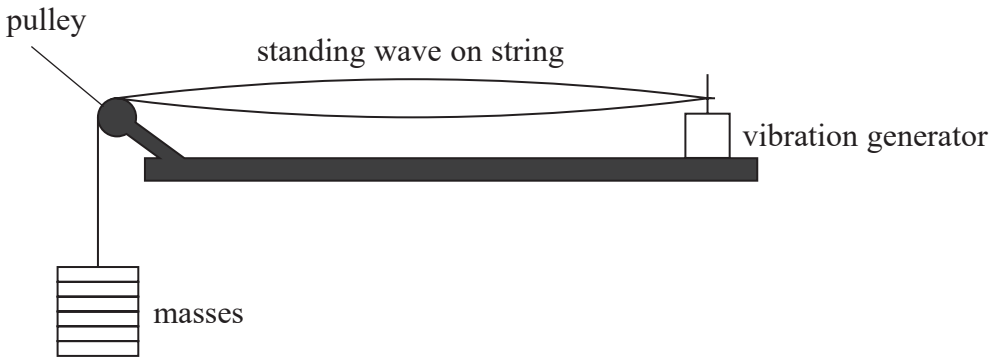
(ii) Describe the behaviour of collagen fibres when the stress in the fibres is increased from the elastic limit until the fibres break.

(3)

(Total for Question 10 = 8 marks)

12 A student was studying musical instruments.

(a) The student set up a standing wave on a string using the apparatus shown.



The standing wave had one antinode, as shown above, when the vibration generator had a frequency f.

The student then increased the frequency.

Describe what was observed as f was gradually increased to $2f$.

(2)

(b) A guitar has metal strings under tension. When a string is plucked it vibrates, producing a sound wave in the air.

Describe how the vibrating string produces pressure variations in the air.

(3)

(c) A guitar player changes the length of string that vibrates by pressing on the string as shown.

The guitar player plucks a string to play a note. A standing wave with one antinode is set up on the string.

He can vary the length of string that vibrates from 21 cm to 63 cm.

Deduce whether a note of frequency 196 Hz can be played on the string.

tension in string = 56 N
mass per unit length of the string = 5.0×10^{-3} kg m^{-1}

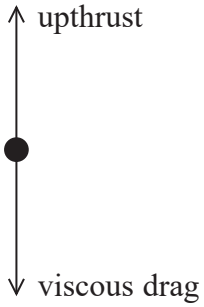
(4)

(Total for Question 12 = 9 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 1.7×10^{-5} 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)

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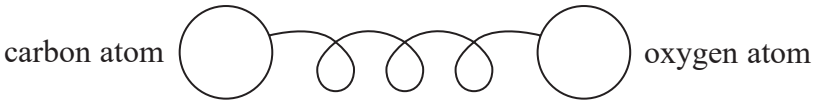
Speed = ...

(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)

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Increase in potential energy = ...

(Total for Question 14 = 7 marks)

TOTAL FOR SECTION A = 57 MARKS