(Total for Question 7 = 1 mark)

8 Which of the following lenses would produce a real image of an object placed 15 cm away from the lens?

☒ **A** converging, focal length = 10 cm

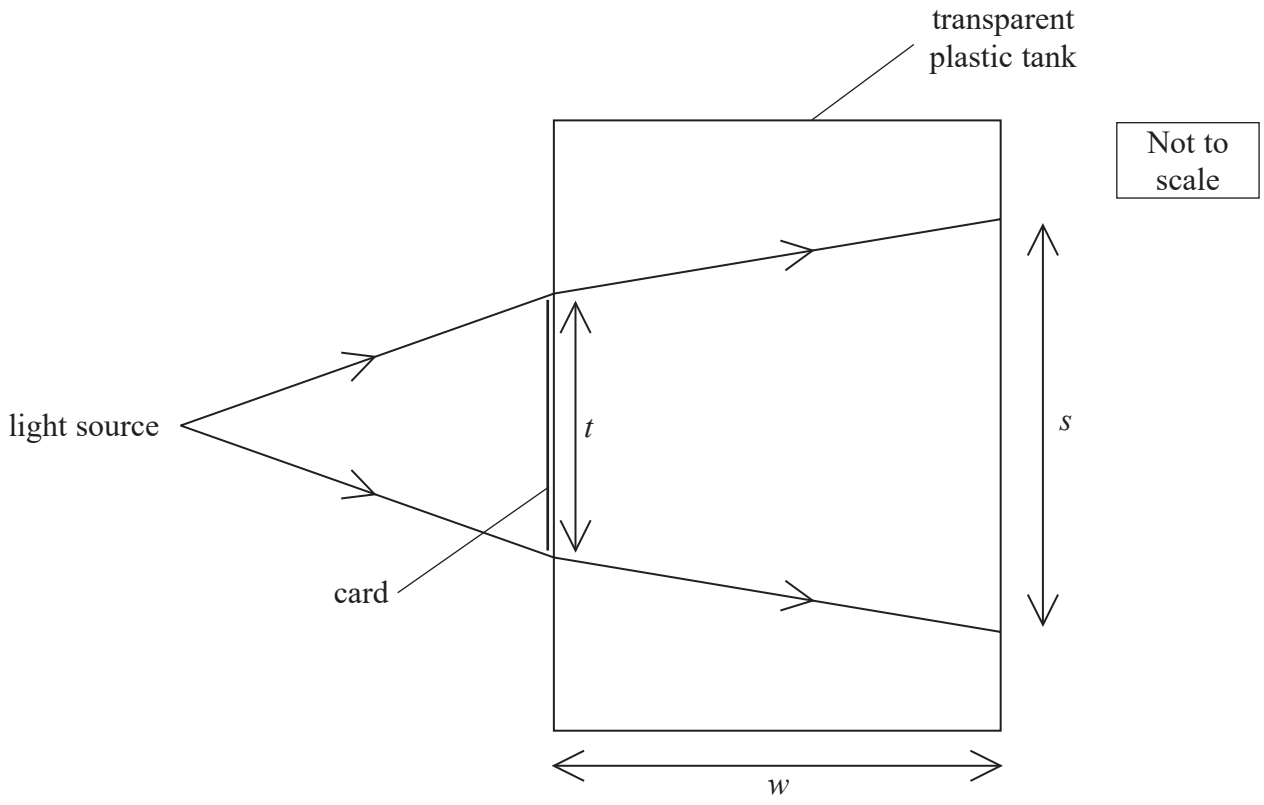
☒ **B** converging, focal length = 20 cm

☒ **C** diverging, focal length = 10 cm

☒ **D** diverging, focal length = 20 cm

(Total for Question 8 = 1 mark)

12 The diagram shows a transparent tank, with thin plastic sides, that can be used to determine the refractive index of a transparent liquid.



A rectangle of opaque card is stuck on the side of the tank containing the liquid. A light source is placed in front of the tank and the width s of the shadow of the card, which is formed on the back of the tank, is measured. The width t of the card and the width w of the tank are also measured.

