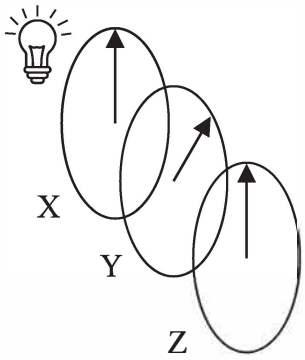
5 Three polarising filters X, Y and Z, are placed in front of a source of unpolarised light. The planes of polarisation of the filters are initially parallel.

Filter Y is rotated by 45° as shown.



Filter Z is then rotated clockwise and the intensity of light emerging from Z is measured.

Which angle of rotation of Z will result in the lowest intensity of light?

☐ **A** 90°

☐ **B** 135°

☐ **C** 180°

☐ **D** 225°

(Total for Question 5 = 1 mark)

6 When light is incident on the surface of a metal, electrons may be emitted by the photoelectric effect. Observations of the photoelectric effect helped to establish that light can exhibit particle behaviour.

Which of the following observations of the photoelectric effect could also be explained by light behaving as a wave?

☐ **A** Emission of photoelectrons occurs immediately the surface is illuminated.

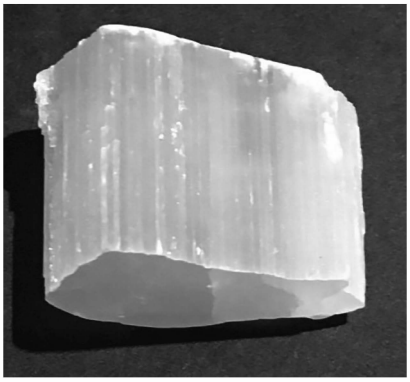
☐ **B** Photoelectrons are only emitted when the frequency of the light is more than a certain minimum value.

☐ **C** The maximum kinetic energy of the photoelectrons is independent of the intensity of the incident light.

☐ **D** When the intensity of the incident light increases, photoelectrons are emitted at a greater rate.

(Total for Question 6 = 1 mark)

12 The photograph shows a sample of the mineral selenite. Selenite is made up of many long, narrow crystals.



Selenite has a refractive index of 1.52

(a) Calculate the speed of light in selenite.

(2)

Speed of light in selenite = ...

(b) (i) State what is meant by critical angle.

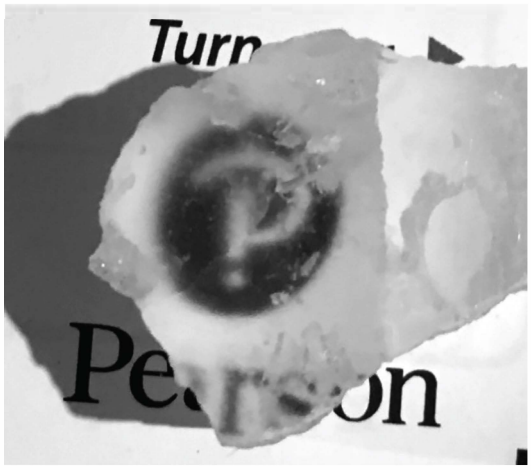
(1)

(ii) Calculate the critical angle for light in selenite.

(2)

Critical angle for light in selenite = ...

(c) Selenite can act as a collection of optical fibres, so that an image of writing beneath the mineral sample appears as if it is at the upper surface as shown.



Explain how light travels through a selenite crystal.

(2)

(Total for Question 12 = 7 marks)

***13** The photograph shows a 'singing bowl'.

When the handles are rubbed with both hands the bowl 'sings', producing a loud note with a frequency of 720 Hz.

A vibration generator is attached to the bowl and connected to a signal generator. The signal generator is adjusted to produce frequencies from 600 Hz to 800 Hz.

At all frequencies in this range the bowl produces a sound at the applied frequency. The sound is quiet for all frequencies except 720 Hz, when it is much louder.

Explain these observations.

(6)

(Total for Question 13 = 6 marks)

15 The photograph shows an ultrasonic mouse repeller used in a house.

The mouse repeller produces ultrasound that repels mice but cannot be heard by humans. The mouse hears ultrasound directly and by reflection from the walls.

The mouse repeller produces ultrasound of frequency 26.0 kHz.

speed of sound = 340 m s^{-1}

(a) Calculate the wavelength of the ultrasound produced.

(2)

Wavelength = ...

(b) State what is meant by superposition of waves.

(2)

(c) A student makes the following suggestion.

