Name: _____

Topic 5: Waves and Particle Nature of Light Part 2

Date:

Time:

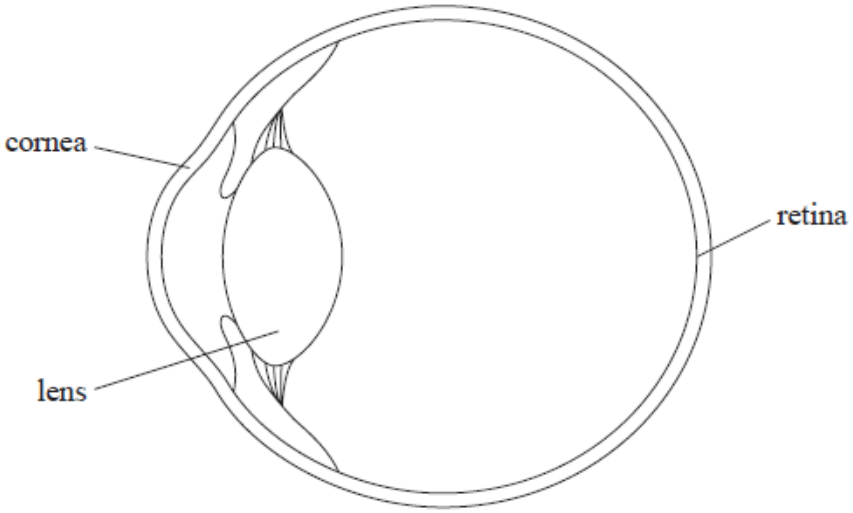
Total marks available:

Total marks achieved: _____

Questions

Q1.

Light entering a normal eye is refracted by both the cornea and the lens before a focused image is formed on the retina.



People swimming under water often wear goggles. The goggles enable them to see objects under water clearly whereas without goggles objects appear blurred.

Explain why wearing goggles has this effect.

speed of light in water = 2.25×10^{8} m s^{-1}

(3)

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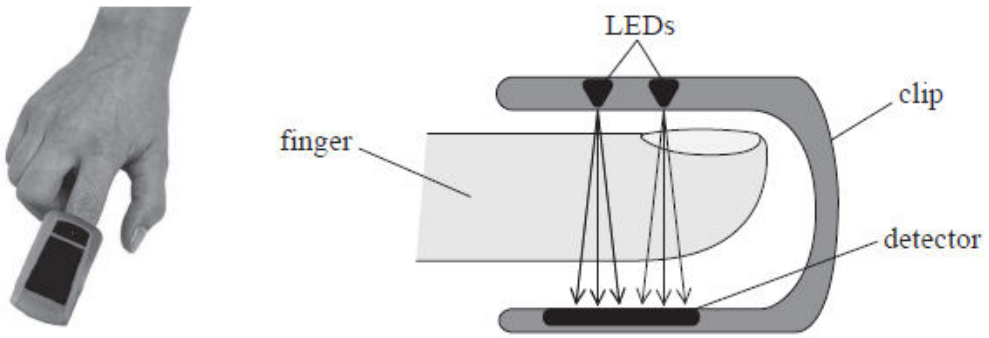
(Total for question = 3 marks)

Q2.

An oximeter is a device used in hospitals to monitor the oxygen level in a patient's blood.

In an oximeter, two light-emitting diodes (LEDs) are mounted opposite light sensors in a clip and attached to the patient's finger. One of the LEDs produces red light and the other produces infrared.



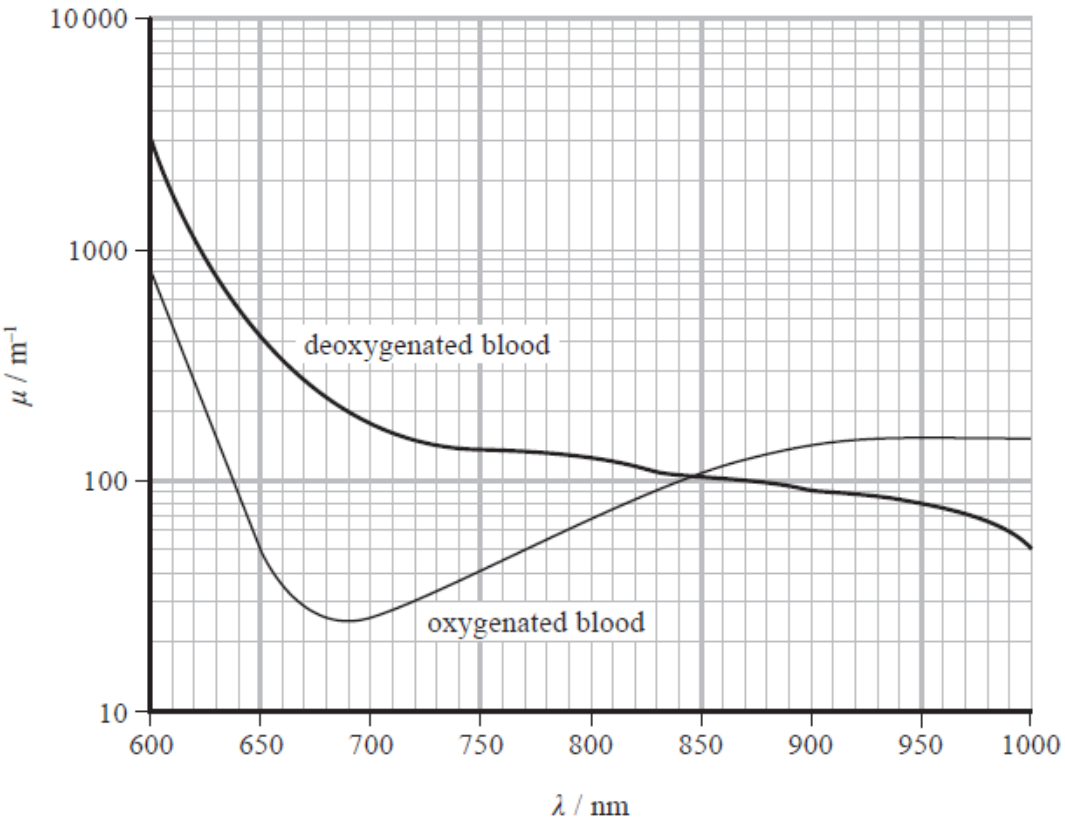
The intensity I of electromagnetic radiation received by the detector, after passing through a thickness x of blood, is given by

$$I = I_0^{e-\mu x}$$

where I_0 is the intensity that would have been received if the blood were not present and μ is the attenuation coefficient of blood.

The red LED emits visible light of wavelength 650 nm and the infrared LED emits infrared of wavelength 950 nm.

The graph shows how μ varies with wavelength λ for oxygenated blood and deoxygenated blood.



The oximeter determines I / I_0 the fraction of radiation transmitted at each wavelength.

Deduce whether I / I_0 will be smaller for the red or the infrared radiation if the blood is deoxygenated.

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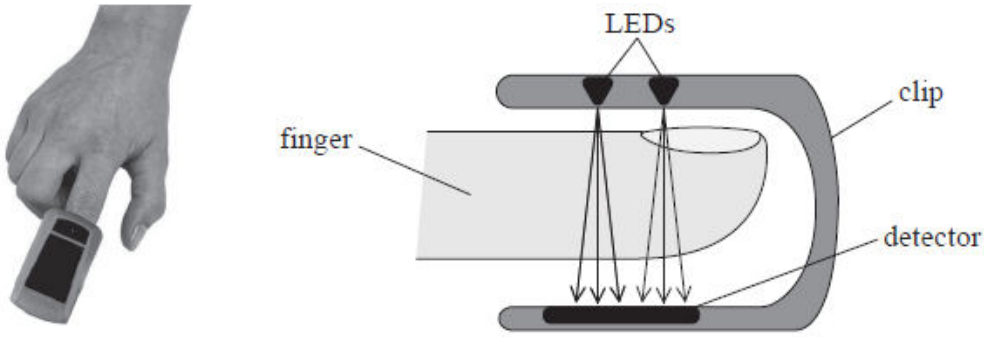
(Total for question = 3 marks)

Q3.