(a) The angle of incidence of the light as it enters the tank is 7.2°

Show that the refractive index of the liquid is about 1.4

$w = 35.0\,\text{cm}$
$t = 4.0\,\text{cm}$
$s = 10.2\,\text{cm}$

(3)

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(b) Determine the speed of light in the liquid.

(2)

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Speed of light = ...

(Total for Question 12 = 5 marks)

DO NOT WRITE IN THIS AREA

DO NOT WRITE IN THIS AREA

DO NOT WRITE IN THIS AREA

17 In 1905 Einstein published his equation for the photoelectric effect.

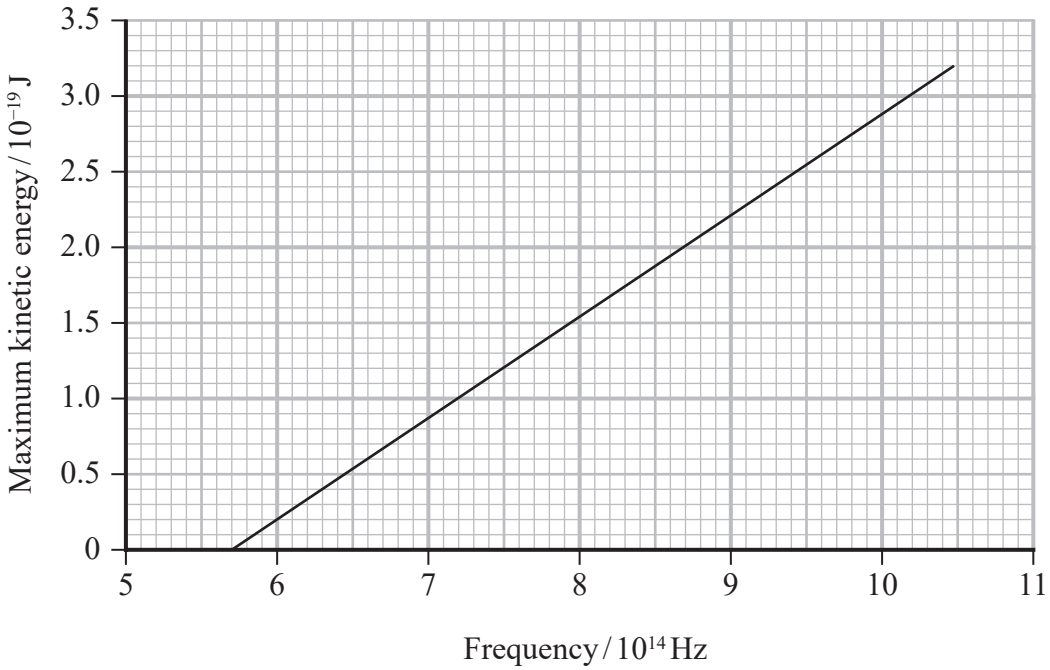
In 1916 Millikan demonstrated that the maximum kinetic energy of photoelectrons is consistent with Einstein's equation.

*(a) Discuss the extent to which our current understanding of observations of the photoelectric effect supports the idea that light behaves as photons rather than as waves.

(6)

(b) Millikan used his data to obtain a value of the Planck constant.

The following graph of maximum kinetic energy of photoelectrons against frequency was produced from his data for the photoelectric effect using lithium.



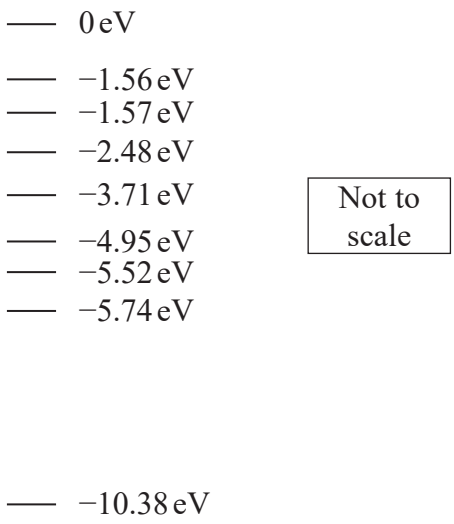
Millikan suggested that the uncertainty from his results for lithium was as little as 1%.