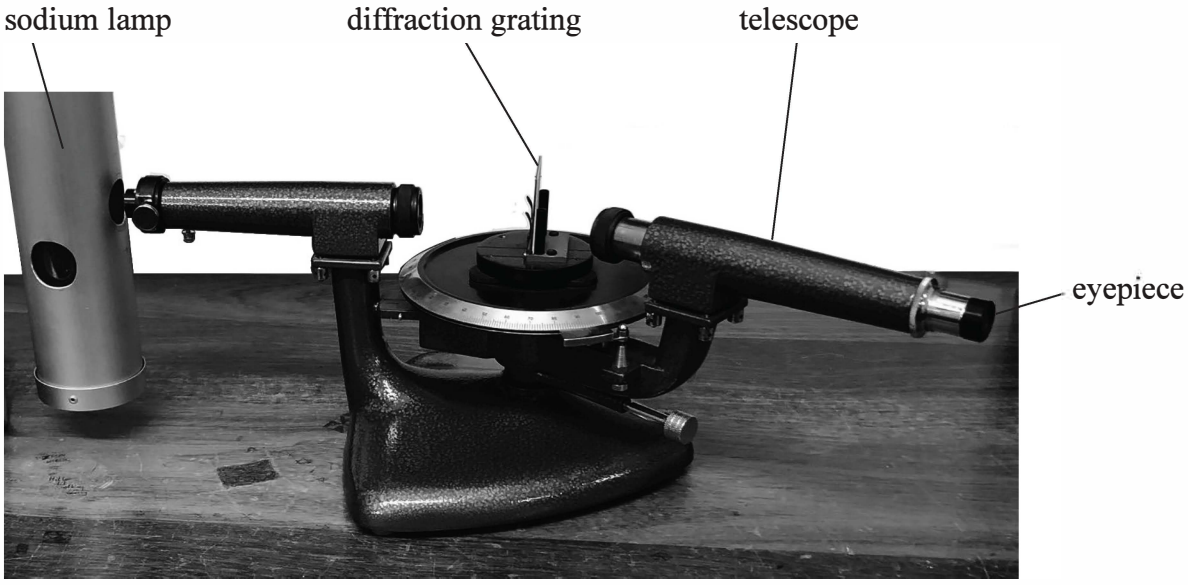
"If the ultrasound reflects off a wall directly opposite the mouse repeller a standing wave is formed, so there will be areas in the room where the mice will not hear the ultrasound."

Evaluate this suggestion.

(6)

(Total for Question 15 = 10 marks)

17 The photograph shows a school spectrometer.



The spectrometer allows parallel rays of light to be passed through a diffraction grating and the resulting angles of diffraction to be measured.

(a) In the telescope, light from the grating is focused to make a real image 16.7 mm in front of the eyepiece lens. The eyepiece lens then uses this real image as an object to produce a magnified virtual image for the observer.

Calculate the magnification produced by the eyepiece lens.

focal length of eyepiece lens = 17.9 mm

(3)

Magnification = ...

(b) The spectrometer and diffraction grating are used to analyse the light from a sodium lamp. In the sodium lamp, sodium is heated until it becomes a vapour and an electric current is passed through it. The vapour then emits light.

After the light passes through the diffraction grating a line spectrum is observed.

(i) Explain why only certain wavelengths are observed.

(6)

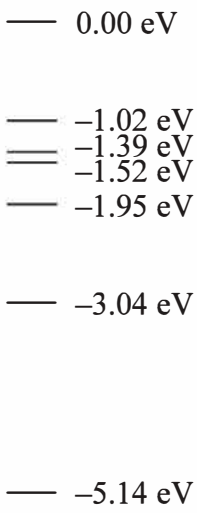
(ii) Diffraction gratings with the following spacings are available:

$d/10^{-6}$ m	1.0	1.7	2.0	3.3

Explain which would be the best spacing to use to measure the diffraction angle for the third order maximum for yellow light of wavelength 589 nm.

(3)

(c) The diagram shows some of the energy levels in a sodium atom.



Add an arrow to the diagram to show the transition involved in the emission of yellow light of wavelength 589 nm.

Show your working below.

(4)

(Total for Question 17 = 16 marks)

6 A proton can be considered to be both a point charge and a point mass. There is an electric field and a gravitational field associated with the proton.

Which of the following statements about the fields is **not** correct?

☒ **A** Field strength is a vector.

☒ **B** Potential is always less than 0.

☒ **C** Potential is proportional to $\frac{1}{\text{distance from proton}}$

☒ **D** Field strength is proportional to $\frac{1}{(\text{distance from proton})^2}$

(Total for Question 6 = 1 mark)

7 A pendulum of length l with a bob of mass m oscillates with frequency f.

What is the frequency of a pendulum of length $4l$ with a bob of mass $2m$?