An oximeter is a device used in hospitals to monitor the oxygen level in a patient's blood.

In an oximeter, two light-emitting diodes (LEDs) are mounted opposite light sensors in a clip and attached to the patient's finger. One of the LEDs produces red light and the other produces infrared.



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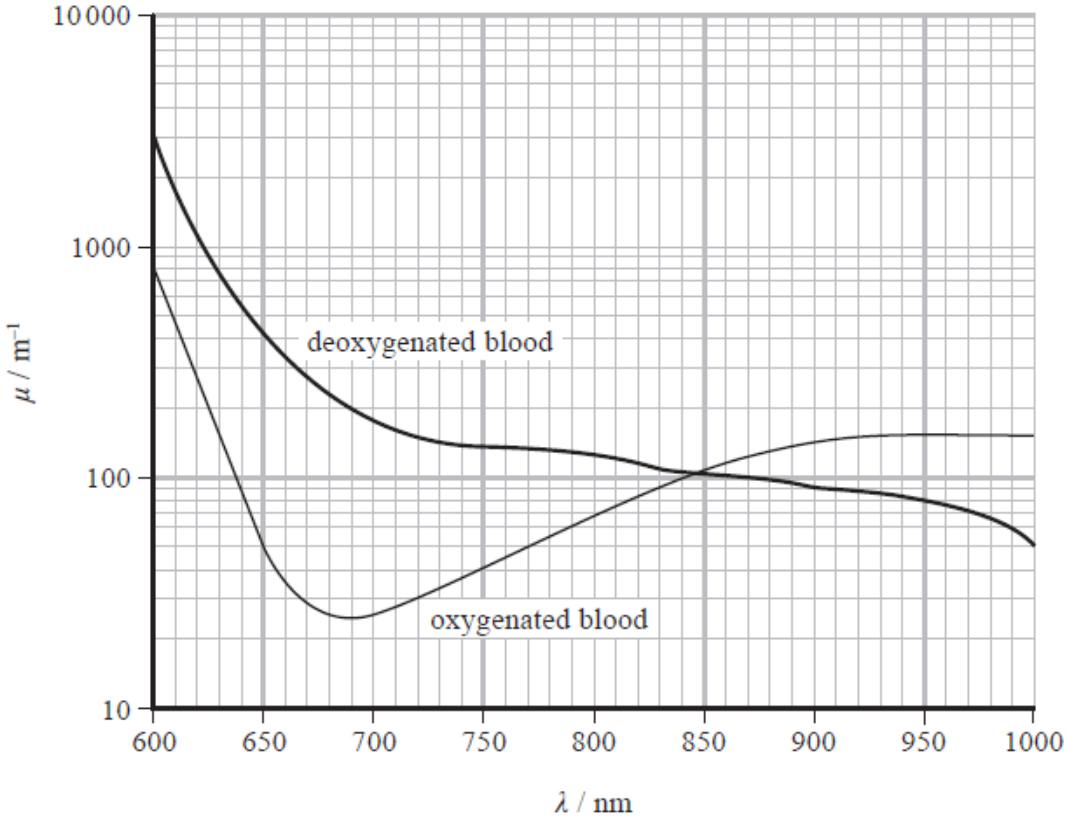

I_0 for the infrared LED is 1.8 W m^{-2}.

Calculate I for the infrared after passing through 1.4 mm of oxygenated blood.

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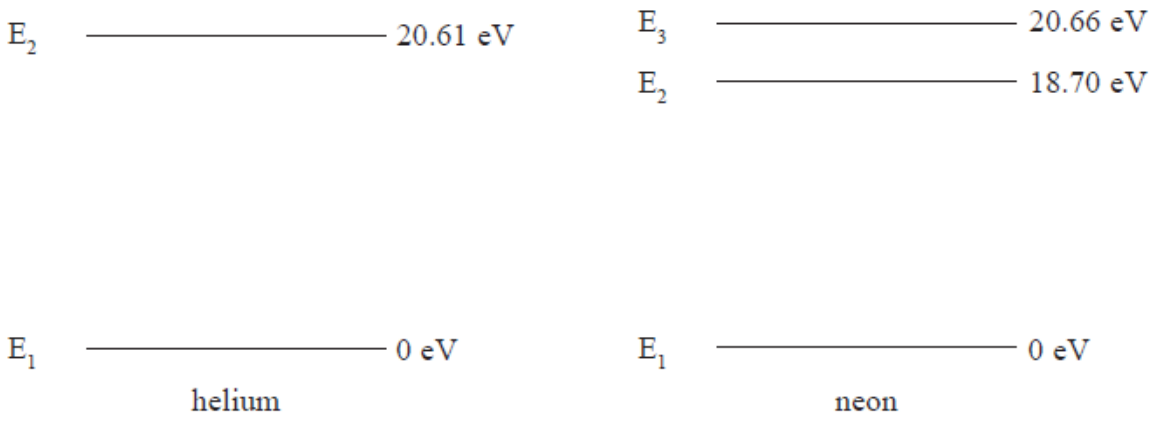
I = ...

(Total for question = 3 marks)

Q4.

A helium-neon gas laser is often used in the laboratory as a source of high intensity, coherent, monochromatic light.

The diagram shows some of the energy levels above the ground level E_3 for helium atoms and for neon atoms. The highest shown levels for helium atoms and neon atoms are almost identical.



Helium atoms in the gas are excited to level E_2 by the current passing through the laser. They collide at high speed with neon atoms. Because the energies are so similar, the energy is transferred from the helium atoms to the neon atoms. The neon atoms become excited in turn to level E_3. As the neon atoms subsequently drop to level E_2 they emit photons.

(a) Explain what is meant by a photon.

(2)

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(b) Calculate the frequency of the photons produced as the neon atoms drop from level E_3 to level E_2.

(3)

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Frequency = ...

(c) An electron in level E_3 of neon has 0.05 eV more energy than an electron in level E_2 of helium.

Suggest the source of the energy to make up this difference.

(1)

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(d) The photograph shows a device for making a vertical slit with variable width.

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When the slit is fully open a laser beam is shone through it and a single point of light is seen on a screen.

As the slit is reduced in width the point of light becomes a horizontal line that gets longer as the slit gets narrower.

Explain this observation

(3)

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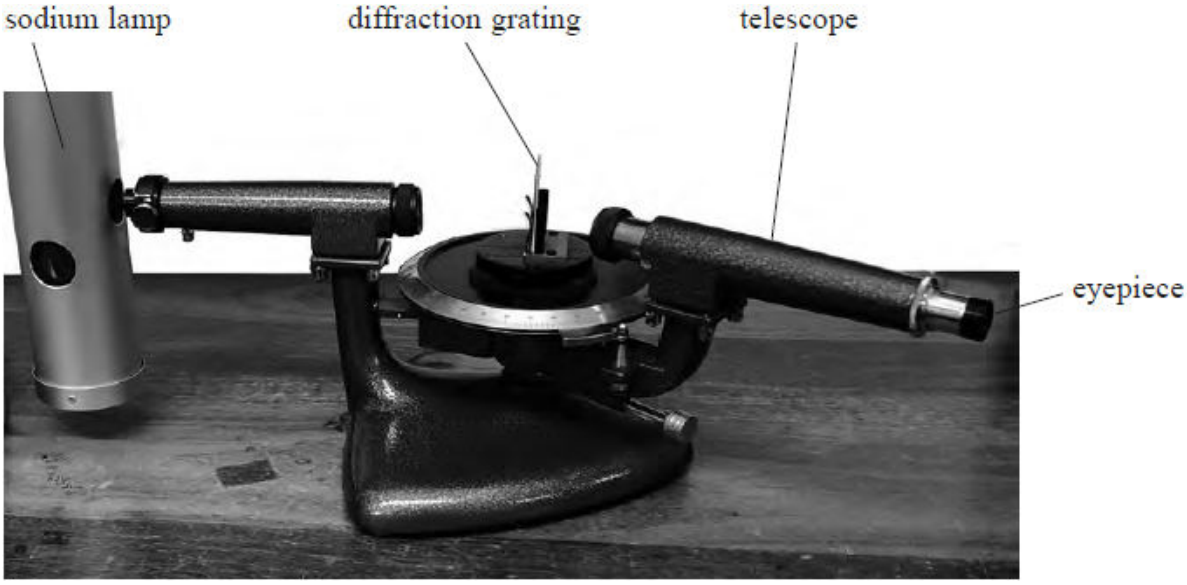
(Total for question = 9 marks)

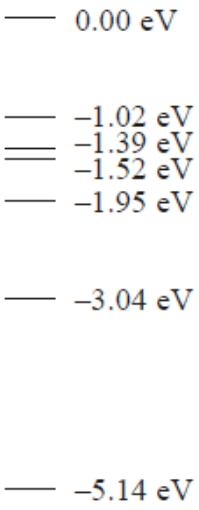
Q5.