Determine whether the value of the Planck constant obtained from this graph is within 1% of the value stated on the data sheet for this examination paper.

(3)

(c) Millikan's experiments involved using different frequencies of light. These were obtained using a mercury vapour lamp which produced an emission spectrum with a specific number of known frequencies.

The diagram shows some energy levels for a mercury atom.



Determine which transition from the −3.71 eV energy level would produce light of wavelength 6.1×10^{-7} m.

(4)

Transition from −3.71 eV to .....

(d) Millikan used a device known as a monochromator to ensure that a single wavelength of light was used to illuminate the surface of the lithium.
A monochromator separates wavelengths using a diffraction grating.

Calculate the angle at which a diffraction grating would produce the most intense line at a single wavelength of 6.1×10^{-7} m.

number of lines per mm for grating = 600 mm^{-1}

(3)

Angle = ...

(Total for Question 17 = 16 marks)

Answer ALL questions.

For questions 1–10, select one answer from A to D and put a cross in the box ☒. If you change your mind, put a line through the box ☒ and then mark your new answer with a cross ☒.

1 Ultrasound can be used to investigate the structure of organs of the human body using the pulse-echo technique.
The level of detail obtained depends on the wavelength and the length of the pulses.

Which line of the table shows a change to wavelength and a change to pulse length that would each improve the level of detail?

		Wavelength	Pulse length
☒	**A**	decrease	decrease
☒	**B**	increase	decrease
☒	**C**	decrease	increase
☒	**D**	increase	increase

(Total for Question 1 = 1 mark)

2 An object is placed in front of a lens.

Which row of the table shows a combination that will produce a real image of the object?

		Focal length of lens / cm	Object distance / cm
☒	**A**	−5	10
☒	**B**	−5	2
☒	**C**	5	10
☒	**D**	5	2

(Total for Question 2 = 1 mark)

(Total for Question 5 = 1 mark)

6 The diagram shows a source of sound waves and an observer.

Which row of the table shows a situation which would result in a decrease in the frequency of sound observed?

		Source	Observer
☒	**A**	moves to the right at $20\,m\,s^{-1}$	moves to the left at $20\,m\,s^{-1}$
☒	**B**	moves to the right at $20\,m\,s^{-1}$	moves to the right at $20\,m\,s^{-1}$
☒	**C**	moves to the right at $20\,m\,s^{-1}$	stationary
☒	**D**	stationary	moves to the right at $20\,m\,s^{-1}$

(Total for Question 6 = 1 mark)

7 The photoelectric effect provides evidence for the particle nature of electromagnetic radiation.

Which of the following observations of the photoelectric effect could also be explained using the wave nature of electromagnetic radiation?

- ☒ **A** The emission of photoelectrons is instantaneous.
- ☒ **B** The maximum kinetic energy of photoelectrons depends on frequency.
- ☒ **C** The rate of emission of photoelectrons depends on intensity.
- ☒ **D** There is a minimum frequency for emission of photoelectrons to occur.

(Total for Question 7 = 1 mark)

8 The acceleration of free fall at the surface of the Earth is $9.81\,\text{m s}^{-2}$.
The mass of the Earth is M and the diameter of the Earth is D.

Which of the following gives the acceleration of free fall, in m s^{-2}, at the surface of a planet with diameter $\frac{D}{2}$ and mass $\frac{M}{9}$?