☒ **A** $4f$

☒ **B** $2f$

☒ **C** f

☒ **D** $\frac{f}{2}$

(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

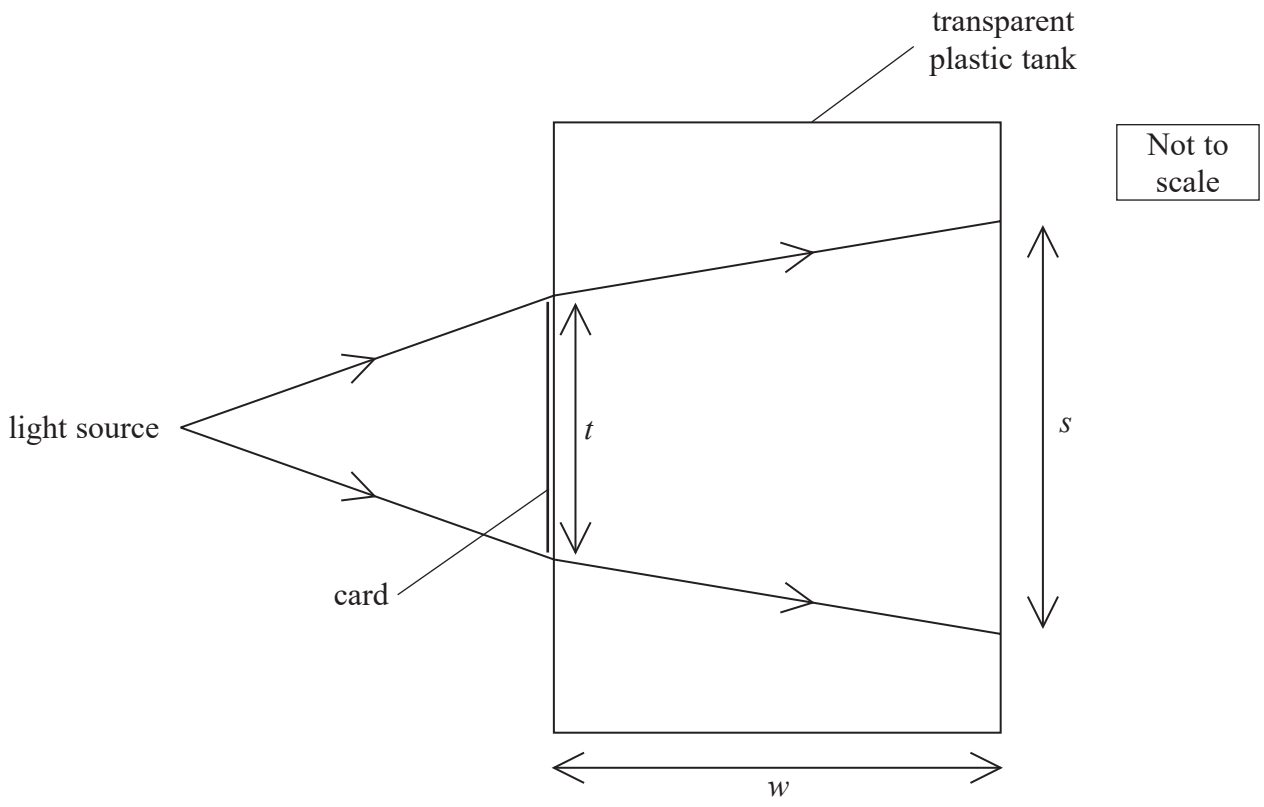
☒ **B** converging, focal length = 20 cm

☒ **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)

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

(2)

.....

.....

.....

.....

Speed of light = ...

(Total for Question 12 = 5 marks)

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

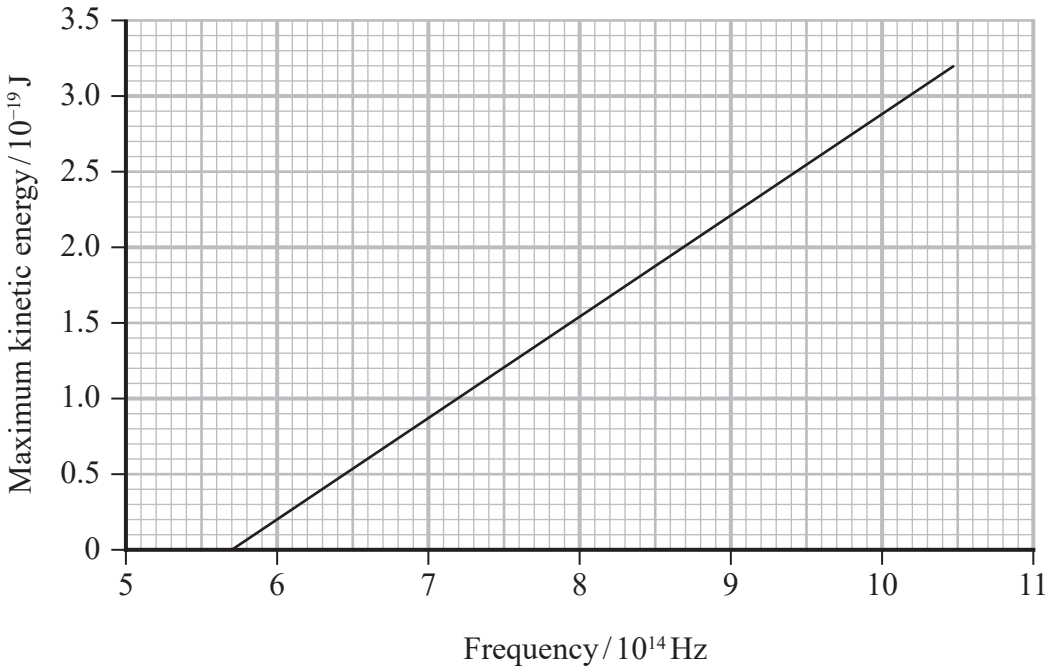
In 1916 Millikan demonstrated that the maximum kinetic energy of photoelectrons is consistent with Einstein's equation.

*(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.



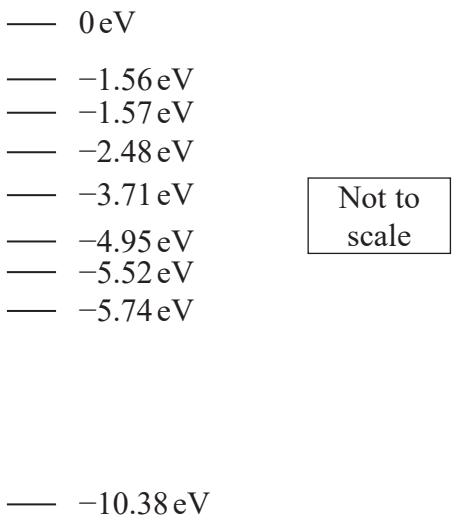
Millikan suggested that the uncertainty from his results for lithium was as little as 1%.