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.

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.

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(Total for question = 4 marks)

Q6.

Phosphogypsum is a by-product in the manufacture of fertiliser. It is slightly radioactive because of the presence of radium-226, a radioisotope with a half-life of 1600 years.

It must be stored securely as long as the activity of the radium-226 it contains is greater than 0.4 Bq per gram of phosphogypsum.

Radium-226 decays to radon-222 by alpha emission.

Determine the energy released in MeV in the decay of a single nucleus of radium-226.

(5)

mass of radium-226 nucleus = 225.97713 u
mass of radon-222 nucleus = 221.97040 u
mass of α particle = 4.00151 u

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Energy released = ... MeV

(Total for question = 5 marks)

Q7.

When a large potential difference is applied to a discharge tube, the gas in the discharge tube emits coloured light. When this light is passed through a diffraction grating, an emission spectrum which is made up of a series of lines of different wavelengths may be seen.

The photographs show the spectra produced from a tube containing hydrogen and a tube containing helium.

Hydrogen:

Helium:

* Explain why different elements produce spectra containing different specific wavelengths of light.

(6)

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Q8.

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 (☒).

An object is placed 6.5 cm from a lens of focal length 3.9 cm. An image is formed 9.8 cm behind the lens.

Which of the following expressions is equal to the magnification?

- ☐ **A** $\frac{3.9}{6.5}$
- ☐ **B** $\frac{6.5}{9.8}$
- ☐ **C** $\frac{6.5}{3.9}$
- ☐ **D** $\frac{9.8}{6.5}$

(Total for question = 1 mark)

Q9.

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 = 1 mark)

Q10.

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.

(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)

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(iv) Calculate the speed of light in seawater.

refractive index of seawater = 1.37

(2)

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Speed of light in seawater = ...

(Total for question = 9 marks)

Q11.

A simple model of the hydrogen atom consists of an electron moving in a circular path around a proton.

(i) In this simple model it is the electrostatic force, rather than the gravitational force, that is responsible for keeping the electron in a circular path.

By means of calculations justify this statement.

radius r of the hydrogen atom = 5.3×10^{-11} m

(4)

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(ii) Ignoring the gravitational force, calculate the velocity of the electron in this simple model of the hydrogen atom.

(3)

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Velocity = ...

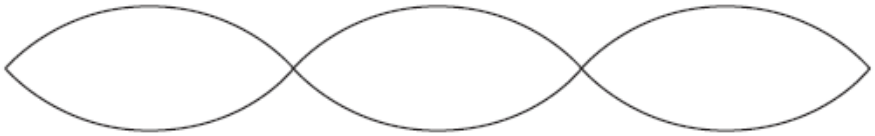
(Total for question = 7 marks)

Q12.

The photograph shows a guitar.

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

The diagram shows a standing wave on a guitar string.



The oscillating length of the guitar string is 66 cm.

(i) State the wavelength for this standing wave.

(1)

Wavelength = ...

(ii) Calculate the frequency of vibration for this standing wave.

tension in guitar string = 88.6 N

mass per unit length of guitar string = 4.47×10^{-3} kg m^{-1}

(3)

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Frequency = ...

(Total for question = 4 marks)

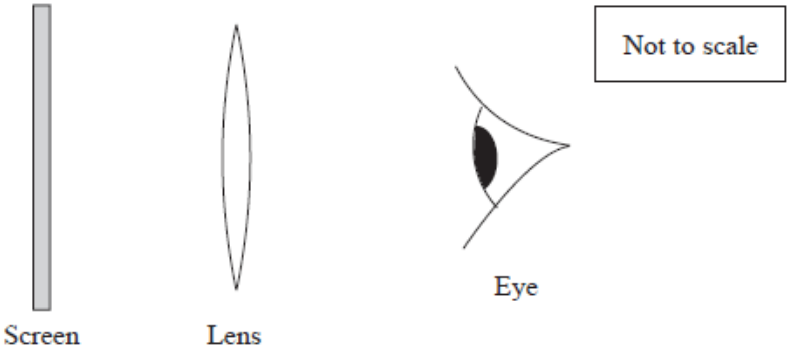
Q13.

The photograph shows a man wearing a virtual reality (VR) headset.

The VR headset gives the illusion of three-dimensional vision.

Inside the VR headset a pair of lenses is used to enable the user to focus on a magnified virtual image of a screen. The lenses can be changed to suit the vision of the user.

In the VR headset the lens is between the eye and the screen, as shown below.



For a particular user of the headset, the image of the screen must be at least 16 cm from the eye and have a magnification of at least 3.0.

Determine whether this would be possible with a lens of focal length 3.8 cm.
Your answer should include a full-scale ray diagram drawn on the grid provided.

(4)

distance from screen to lens = 2.8 cm
distance from lens to eye = 2.2 cm

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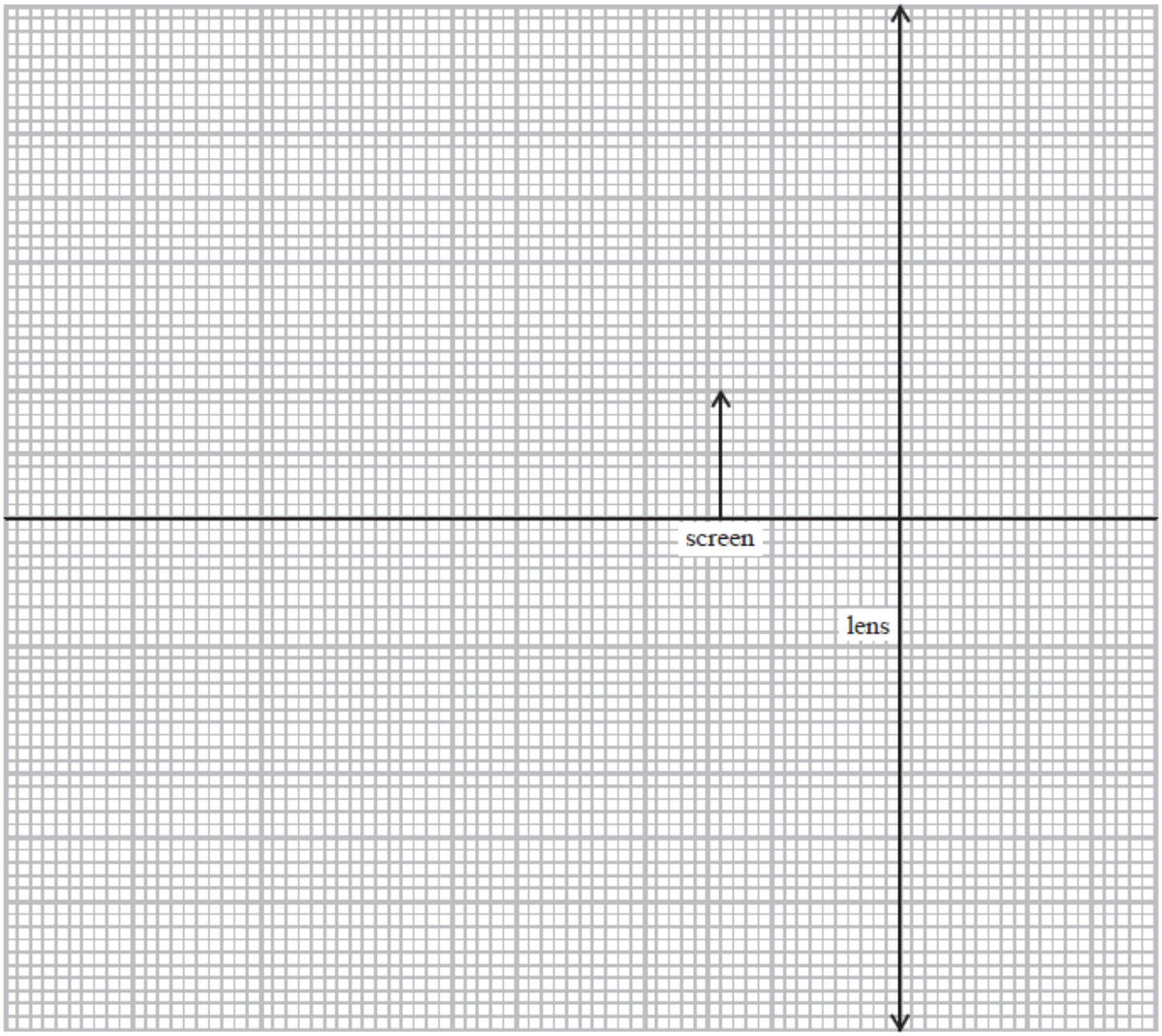