- ☒ **A** $\frac{9.81 \times 2}{9}$
- ☒ **B** $\frac{9.81 \times 4}{9}$
- ☒ **C** $\frac{9.81 \times 2}{3}$
- ☒ **D** $\frac{9.81 \times 9}{4}$

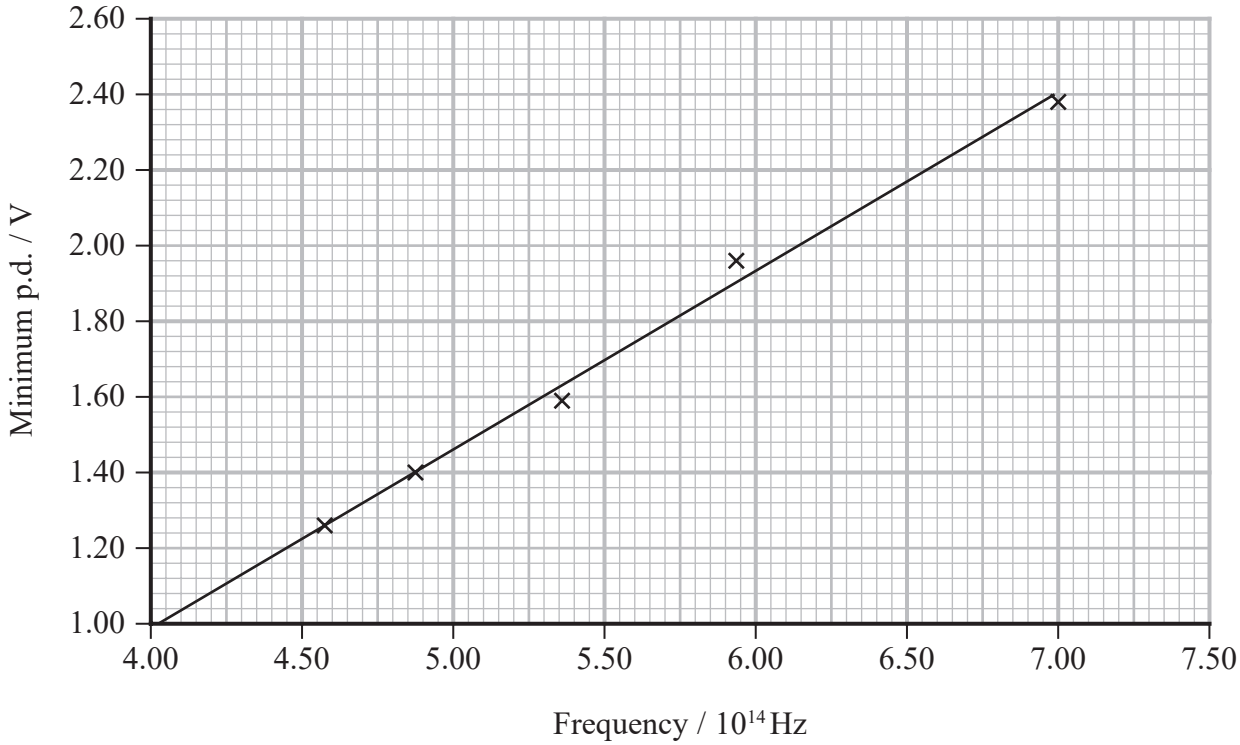
(Total for Question 8 = 1 mark)

16 The Planck constant can be determined in a school laboratory using light emitting diodes (LEDs).

An LED emits light when the potential difference (p.d.) across it is large enough to transfer sufficient energy to an electron to result in the emission of a photon. The electron must have energy greater than or equal to the photon energy.

The minimum p.d. required to produce light from LEDs emitting different frequencies was measured by increasing the p.d. from zero until light was first seen.

The graph shows the results.



(a) Determine the value of the Planck constant given by this graph.

(4)

Value of Planck constant given by graph = ...

(b) There are two problems with using LEDs to determine the Planck constant:

- when the p.d. is increased and the LED first emits light it is difficult to see
- the LEDs do not emit a single frequency but also light of frequencies slightly above and below the recorded frequency.

Discuss the extent to which these problems are consistent with obtaining a result from this graph for the Planck constant which is higher than the accepted value.

(3)

(Total for Question 16 = 7 marks)

19 The lens in the eye of an octopus focuses light onto the retina at the back of the eye.

The octopus focuses on objects at different distances from the eye by changing the shape of the eye to move the lens closer or further from the retina.

(a) (i) The power of an octopus lens is 118 D.