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 = $600\,\text{mm}^{-1}$

(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)

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

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 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** $\frac{9.81 \times 9}{4}$

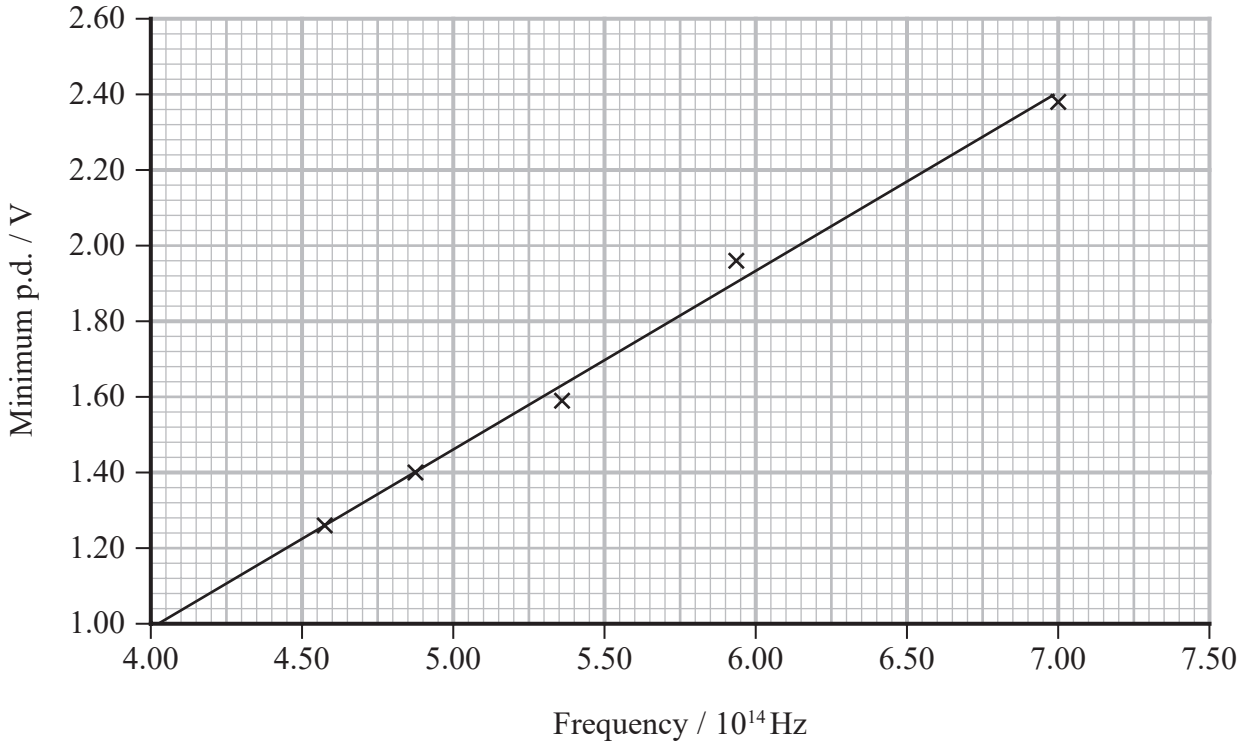
(Total for Question 8 = 1 mark)

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)

(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)

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 ☒ 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 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)

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** $\sin C = \frac{1}{n_g}$

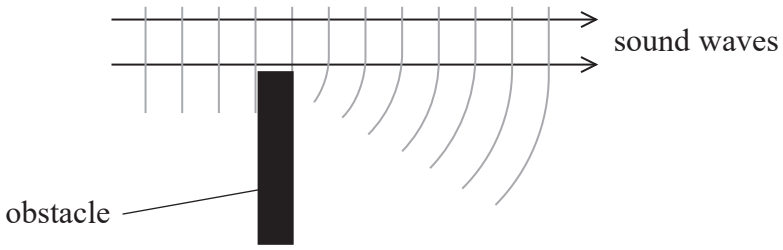
☒ **B** $\sin C = \frac{n_w}{n_g}$

☒ **C** $\sin C = \frac{n_g}{n_w}$

☒ **D** $\sin C = \frac{1}{n_w}$

(Total for Question 2 = 1 mark)

3 Sound waves can diffract around obstacles as shown in the diagram.



The diffraction effect is

- ☒ **A** greater for large amplitude sound waves.
- ☒ **B** greater for low frequency sound waves.
- ☒ **C** independent of the frequency of the sound waves.
- ☒ **D** independent of the speed of the sound waves.