(Total for question = 4 marks)

Q14.

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 detector is placed 30 cm from a gamma source, the count rate is 64 counts per minute.

The detector is then placed 60 cm from the source. The background rate is presumed to be a constant 24 counts per minute.

Which of the following gives the expected counts per minute?

☐ **A** 16

☐ **B** 32

☒ **C** 34

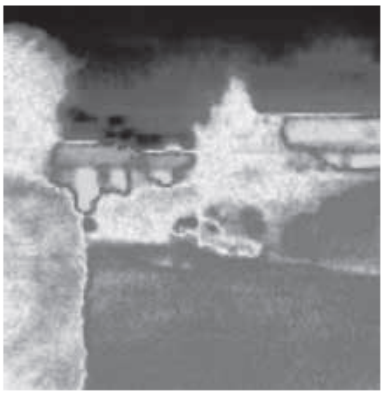
☒ **D** 44

(Total for question = 1 mark)

Q15.

Infrared cameras are used to create images that show the infrared radiation emitted by objects.

The photographs show the same scene taken first with an ordinary camera and then with an infrared camera.



The photograph shows the result when someone tries to take an infrared photograph of the same scene through a window. The image does not show the outdoor scene but does show an image of the photographer.

State what can be concluded about glass and infrared radiation.

(2)

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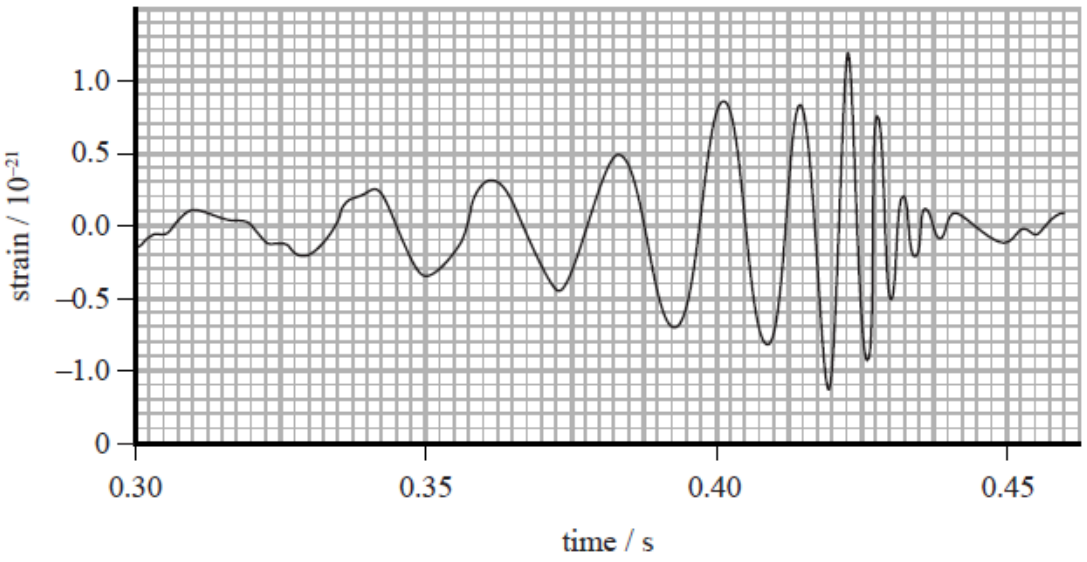
(Total for question = 2 marks)

Q16.

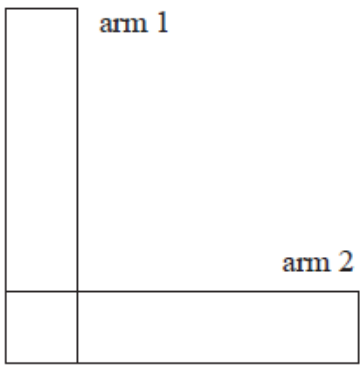
In 2016 scientists at the Laser Interferometer Gravitational-Wave Observatory (LIGO) announced that gravitational waves had been detected.

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

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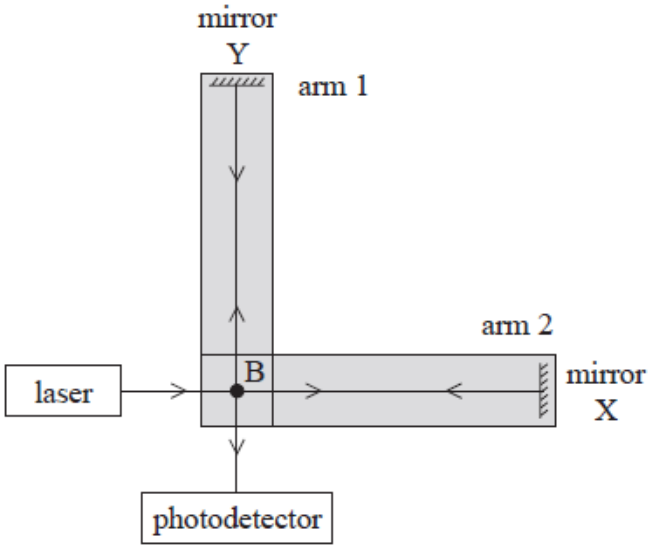
(ii) In the LIGO detector, any change in the lengths of the arms is detected using a laser beam and photodetector.



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.

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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.

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(Total for question = 9 marks)

Q17.

Our understanding of the atom has developed over time, from early models in which atoms were considered to be hard incompressible spheres, through to the nuclear model of the atom and the ladder model in which electrons exist in a discrete number of allowed energy states.

In the energy ladder model of the atom, electrons exist in a discrete number of allowed energy states. The collision of electrons with gold atoms may lead to the production of high frequency electromagnetic radiation.

Explain how high frequency electromagnetic radiation may be produced when electrons collide with atoms in a metal.

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(Total for question = 4 marks)

Q18.

A diverging lens is used to produce an image of a real object.

Select the row of the table that correctly identifies the nature of the image produced.

☐	**A**	Real	Upright
☐	**B**	Real	Inverted
☐	**C**	Virtual	Upright
☐	**D**	Virtual	Inverted

(Total for question = 1 mark)

Q19.

Our understanding of the atom has developed over time, from early models in which atoms were

considered to be hard incompressible spheres, through to the nuclear model of the atom and the ladder model in which electrons exist in a discrete number of allowed energy states.

* The model of atoms as hard incompressible spheres, moving rapidly and randomly, can be used to explain why gases exert a pressure.

Explain, using ideas of momentum, why the pressure exerted by a gas increases as the temperature of the gas increases.

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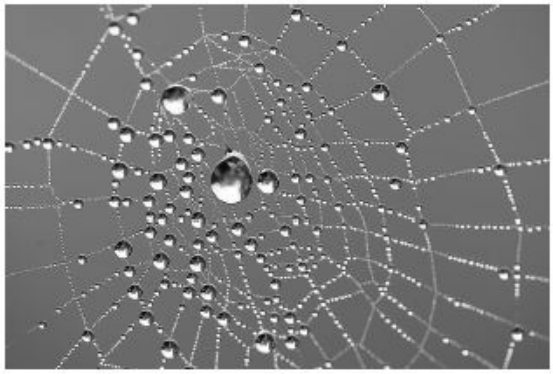
(Total for question = 6 marks)

Q20.

