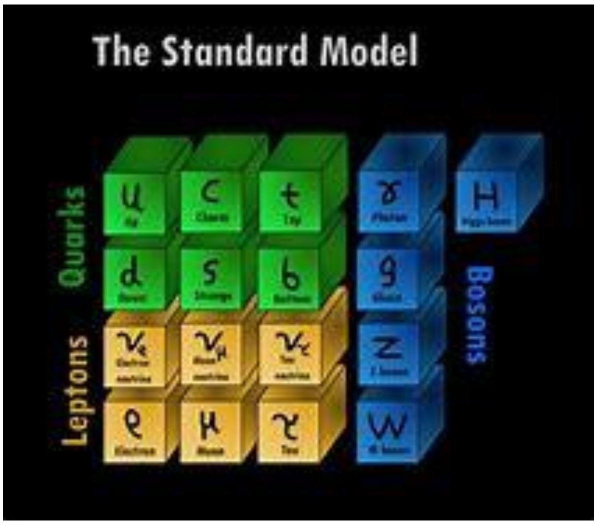


CfE Higher Physics

Particles & Waves

2015 to 2018 Past papers

1.

The emission of beta particles in radioactive decay is evidence for the existence of

A quarks

B electrons

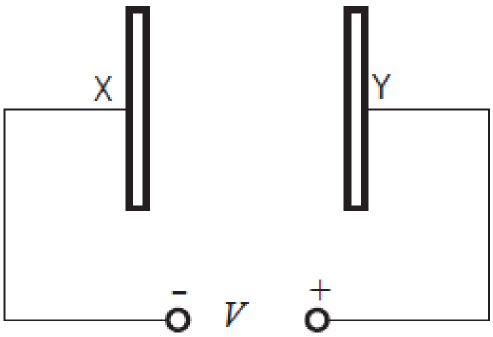
C gluons

D neutrinos

E bosons.

2

Two parallel metal plates X and Y in a vacuum have a potential difference V across them.



An electron of charge e and mass m, initially at rest, is released from plate X.

The speed of the electron when it reaches plate Y is given by

A $\frac{2eV}{m}$

B $\sqrt{\frac{2eV}{m}}$

C $\sqrt{\frac{2V}{em}}$

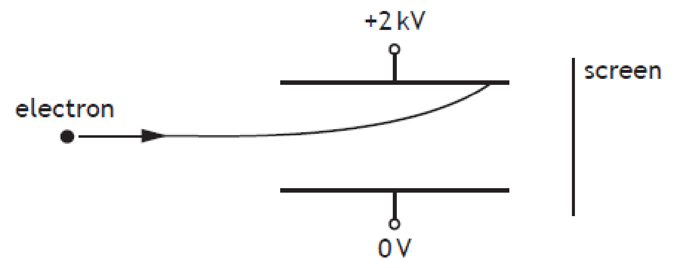
D $\frac{2V}{em}$

E $\frac{2mV}{e}$

3

A potential difference of 2 kV is applied across two metal plates.

An electron passes between the metal plates and follows the path shown.



A student makes the following statements about changes that could be made to allow the electron to pass between the plates and reach the screen.

I Increasing the initial speed of the electron could allow the electron to reach the screen.

II Increasing the potential difference across the plates could allow the electron to reach the screen.

III Reversing the polarity of the plates could allow the electron to reach the screen.

Which of these statements is/are correct?

A I only

B II only

C III only

D I and II only

E I and III only

4

One type of hadron consists of two down quarks and one up quark.

The charge on a down quark is −⅓.

The charge on an up quark is +⅔.

Which row in the table shows the charge and type for this hadron?

	charge	*type of hadron*
A	0	baryon
B	+1	baryon
C	−1	meson
D	0	meson
E	+1	meson

5.

A student makes the following statements about sub-nuclear particles.

I The force mediating particles are bosons.

II Gluons are the mediating particles of the strong force.

III Photons are the mediating particles of the electromagnetic force.

Which of these statements is/are correct?

A I only

B II only

C I and II only

D II and III only

E I, II and III

6

How many types of quark are there?