(Total for Question 3 = 1 mark)

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

- ☒ **A** $\mathrm{W\,m^{-2}}$
- ☒ **B** $\mathrm{N\,m\,s^{-2}}$
- ☒ **C** $\mathrm{J\,s^{-1}}$
- ☒ **D** $\mathrm{J\,m^{-2}}$

(Total for Question 4 = 1 mark)

5 Betelgeuse is a red giant star.

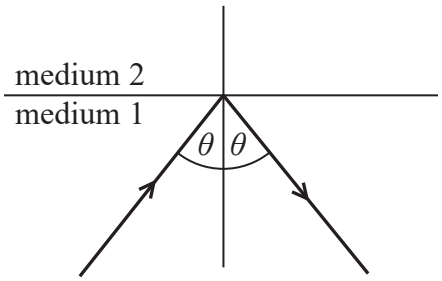
The surface temperature of Betelgeuse is T_B and the surface area of Betelgeuse is A_B.
The surface temperature of the Sun is T_S and the surface area of the Sun is A_S.

Which row in the table shows a correct comparison of the surface temperature and surface area of Betelgeuse with those of the Sun?

	$T_B > T_S$	$A_B > A_S$
☒ **A**	false	false
☒ **B**	false	true
☒ **C**	true	false
☒ **D**	true	true

(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)

10 A student used a Geiger-Müller (GM) tube to determine a value for the background count. He recorded the count for 2 minutes, every 15 minutes, as shown in the table.

Time / min	Count for 2 min
0	34
15	39
30	28

The counts are not the same.

Which of the following is the reason for this?

☒ **A** The background count rate is random.

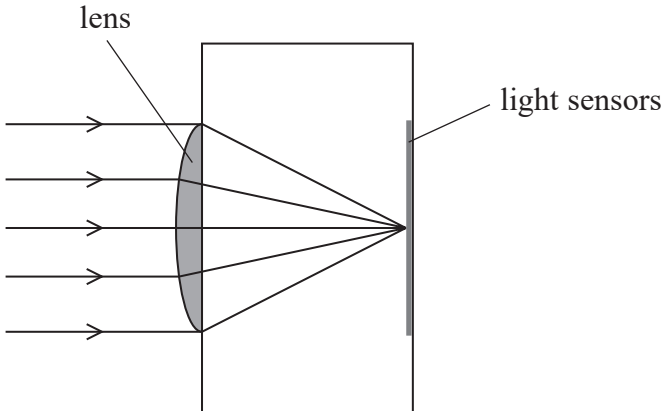
☒ **B** The counter is incorrectly calibrated.

☒ **C** The temperature has not stayed constant.

☒ **D** There is a systematic error in the measurement.

(Total for Question 10 = 1 mark)

11 The lens of a mobile phone camera has a focal length of 4.25 mm. Light is focused onto light sensors at the back of the camera, as shown.



(a) The camera is initially focused on an object in the far distance.

Calculate the displacement of the lens that would be required to focus on an object 25.0 cm from the camera.

(4)

Displacement of lens = ...

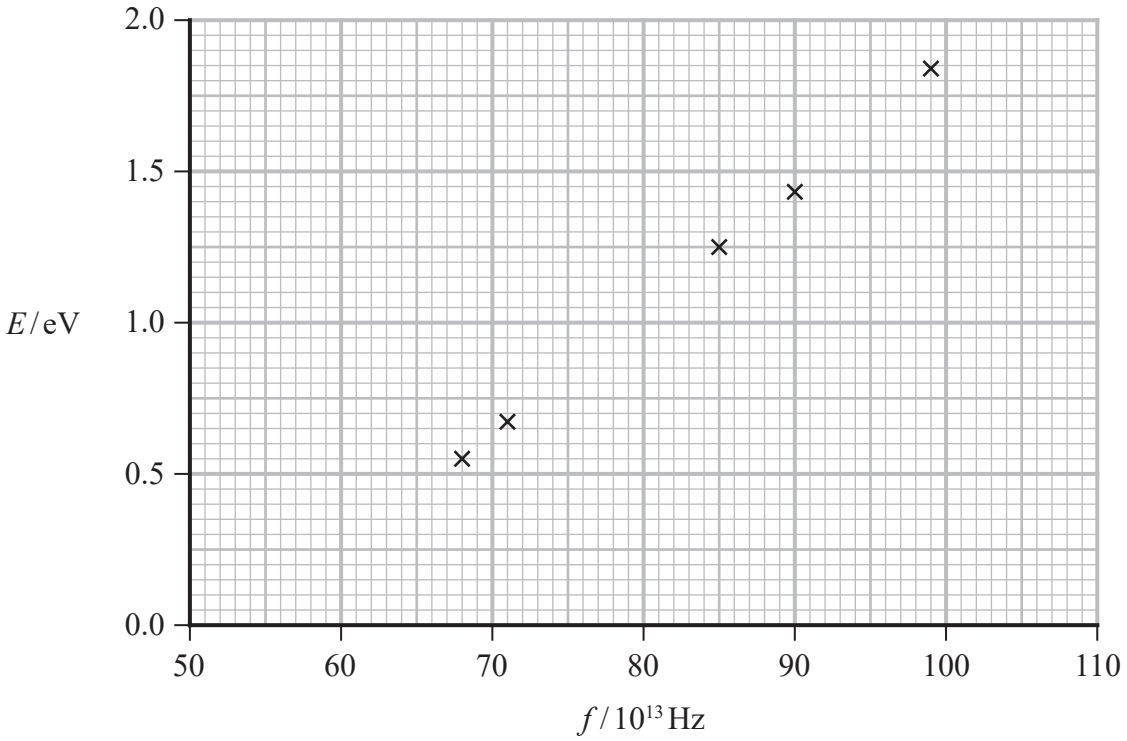
(b) State why the lens and the light sensors in a mobile phone camera can be positioned a fixed distance apart.