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.

* Explain how stationary waves can be setup on a thread of spider silk, and how this can account for the collection of water droplets at certain points on the thread.

(6)

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Q21.

In February 2013 the largest known meteor for a century exploded over the Ural region of Russia.

The explosion was detected by stations monitoring infrasound, a type of sound with a frequency too low for humans to hear.

Describe how infrasound travels through the air.

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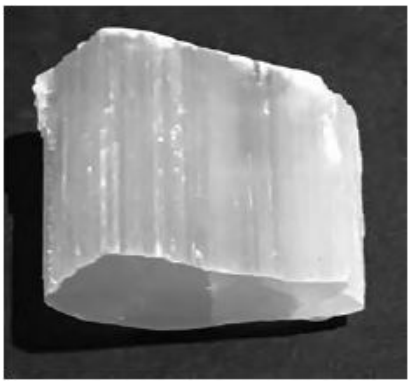
(Total for question = 3 marks)

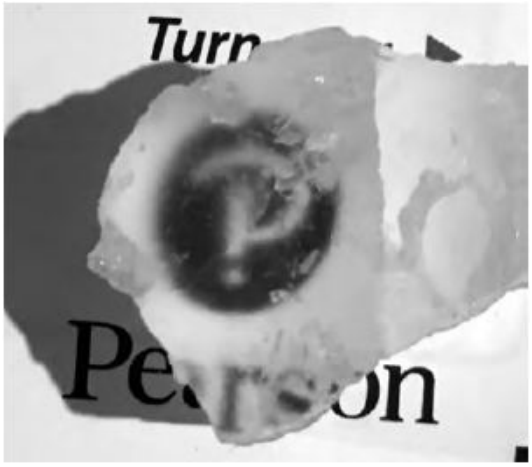
Q22.

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

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)

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(Total for question = 2 marks)

Q23.

Barnard's star is a red dwarf star in the vicinity of the Sun. The wavelength of a line in the spectrum of light emitted from Barnard's star is measured to be 656.0 nm. The same light produced by a source in a laboratory has a wavelength of 656.2 nm.

Visible light from the star originates from the photosphere. In the photosphere of Barnard's star, hydrogen and helium atoms are at a temperature of 3100 K.

(i) Calculate the mean kinetic energy of an atom in the photosphere at a temperature of 3100 K.

(2)

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Mean kinetic energy = ...

(ii) Describe how these atoms emit visible light.

(2)

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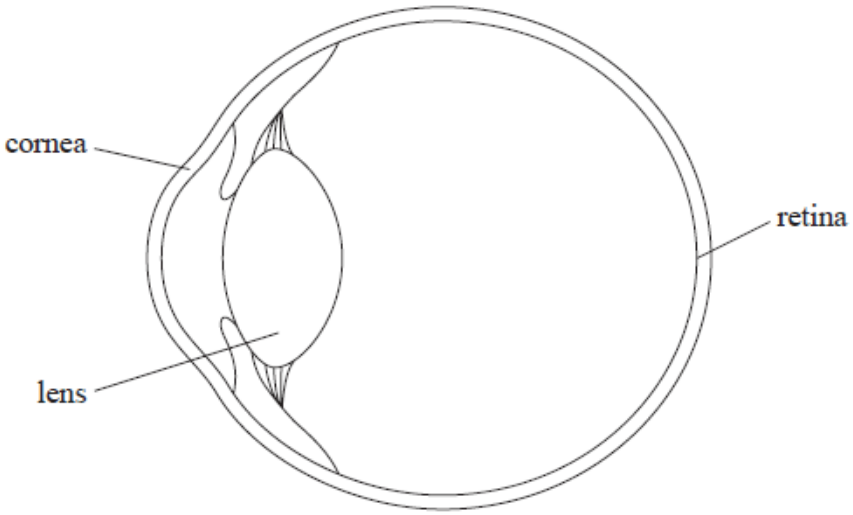
(Total for question = 4 marks)

Q24.

Light entering a normal eye is refracted by both the cornea and the lens before a focused image is formed on the retina.



Light from a point object forms a focused image on the retina.

The cornea and lens may be treated as a single lens of focal length 1.6 cm that is 2.4 cm from the retina.

(i) Calculate the distance from the point object to this single lens when a focused image is formed on the retina.

(2)

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Distance = ...

(ii) A ray of light strikes the front of the cornea at an angle to the normal in air of 15°.

Calculate the angle of the ray to the normal in the cornea.

speed of light in air = 3.00×10^8 m s^{-1}

speed of light in cornea = 2.18×10^8 m s^{-1}

(3)

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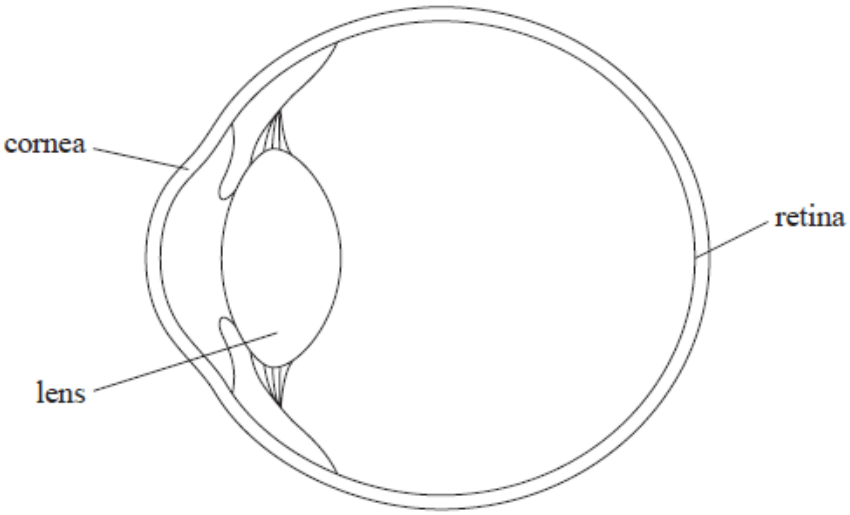
Angle to normal in cornea = ...

(Total for question = 5 marks)

Q25.

Light entering a normal eye is refracted by both the cornea and the lens before a focused image is formed on the retina.



It is suggested that the cornea provides 80% of the focusing power of the eye.

Determine whether this is correct.

focal length of cornea = 2.23 cm

focal length of lens for near object = 5.27 cm

(4)

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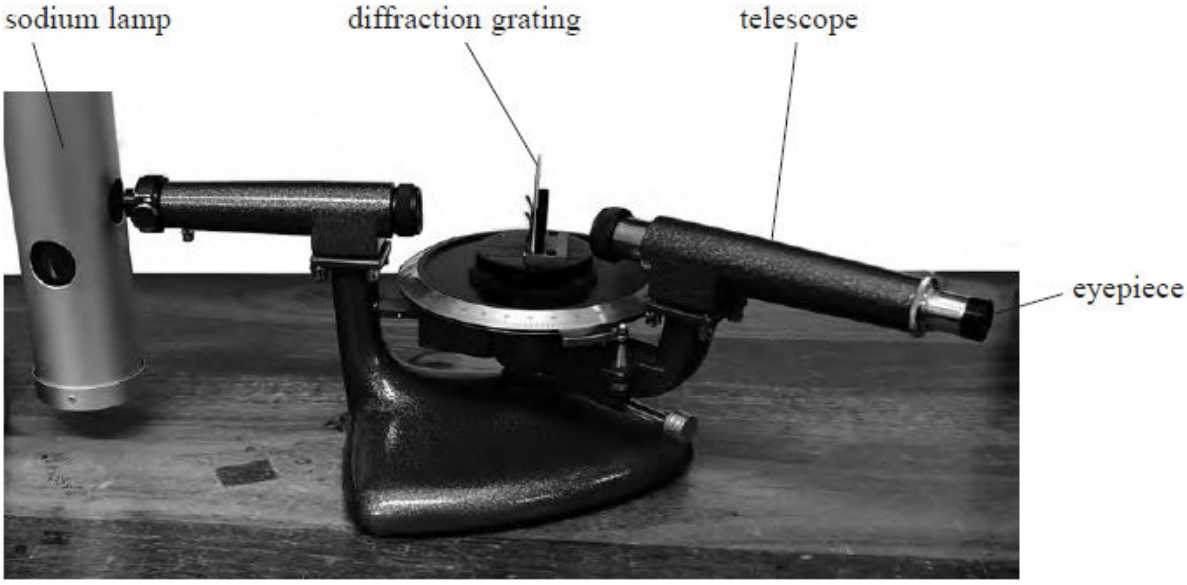
(Total for question = 4 marks)

Q26.