Show that the focal length of the lens is about 8.5 mm.

(2)

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(ii) Calculate the shortest distance from the eye at which an object may be focused clearly on the retina.

maximum distance from lens to retina = 2.0 cm

(2)

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Shortest distance from the eye = ...

(iii) The lens in the eye of an octopus is in contact with seawater. The refractive index of freshwater is less than the refractive index of seawater.

Deduce what would happen to the shortest distance from the eye at which an object may be focused clearly if the octopus was in freshwater.

(3)

(iv) Calculate the speed of light in seawater.

refractive index of seawater = 1.37

(2)

Speed of light in seawater = ...

(b) An octopus can detect the orientation of polarised light.

State what is meant by polarised light.

(2)

(Total for Question 19 = 11 marks)

Answer ALL questions.

All multiple choice questions must be answered with a cross in the box

(Total for Question 1 = 1 mark)

2 Light travelling in glass of refractive index n_g is incident at a boundary with water of refractive index n_w. The critical angle for the boundary is C.

Which of the following expressions is correct for this boundary?

☒ **A** $\sin C = \frac{1}{n_g}$

☒ **B** $\sin C = \frac{n_w}{n_g}$

☒ **C** $\sin C = \frac{n_g}{n_w}$

☒ **D** $\sin C = \frac{1}{n_w}$

(Total for Question 2 = 1 mark)

(Total for Question 3 = 1 mark)

4 Which of the following is a valid unit for luminosity?

☒ **A** $W m^{-2}$

☒ **B** $N m s^{-2}$

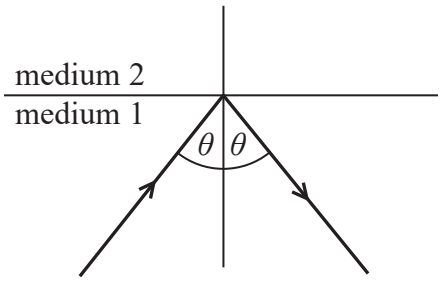
☒ **C** $J s^{-1}$

☒ **D** $J m^{-2}$

(Total for Question 4 = 1 mark)

(Total for Question 5 = 1 mark)

8 Total internal reflection occurs when light is incident on the boundary between medium 1 and medium 2, as shown.



The refractive index of medium 1 is n_1 and the refractive index of medium 2 is n_2.

The critical angle for the boundary is C.

Which row of the table is correct?

☒ **A**	$\theta < C$	$n_1 > n_2$
☒ **B**	$\theta < C$	$n_2 > n_1$
☒ **C**	$\theta > C$	$n_1 < n_2$
☒ **D**	$\theta > C$	$n_2 < n_1$

(Total for Question 8 = 1 mark)

9 The focal length and power of a converging glass lens are determined for the lens in air. The lens is then immersed in water.

Which row in the table shows how the focal length and power of the lens change?

		Focal length	Power of lens
☒	**A**	decreases	decreases
☒	**B**	decreases	increases
☒	**C**	increases	decreases
☒	**D**	increases	increases

(Total for Question 9 = 1 mark)

12 In February 2021 the spacecraft Perseverance Rover landed on Mars. When the spacecraft was 11.0 km above the surface of Mars, parachutes opened to slow the descent. The parachutes detached from the spacecraft when it was 2.1 km above the surface of Mars.

Calculate the change in gravitational potential energy of the spacecraft during the parachute section of its descent.

mass of spacecraft = 1030 kg
mass of Mars = 6.39×10^{23} kg
radius of Mars = 3390 km

Change in gravitational potential energy of the spacecraft = ...

(Total for Question 12 = 3 marks)

13 Actinium-225 and bismuth-210 are radioactive isotopes. A sample of each isotope is prepared so that each sample has the same number of nuclei initially.

Explain why the activity of each sample would be the same after 10 days.

half-life of actinium-225 = 10 days
half-life of bismuth-210 = 5 days

(Total for Question 13 = 4 marks)

(ii) State why white light reflected from coated lenses is seen as purple.

(1)

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.....