(1)

(Total for Question 11 = 5 marks)

16 In an investigation of the photoelectric effect, electromagnetic radiation of frequency f was directed onto a metal plate. The maximum kinetic energy E of the photoelectrons emitted from the metal plate was determined. The procedure was repeated for a range of frequencies.

The graph shows how E depended upon f.



(a) Determine a value for the Planck constant, h, in J s.

(4)

h = ... J s

(b) The table gives data for different metal surfaces.

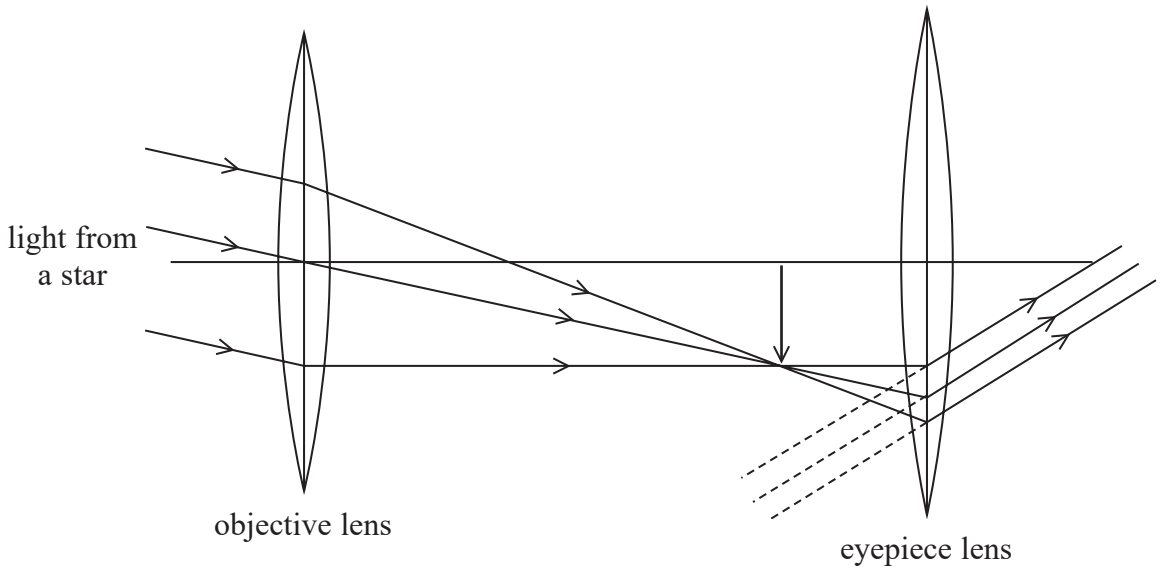
Metal surface	Work function / eV
Caesium	2.0
Calcium	2.9
Magnesium	3.7

Deduce which metal was being used in the investigation.

(3)

(Total for Question 16 = 7 marks)

17 A simple astronomical refracting telescope consists of two converging lenses. Light from a star is brought to a focus by the objective lens and then viewed through an eyepiece lens as shown.



(a) (i) In the arrangement shown, the final image is formed at infinity.

Explain why the separation of the objective and eyepiece lenses is equal to the sum of their focal lengths.

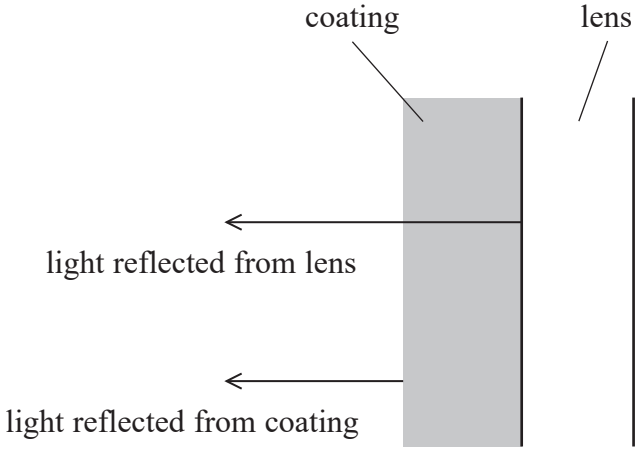
(2)

(ii) State why the final image is inverted.

(1)

(b) Glass lenses used for optical instruments often have an anti-reflective coating. The coating is a thin layer of a transparent substance with refractive index n_c.

Light is reflected from the coating surface and from the lens surface as shown. The reflected light interferes destructively.



When a single-layer coating is used, the coating thickness is chosen to eliminate reflections for green light, which is in the middle of the visible spectrum.

(i) Calculate the minimum thickness d of the coating required for the reflection of green light to be eliminated.

frequency of green light = 6.00×10^{14} Hz
$n_c = 1.38$

(4)

$d =$ .....

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

(1)

.....

.....

(Total for Question 17 = 8 marks)

19 A fine-beam tube is used for investigating properties of electrons.

An electron beam is produced inside a spherical glass bulb. The bulb contains neon gas at a very low pressure.

(a) The neon gas is at a pressure of 1.25 Pa and a temperature of 25 °C.