A 8

B 6

C 4

D 3

E 2

7

An electron is a

A boson

B hadron

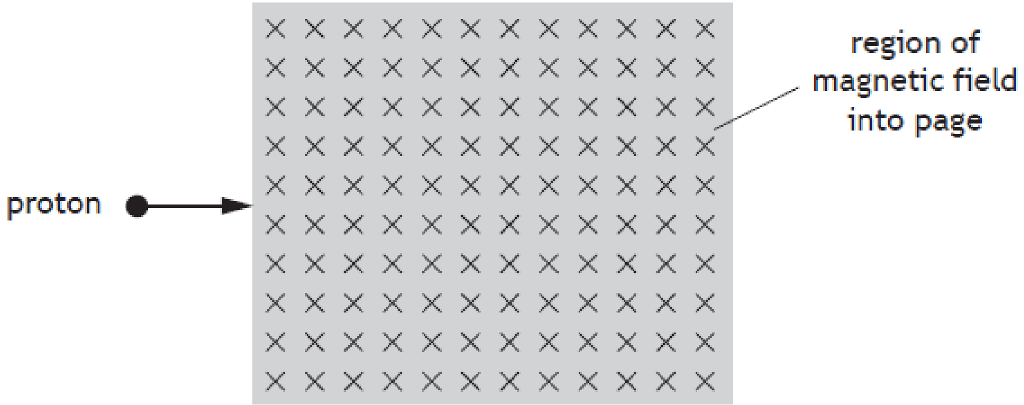
C baryon

D meson

E lepton.

8

A proton enters a region of magnetic field as shown.



On entering the magnetic field the proton

A deflects into the page

B deflects out of the page

C deflects towards the top of the page

D deflects towards the bottom of the page

E is not deflected.

9

The following statement describes a fusion reaction.

$${}^{2}_{1}H + {}^{2}_{1}H \rightarrow {}^{3}_{2}He + {}^{1}_{0}n + \text{energy}$$

The total mass of the particles before the reaction is $6{\cdot}684 \times 10^{-27}$ kg.

The total mass of the particles after the reaction is $6{\cdot}680 \times 10^{-27}$ kg.

The energy released in the reaction is

A $6{\cdot}012 \times 10^{-10}$ J

B $6{\cdot}016 \times 10^{-10}$ J

C $1{\cdot}800 \times 10^{-13}$ J

D $3{\cdot}600 \times 10^{-13}$ J

E $1{\cdot}200 \times 10^{-21}$ J.

10

The last two changes in a radioactive decay series are shown below.

A Bismuth nucleus emits a beta particle and its product, a Polonium nucleus, emits an alpha particle.

$$^{P}_{Q}\mathrm{Bi} \xrightarrow[\text{decay}]{\beta} {}^{R}_{S}\mathrm{Po} \xrightarrow[\text{decay}]{\alpha} {}^{208}_{82}\mathrm{Pb}$$

Which numbers are represented by P, Q, R and S?

	P	*Q*	*R*	*S*
A	210	83	208	81
B	210	83	210	84
C	211	85	207	86
D	212	83	212	84
E	212	85	212	84

11

The following statement represents a nuclear reaction.

$$^{256}_{103}\mathrm{Lr} \rightarrow \mathrm{Z} + {}^{4}_{2}\mathrm{He}$$

Nucleus Z is

A $^{252}_{101}\mathrm{Md}$

B $^{252}_{101}\mathrm{No}$

C $^{256}_{101}\mathrm{Md}$

D $^{260}_{105}\mathrm{Db}$

E $^{252}_{103}\mathrm{Lr}$.

12

A nuclear fission reaction is represented by the following statement.

$${}^{1}_{0}n + {}^{235}_{92}U \rightarrow {}^{141}_{56}Ba + X + 3\,{}^{1}_{0}n$$

The nucleus represented by X is

A $^{96}_{40}Zr$

B $^{92}_{36}Kr$

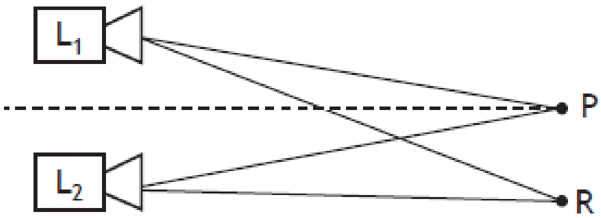
C $^{97}_{40}Zr$

D $^{93}_{36}Kr$

E $^{94}_{40}Zr$.

13

Two identical loudspeakers, L_1 and L_2, are operated at the same frequency and in phase with each other. An interference pattern is produced.



At position P, which is the same distance from both loudspeakers, there is a maximum.