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.

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)

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(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)

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(Total for question = 9 marks)

Q27.

An object is placed 6.5 cm away from a lens of focal length 3.9 cm. An image is formed 9.8 cm from the lens.

Which of the following is the magnification?

(1)

☒ **A** 0.60

☒ **B** 0.66

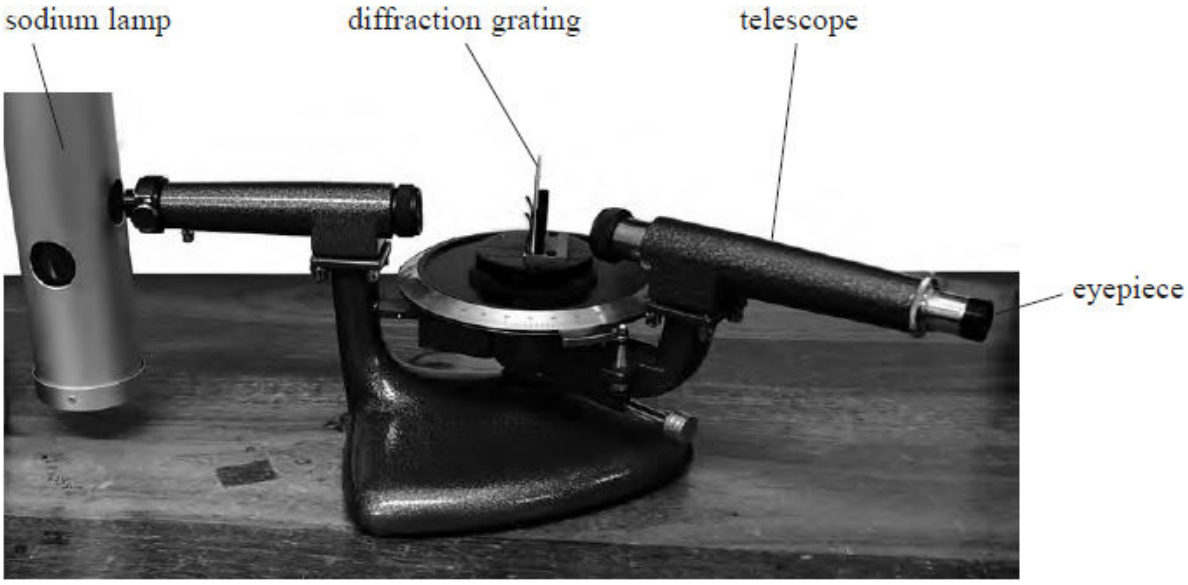
☒ **C** 1.5

☒ **D** 1.7

(Total for question = 1 mark)

Q28.

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.

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 = ...

(Total for question = 3 marks)

Q29.

A converging lens is used as a magnifying glass. An image is produced that is 30 cm away from the lens and twice as big as the object.

Choose the row that correctly identifies the nature of the image and the object distance.

	Nature of image	Object distance/cm
☒ **A**	real	15
☒ **B**	real	60
☒ **C**	virtual	15
☒ **D**	virtual	60

(Total for question = 1 mark)

Q30.

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 monochromatic light is incident on the surface of a metal, electrons are emitted by the photoelectric effect.

If other conditions are unchanged, the maximum kinetic energy of the electrons will be increased by

☒ **A** increasing the frequency of the incident light.

☒ **B** increasing the intensity of the incident light.

☒ **C** using a metal with a higher threshold frequency.

☒ **D** using a metal with a higher work function.

(Total for question = 1 mark)

Mark Scheme

Q1.

Question Number	Acceptable answers		Additional guidance	Mark
	• difference in speed for air to cornea much greater than difference in speed from water to cornea **Or** lower refractive index for water to cornea (= 1.03)	**(1)**	MP1: Seeing values of refractive index as 1.03 and 1.38 is not enough, a comparison is required.	
	• so less refraction **Or** so power of eye/cornea reduced **Or** so focal length of eye/cornea increased	**(1)**		
	• if goggles worn the interface is with air and refraction is as normal **Or** if goggles worn the interface is with air and image focused on retina	**(1)**		**3**

Q2.

Question Number	Acceptable Answer		Additional Guidance	Mark
	• (for deoxygenated blood) μ is greater for red	**(1)**	Accept values for μ which show $\mu_{red} > \mu_{IR}$ for MP1	
	• hence more red is absorbed **Or** intensity is smaller for red **Or** $e^{-\mu x}$ is smaller for red	**(1)**	Allow numerical substitutions for MP2 and MP3	
	• So I/I_0 is smaller for red [dependent upon MP2]	**(1)**	Accept converse argument leading to same conclusion	**3**

Q3.

Question Number	Acceptable Answer		Additional Guidance	Mark
	• μ read from graph	(1)	Accept μ in the range 140 (m^{-1}) - 160 (m^{-1})	
	• Use of $I = I_0 e^{-\mu x}$	(1)		
	• $I = 1.5$ W m^{-2}	(1)	Accept answers that round to 1.4 W m^{-2} or 1.5 W m^{-2} dependent upon value of μ for MP3 Example of calculation: I=1.8 W m^{-2} $\times e^{-150\ m^{-1} \times 1.4 \times 10^{-3}\ m} = 1.46$ W m^{-2}	3

Q4.

Question Number	Answer		Mark
(a)	Photon – quantum/packet of something relevant e.g. light, radiation, any other named e-m radiation, energy	(1)	
	(quantum/packet) of electromagnetic energy/radiation/waves (dependent mark)	(1)	2
(b)	Use of $(20.66 - 18.70) \times 1.6 \times 10^{-19}$	(1)	
	Use of $E = hf$ (with energy in eV or J)	(1)	
	$f = 4.7 \times 10^{14}$ Hz	(1)	3
	Example of calculation $f = (20.66 - 18.70) \times 1.6 \times 10^{-19} / 6.63 \times 10^{-34}$ $f = 4.73 \times 10^{14}$ Hz		
(c)	From kinetic energy of atoms	(1)	1
(d)	Diffraction	(1)	
	Light spreads (sideways) as it passes through the slit	(1)	
	Narrower slit causes more diffraction/spreading **Or** diffraction increasing as gap width gets closer to wavelength	(1)	3
	Total for question		9

Q5.

Question Number	Acceptable answers	Additional guidance	Mark
	• Use of $E = hf$ and $c = f\lambda$ (1) • Convert J to eV (1) • 2.1 eV (1) • Arrow drawn on diagram from −3.04 eV to −5.14 eV (1)	Example of calculation $E = 6.63 \times 10^{-34}$ Js $\times$ 3.00 $\times 10^{8}$ m s^{-1} / 5.89×10^{-7} m $= 3.38 \times 10^{-19}$ J 3.38×10^{-19} J / 1.60×10^{-19} C = 2.11 eV	4

Q6.

Question Number	Acceptable answers	Additional guidance	Mark
	• attempt to determine mass difference between radium and radon-plus-alpha (1) • conversion to kg (1) • Use of $\Delta E = c^2\Delta m$ (1) • Use of 1.6×10^{-19} factor (1) • Answer = 4.87 (MeV) (1)	Δm = 225.97713u − (221.97040u + 4.00151 u) = 5.22×10^{-3} u = $5.22 \times 10^{-3} \times 1.66 \times 10^{-27}$ kg = 8.67×10^{-30} kg $\Delta E = c^2\Delta m$ = (3 $\times 10^{8}$ m s^{-1})^2 $\times$ 8.67×10^{-30} kg = 7.80×10^{-13} J ΔE in MeV = 7.80×10^{-13} J ÷ 1.6×10^{-19} C = 4.87 MeV	5

Q7.