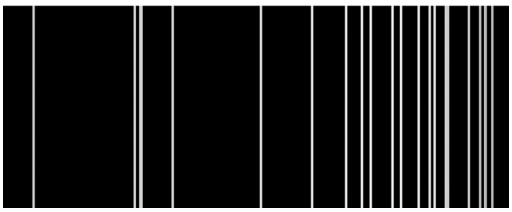
Calculate the number N of neon atoms inside the bulb.

bulb diameter = 16.0 cm

(4)

$N =$ .....

*(b) Interactions between electrons and the neon atoms in the tube make the beam visible. Part of the spectrum of visible light produced by these interactions is shown.



(Source: © MoFarouk/Shutterstock)

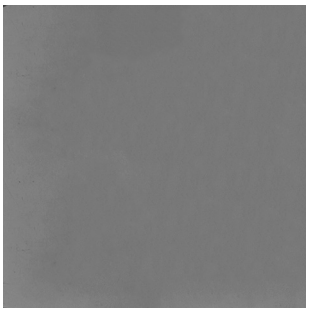
Explain the process that results in the emission of this spectrum. Your answer should include reference to energy levels in atoms.

(6)

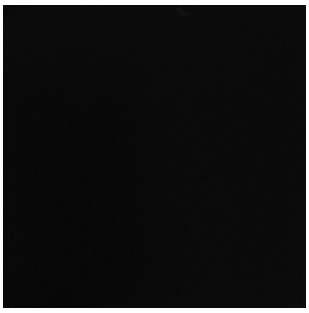
(Total for Question 19 = 10 marks)

2 A source of light is viewed through a polarising filter, as shown in photograph 1.

The filter is rotated through an angle and then viewed, as shown in photograph 2.



Photograph 1



Photograph 2

Which row of the table shows whether the light emitted by the source is polarised or unpolarised, and the angle of rotation of the filter?

	Light emitted by source	Angle of rotation / radians
☒ **A**	polarised	$\frac{\pi}{2}$
☒ **B**	polarised	π
☒ **C**	unpolarised	$\frac{\pi}{2}$
☒ **D**	unpolarised	π

(Total for Question 2 = 1 mark)

3 Two stars, P and Q, are observed from Earth. The intensity of radiation from P is less than that from Q. The parallax angle for P is greater than that for Q.

Which row of the table is correct?

	Distance from Earth	Comparison of luminosities
☒ **A**	P is closer than Q	luminosity of P is greater than Q
☒ **B**	P is closer than Q	luminosity of P is less than Q
☒ **C**	P is further away than Q	luminosity of P is greater than Q
☒ **D**	P is further away than Q	luminosity of P is less than Q

(Total for Question 3 = 1 mark)

6 Monochromatic light of wavelength λ is incident normally on two slits, S_1 and S_2, producing an interference pattern on a screen as shown. V, W, X, Y and Z represent positions of adjacent maxima.

The distance from S_1 to X is represented as S_1X.

Which of the following expressions is equal to 2λ?

- ☒ **A** $S_1Z - S_2X$
- ☒ **B** $S_1V - S_2V$
- ☒ **C** $S_1Y - S_2Y$
- ☒ **D** $S_1W - S_2Y$

(Total for Question 6 = 1 mark)

7 Carbon-14 is a radioactive isotope with a decay constant of 1.2×10^{-4} year^{-1}.

The fossil of a plant contains 24% of the amount of carbon-14 that would have been present when the plant was alive.

Which of the following expressions gives the age of the fossil in years?

☒ **A** $1.2 \times 10^{-4} \times \ln \frac{1}{0.24}$

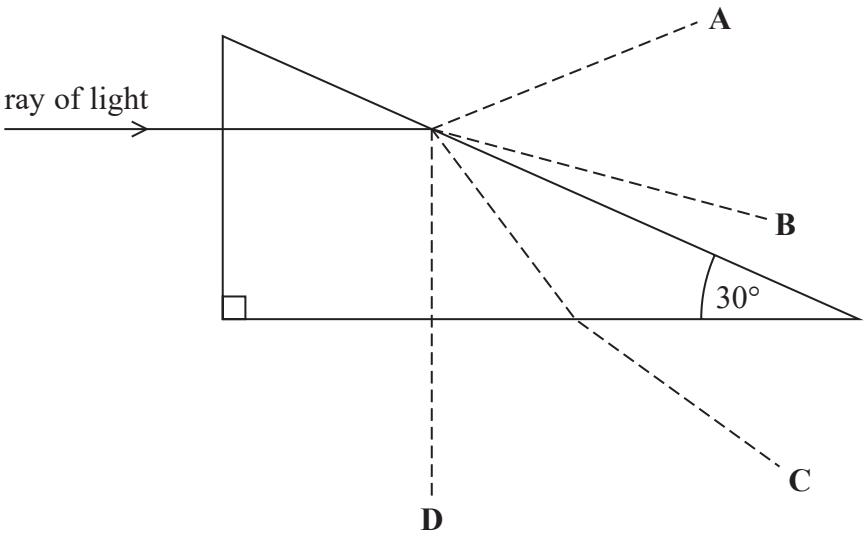
☒ **B** $1.2 \times 10^{-4} \times \ln \frac{0.76}{0.24}$

☒ **C** $\frac{1}{1.2 \times 10^{-4}} \times \ln \frac{1}{0.24}$

☒ **D** $\frac{1}{1.2 \times 10^{-4}} \times \ln \frac{0.76}{0.24}$

(Total for Question 7 = 1 mark)

8 A ray of light is directed towards a prism as shown.
The prism is made from a material with refractive index 1.5



Which of the dashed lines best shows the subsequent path of this ray of light?