The next maximum is at position R, where L_1R = 5·6 m and L_2R = 5·3 m.

The speed of sound in air is 340 m s^{-1}.

The frequency of the sound emitted by the loudspeakers is

A 8·8 × 10^{-4} Hz

B 3·1 × 10^{1} Hz

C 1·0 × 10^{2} Hz

D 1·1 × 10^{3} Hz

E 3·7 × 10^{3} Hz.

14

An experiment is carried out to measure the wavelength of red light from a laser.

The following values for the wavelength are obtained.

650 nm   640 nm   635 nm   648 nm   655 nm

The mean value for the wavelength and the approximate random uncertainty in the mean is

A (645 ± 1) nm

B (645 ± 4) nm

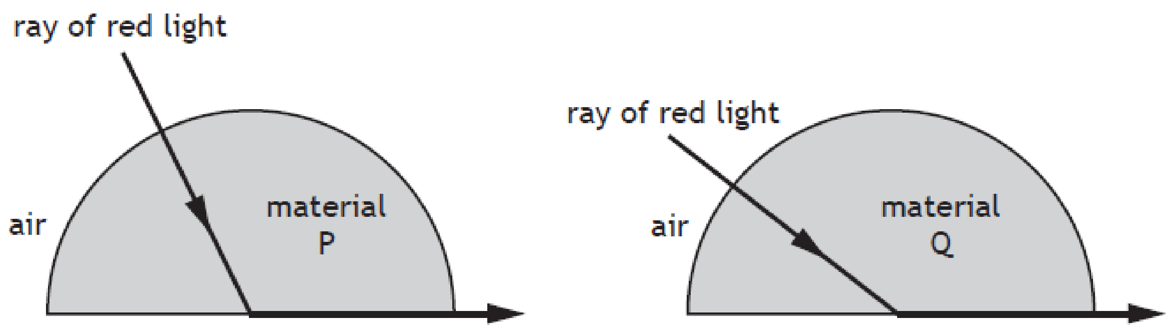
C (646 ± 1) nm

D (646 ± 4) nm

E (3228 ± 20) nm.

15

Red light is used to investigate the critical angle of two materials P and Q.



A student makes the following statements.

I Material P has a higher refractive index than material Q.

II The wavelength of the red light is longer inside material P than inside material Q.

III The red light travels at the same speed inside materials P and Q.

Which of these statements is/are correct?

A I only

B II only

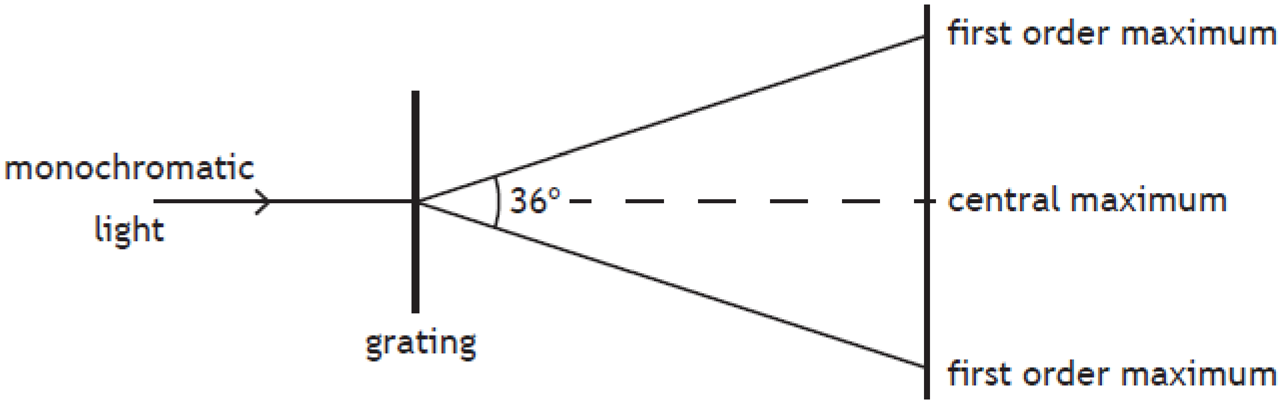
C III only

D I and II only

E I, II and III

16

A ray of monochromatic light is incident on a grating as shown.



The wavelength of the light is 633 nm.