(Total for Question 17 = 8 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 $1070\,\text{kg}\,\text{m}^{-3}$. One string has a diameter of $1.14\,\text{mm}$.

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

(2)

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

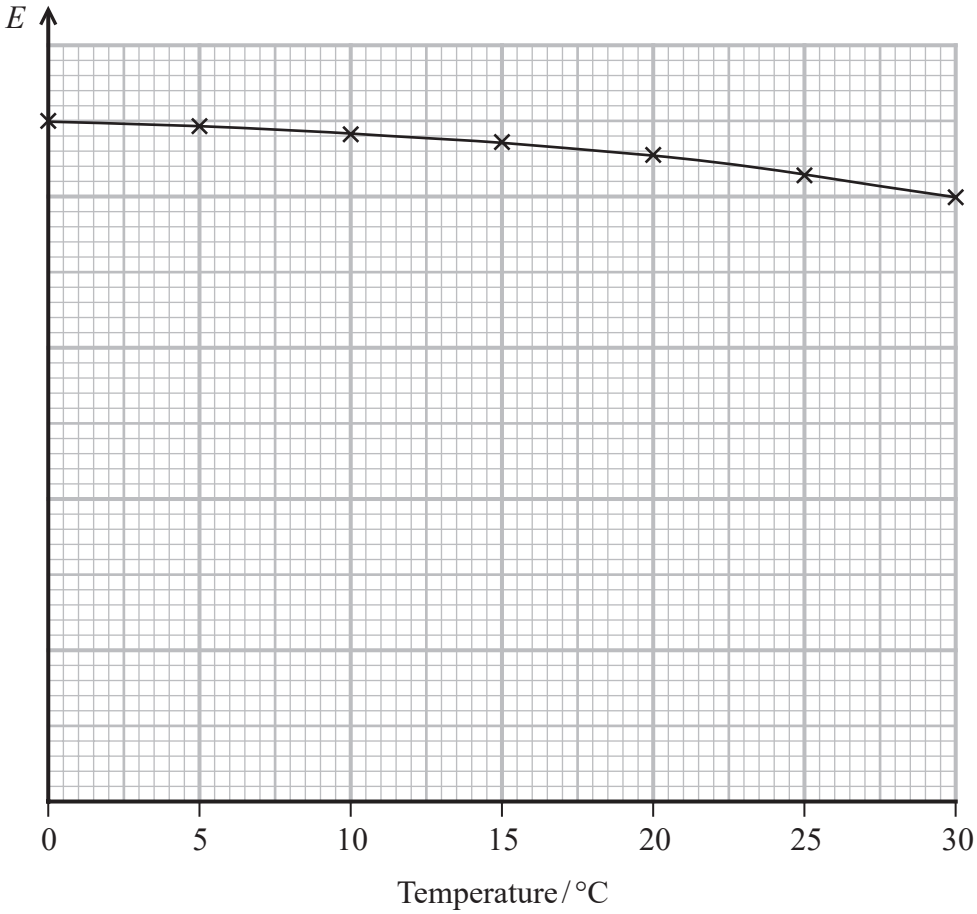
Calculate the tension in the string.

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.



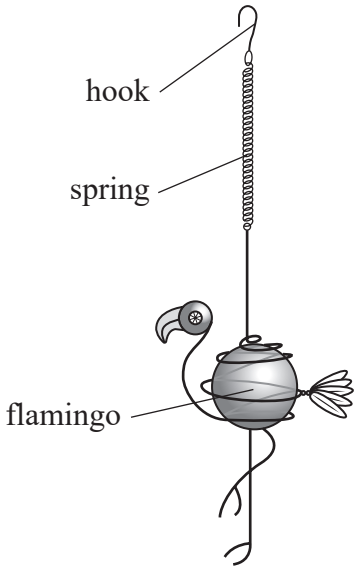
When the harp is played, the temperature of the string increases.

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)

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)

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(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)

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

Calculate the maximum velocity of the flamingo pendulum.

(3)

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Maximum velocity = ...

(Total for Question 20 = 12 marks)