☒ **A**

☒ **B**

☒ **C**

☒ **D**

(Total for Question 8 = 1 mark)

11 The photograph shows a stringed instrument called a cello being played with a bow.

(Source: © Vadim Ponomarenko/Alamy Stock Photo)

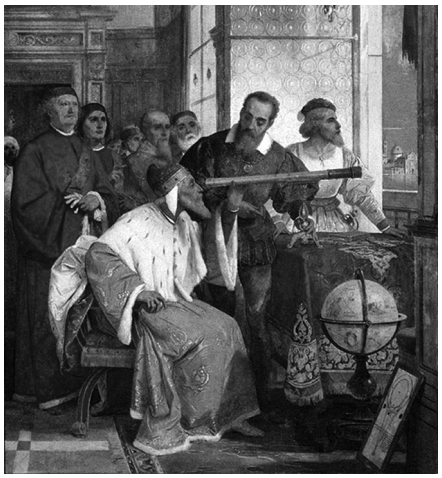
A standing wave forms on a cello string when the bow moves across the string.

Deduce whether a thicker string will produce a note of higher or lower frequency compared with a thinner string.

Assume each string is the same length and at the same tension.

(Total for Question 11 = 4 marks)

18 Galileo is credited with inventing the first telescope in 1610. The picture shows an early demonstration of the telescope.



(Source: © CPA Media Pte Ltd/Alamy Stock Photo)

A converging lens was positioned at one end of the telescope. A diverging lens was placed at the other end and a person looked through this lens.

(a) The converging lens produced an image at a distance equal to the focal length of the lens.

Explain what can be concluded about the object being viewed.

(2)

(b) The final image produced by the telescope is described as virtual and upright.

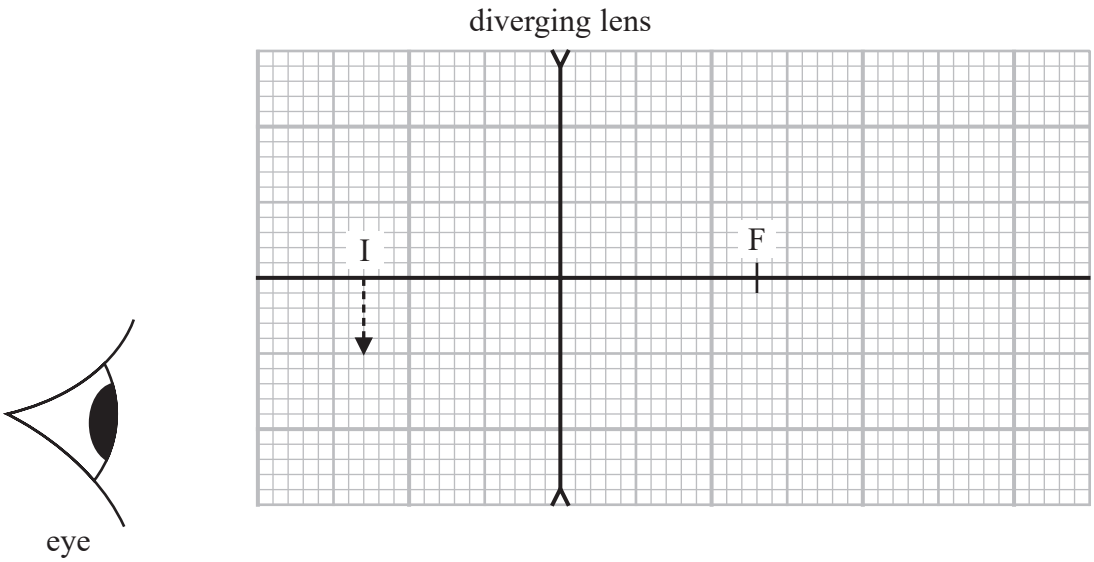
State what is meant by virtual and upright.

(2)

Virtual

Upright

(c) The image, I, produced by the converging lens is at a distance from the diverging lens equal to the focal length of the diverging lens, as shown. This image acts as an object for the diverging lens.



The distance equal to the focal length on the other side of the lens is marked with F.

Draw the ray diagram for the diverging lens.

(3)

(d) Galileo's first telescope had a magnification of 10, and a distance between the centres of the two lenses of 90 cm.

$$\text{The magnification of the telescope} = \frac{\text{focal length of converging lens}}{\text{focal length of diverging lens}}$$

Calculate the focal length of each lens.

(2)

.....

.....

.....

.....

.....

Focal length of converging lens = ...

Focal length of diverging lens = ...

(e) Galileo was the first person to observe Jupiter's larger moons.

Ganymede is Jupiter's largest moon. The distance between the centre of Ganymede and the centre of Jupiter is 1.07×10^6 km. Ganymede takes 171 hours to complete an orbit around Jupiter.

Calculate the mass of Jupiter.

(5)

Mass of Jupiter = ...

(Total for Question 18 = 14 marks)

TOTAL FOR PAPER = 90 MARKS