<table>
<tr><th>Question Number</th><th>Acceptable answers</th><th>Additional guidance</th><th>Mark</th></tr>
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Marks are awarded for indicative content and for how the answer is structured and shows lines of reasoning.

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</table>

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

Indicative content

- electrons/atoms move to higher energy levels
  Or electrons/atoms are excited
- they then move to lower energy levels (accept ground state) and the energy (from the change) is given out in the form of a photon

marks for linkages).

(6)

	• the energy levels are discrete **Or** only certain energy levels are possible • the energy of the photon is equal to the difference in energy levels **Or** $hf = E_2 - E_1$ **Or** $hc/\lambda = E_2 - E_1$ • there are only a limited number of energy differences and only a corresponding set of frequencies/wavelengths • different elements have different energy level (differences), so they will produce different frequencies/wavelengths	looking for energy differences /changes **not** energy levels	

Q8.

Question Number	Acceptable answers	Additional guidance	Mark
	The only correct answer is **D** because magnification is numerically equal to image distance divided by object distance A is not correct because magnification is numerically equal to image distance divided by object distance, but this is focal length divided by object distance B is not correct because magnification is numerically equal to image distance divided by object distance, but this is object distance divided by image distance C is not correct because magnification is numerically equal to image distance divided by object distance, but this is object distance divided by focal length		1

Q9.

Question Number	Answer	Mark
	The only correct answer is C because 10 cm is more than the focal length from a converging lens A diverging lenses do not form real images from real objects B diverging lenses do not form real images from real objects D an object at less than the focal length from a converging lens will form a virtual image	1

Q10.

Question Number	Acceptable answers		Additional guidance	Mark
(i)	• Use of $P = 1/f$ • $f = 8.47$ (mm)	(1) (1)	Example of calculation $f = 1 / 118$ D = 8.47 mm	2
(ii)	• Use of $1/v + 1/u = 1/f$ (allow u and v reversed, but not f) • $u = 14.8$ mm (ecf for f from 19(a)(i))	(1) (1)	Example of calculation 1/20 mm + $1/u$ = 1/8.5 mm $u = 14.8$ mm	2
(iii)	• (Freshwater has a lower refractive index than seawater, so) there will be greater refraction of light on entering the lens • This means that the power of the lens is greater in freshwater **Or** this means that the focal length is less in freshwater • This means that the shortest distance will be decreased	(1) (1) (1)		3
(iv)	• Use of $n = c/v$ • $v = 2.2 \times 10^8$ m s^{-1}	(1) (1)	Example of calculation $1.37 = 3.00 \times 10^8$ m s^{-1} / v $v = 2.2 \times 10^8$ m s^{-1}	2

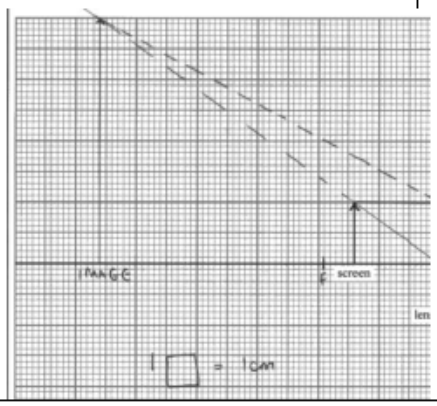
Q11.

Question number	Acceptable answers	Additional guidance	Mark
(i)	• use of $F = Q_1Q_2/4\pi\varepsilon_0 r^2$ **(1)** • use of $F = Gm_1m_2/r^2$ **(1)** • Expresses forces as a ratio **(1)** **OR** calculates the individual forces F_e=8.1 x 10^{-8} N F_g = • 3.6 x 10^{-47} N **(1)** • Ratio = 2 x 10^{39} or 5 x 10^{-40} and identifies gravitational force as insignificant **(1)**		4
(ii)	• use of $F = mv^2/r$ and $F = Q_1Q_2/4\pi\varepsilon_0 r^2$ **(1)** • to derive $v = \sqrt{\frac{Q_1Q_2}{4\pi\epsilon_0 rm}}$ **(1)** • velocity = 2.2× 10^6 m s^{-1} **(1)**	Example of calculation: $v = \sqrt{\frac{Q_1Q_2}{4\pi\epsilon_0 rm}}$ $v = \sqrt{\frac{1.6\times10^{-19}\text{ C}\times1.6\times10^{-19}\text{ C}}{4\pi\times8.85^{-12}\text{ Fm}^{-1}\times5.3\times10^{-11}\text{m}\times9.1\times10^{-81}\text{ kg}}}$ $v = 2.185 \times 10^6$ m s^{-1}	3

Q12.

Question Number	Acceptable answers		Additional guidance	Mark
(i)	• Wavelength = 44 cm	(1)		1
(ii)	• Use of $v = \sqrt{\frac{T}{\mu}}$ • Use of $v = f\lambda$ (ecf from (i)) • f = 320 Hz	(1) (1) (1)	Example of calculation $v = \sqrt{\frac{88.6\ \text{N}}{4.47 \times 10{-}3\ \text{kg m}{-}1}}$ = 141 m s^{-1} f = 141 m s^{-1} / 0.44 m = 320 Hz	3

Q13.

Question Number	Acceptable answers		Additional guidance	Mark
	• Two rays correctly drawn including extrapolation • Completes diagram with image at 10.6 cm (range 9.0 cm to 12.0 cm) • Magnification = 3.8 (3.5 to 4.0) • Conclusion consistent with values for distance and M	(1) (1) (1) (1)	Acceptable rays: • from arrowhead on object through the optical centre of the lens • from arrowhead on object parallel to the axis up to the lens and then through the principal focus on the other side • from the principal focus on the same side and through the arrowhead on the object to the lens and then parallel to the axis Example of calculation M = image size / object size (accept use of distances) = 8.0 cm / 2.0 cm = 4.0 	4

Q14.

Question Number	Acceptable answer	Additional guidance	Mark
	C	The only correct answer is **C** because the corrected count rate at 30 cm is 40 counts per minute, the corrected rate at twice the distance is a quarter of this value, which is 10 counts per minute, and adding the background gives the value of 34 A is not the correct answer because it is 16 C is not the correct answer because it is 32 D is not the correct answer because it is 44	**1**

Q15.

Question Number	Acceptable answers		Additional guidance	Mark
	• Glass reflects (these wavelengths of) IR radiation	**(1)**		
	• Glass does not transmit (these wavelengths of) IR radiation	**(1)**	Accept IR does not pass through glass	**2**

Q16.

Question Number	Acceptable answers		Additional guidance	Mark
(i)	• use of strain = extension / length	**(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	
	• change in length = 4.8×10^{-18} (m) **Or** max strain for 0.001× proton size = 2.2×10^{-22}	**(1)**		
	• comparison of their change in length to 8.8×10^{-19}(m) **Or** comparison of their max strain to 1.2×10^{-21}	**(1)**		**3**

Question Number	Acceptable answers		Additional guidance	Mark
(ii)	• half wavelength path difference means waves in antiphase	(1)	Do not accept 'out of phase' for MP1	
	• so destructive interference takes place	(1)		
	• this results in zero amplitude, (so no signal detected)	(1)		
	• 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)	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	(1)	MP2 alternative: a change from minimum amplitude would represent a much larger percentage (therefore more sensitive)	
	• a change from max amplitude would represent a much smaller percentage (therefore less sensitive)	(1)	MP2 Accept 'it is easier to detect the change from no light to light' MP2 Accept suitable reference to uncertainty	**2**

Q17.

Question Number	Acceptable Answer		Additional Guidance	Mark
	• Electrons are excited to higher energy states / levels (by incident electrons)	(1)	For MP1 and MP2 allow • Electrons knock electrons out of low energy levels • Electrons cascade down to fill up the levels	
	• An electron returns to the lower energy state / level resulting in the emission of a <u>photon</u>	(1)		**4**
	• The energy of the photon is equal to the difference of the energy states / levels	(1)		
	• Large difference in energy states / levels so as $E = hf$, radiation is high frequency	(1)		

Q18.

Question Number	Acceptable answers	Additional guidance	Mark
	C		1

Q19.

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<tr><th>IC Points</th><th>IC Mark</th><th>Max linkage mark avail.</th><th>Max final mark</th></tr>
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<tr><td>5</td><td>3</td><td>2</td><td>5</td></tr>
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</table>

IC3 and IC4 must include a mention of the walls/container
</td>
<td>6</td>
</tr>
</table>

	Indicative content: 1. As the temperature of the gas increases the (average) speed/E_k of the atoms increases 2. Greater speed/E_k so the momentum of the atoms increases 3. The rate/frequency of collision of atoms with the container walls increases **Or** the time between collisions with the walls decreases 4. The rate of change of momentum at the walls increases 5. Rate of change of momentum is equal to the force 6. Pressure is $\frac{\text{force}}{\text{area}}$ and the force (on the walls) is greater		

Q20.

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</td><td></td><td>(6)</td></tr>
</table>

	Indicative content • the progressive waves are reflected and two waves travelling in opposite directions meet • superposition/interference takes place • where the waves are in phase, it is constructive, forming antinodes • where the waves are in antiphase, it is destructive, forming nodes • antinodes are points of maximum amplitude, so water will not remain at antinodes • nodes are points of zero displacement, so water can stay at these points		

Q21.

Question Number	Answer	Mark
	Oscillations/vibrations of (air) particles/molecules/atoms (1) Oscillations/vibrations/displacement parallel to direction of propagation **Or** Oscillations/vibrations/displacement parallel to direction of energy transfer (1) (Producing) compressions and rarefactions **Or** regions of high and low pressure **Or** it is a longitudinal wave (1)	3
	Total for question	**3**

Q22.

Question Number	Acceptable answers	Additional guidance	Mark
	• Light strikes the edges of the long crystals at angles greater than the critical angle (1) • It is repeatedly totally internally reflected along the crystal (1)		2

Q23.

Question Number	Acceptable Answer	Additional Guidance	Mark
(i)	• Use of $\frac{1}{2}m\langle c^2\rangle = \frac{3}{2}kT$ (1) • mean kinetic energy $= 6.4\times10^{-20}$J (1)	Example of calculation: $\frac{1}{2}m\langle c^2\rangle = \frac{3}{2}kT$ $= \frac{3}{2}\times1.38\times10^{-23}\text{JK}^{-1}\times3100\text{K} = 6.42\times10^{-20}\text{J}$	2

Question Number	Acceptable Answer	Additional Guidance	Mark
(ii)	• There are electron transitions between energy levels in the atoms, (1) • When electrons return to a lower level they emit energy in the form of photons (1)		2

Q24.

Question Number	Acceptable answers	Additional guidance	Mark
(i)	• use of $1/f = 1/u + 1/v$ (1) • $u = 4.8$ cm (1)	Example of calculation 1/1.6 cm = 1/u + 1/ 2.4 cm u = 4.8 cm	2

Question Number	Acceptable answers	Additional guidance	Mark
(ii)	• use of $n = c / v$ (1) • use of $n_1 \sin\theta_1 = n_2 \sin\theta_2$ **Or** $n = \sin i / \sin r$ with correct angles (1) • $\theta = 11°$ (1)	Accept use of $v_2 \sin\theta_1 = v_1 \sin\theta_2$ for MP1 and MP2 but $v_1 \sin\theta_1 = v_2 \sin\theta_2$ scores neither Example of calculation $n = 3 \times 10^8$ m s^{-1} / 2.18×10^8 m s^{-1} = 1.376 $1 \times \sin 15° = 1.376 \times \sin\theta$ $\theta = 10.8°$	3

Q25.

Question Number	Acceptable answers	Additional guidance	Mark
	• use of $P = 1/f$ (1) • use of $P = P_1 + P_2$ etc (1) • total power = 63.8 (D) (1) • Comparative statement consistent with their values (1)	**MP4** An attempt at a % must be made and a clear comparison with the 80% must be made e.g % for cornea from 44.8 / 63.8 is 71% which is not 80% so no Example of calculation P_{cornea} = 1/ 0.0223 m = 44.84 D P_{lens} = 1/ 0.0527 m = 18.98 D Total power = 63.82 D	4

Q26.

Question Number	Acceptable answers	Additional guidance	Mark
(i)	• The electrons/atoms can only exist in discrete/specific energy levels (in the sodium atoms) (1) • Electrons/atoms become excited **Or** Electrons/atoms move to higher energy levels (1) • The electrons/atoms then move to lower energy levels, giving out energy in the form of photons (1) • The energy of the photon is equal to the energy difference between the energy levels (1) • $E = hf$ and $\lambda = c/f$ so wavelength depends on the photon energy (1) • There are only certain energy transitions possible (between discrete levels) so only certain frequencies/wavelengths are visible. (1)	accept $E = hc / \lambda$ MP6 – Allow reference to few or limited number for 'certain'. Allow reference to discrete differences in energy levels.	6

(ii)	• Use of $n\lambda = d \sin\theta$ (1) • $d = 1.77 \times 10^{-6}$ m (1) • Choose $d = 2.0 \times 10^{-6}$ m as a smaller value than $d = 1.77 \times 10^{-6}$ m would cause greater diffraction angles so the third order would not be seen, but 3.3×10^{-6} m would produce smaller angles than 2.0×10^{-6} m, causing larger relative uncertainty in measurement (1) (1) **Or** • Use of $n\lambda = d \sin\theta$ • A correct value of sin θ or θ $d = 1.0 \times 10^{-6}$ m → 1.77 $d = 1.7 \times 10^{-6}$ m → 1.04 $d = 2.0 \times 10^{-6}$ m → 0.88 62.° $d = 3.3 \times 10^{-6}$ m → 0.535 32.° (1) • Choose $d = 2.0 \times 10^{-6}$ m. 1.7×10^{-6} m would give a sine value greater than 1, so no 3rd order is visible, and 3.3×10^{-6} m would produce smaller angles than 2.0×10^{-6} m, causing larger relative uncertainty in measurement (1)	Example of calculation $3 \times 5.89 \times 10^{-7}$ m = $d \sin 90°$ $d = 1.77 \times 10^{-6}$ m	3

Q27.

Question Number	Answer	Mark
	C - 1.5	1
	Incorrect Answers: all select incorrect data from question Correct method: image distance ÷ object distance A – uses focal length ÷ object distance B – uses object distance ÷ image distance D – uses object distance ÷ focal length	

Q28.

Question Number	Acceptable answers	Additional guidance	Mark
	• Use of lens equation $1/f = 1/v + 1/u$ (1) • Use of magnification = v/u (1) • Magnification = 15 (1)	Example of calculation 1/17.9 mm = 1/v + 1/16.7 mm v = (-)249 mm magnification = 249 mm / 16.7 mm = 14.9	3

Q29.

Question Number	Acceptable answers	Additional guidance	Mark
	C		1

Q30.

Question Number	Acceptable answers	Additional guidance	Mark
	The only correct answer is **A** because, using Einstein's photoelectric equation, $hf = \varphi + \frac{1}{2} mv^2_{max}$, since the work function is constant, an increase in frequency results in an increase in the maximum kinetic energy of the photoelectrons B is not correct because, using Einstein's photoelectric equation, $hf = \varphi + \frac{1}{2} mv^2_{max}$, intensity has no effect on the maximum kinetic energy of the photoelectrons, just the rate at which they are emitted C is not correct because , using Einstein's photoelectric equation, $hf = \varphi + \frac{1}{2} mv^2_{max}$, and since the work function is equal to (the Planck constant × threshold frequency), a higher threshold frequency will lead to a lower maximum kinetic energy of the photoelectrons D is not correct because, using Einstein's photoelectric equation, $hf = \varphi + \frac{1}{2} mv^2_{max}$, a higher work function will lead to a lower maximum kinetic energy of the photoelectrons		1