The separation of the slits on the grating is

A $1{\cdot}96 \times 10^{-7}$ m

B $1{\cdot}08 \times 10^{-6}$ m

C $2{\cdot}05 \times 10^{-6}$ m

D $2{\cdot}15 \times 10^{-6}$ m

E $4{\cdot}10 \times 10^{-6}$ m.

17

Light travels from glass into air.

Which row in the table shows what happens to the speed, frequency and wavelength of the light as it travels from glass into air?

	Speed	*Frequency*	*Wavelength*
A	decreases	stays constant	decreases
B	decreases	increases	stays constant
C	stays constant	increases	increases
D	increases	increases	stays constant
E	increases	stays constant	increases

18

A student makes the following statements about waves from coherent sources.

I Waves from coherent sources have the same velocity.

II Waves from coherent sources have the same wavelength.

III Waves from coherent sources have a constant phase relationship.

Which of these statements is/are correct?

A I only

B II only

C I and II only

D I and III only

E I, II and III

19

A ray of red light passes from a liquid to a transparent solid.

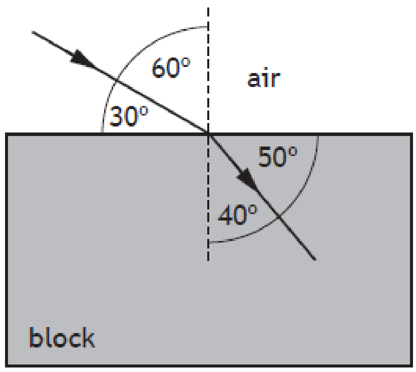
The solid and the liquid have the same refractive index for this light.

Which row in the table shows what happens to the speed and wavelength of the light as it passes from the liquid into the solid?

	Speed	*Wavelength*
A	decreases	decreases
B	decreases	increases
C	no change	increases
D	increases	no change
E	no change	no change

20

A ray of blue light passes from air into a transparent block as shown.



The speed of this light in the block is

A $1{\cdot}80 \times 10^8\,\text{m s}^{-1}$

B $1{\cdot}96 \times 10^8\,\text{m s}^{-1}$

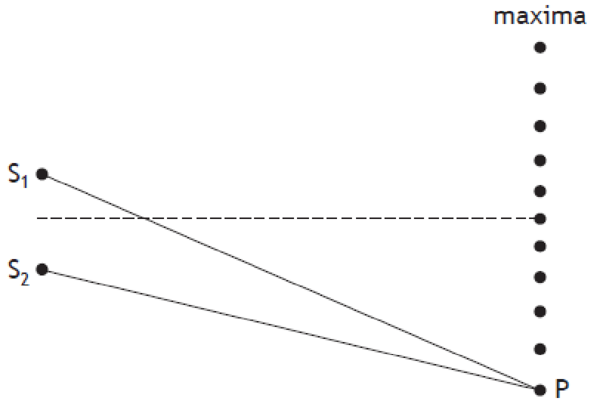
C $2{\cdot}00 \times 10^8\,\text{m s}^{-1}$

D $2{\cdot}23 \times 10^8\,\text{m s}^{-1}$

E $2{\cdot}65 \times 10^8\,\text{m s}^{-1}$.

21

Waves from two coherent sources, S_1 and S_2, produce an interference pattern. Maxima are detected at the positions shown below.



The path difference $S_1P - S_2P$ is 154 mm.

The wavelength of the waves is

A 15·4 mm

B 25·7 mm

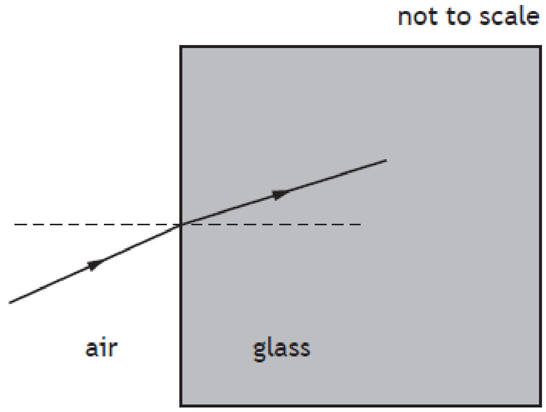
C 28·0 mm

D 30·8 mm

E 34·2 mm.

22

A ray of monochromatic light passes from air into a block of glass as shown.



The wavelength of this light in air is $6{\cdot}30 \times 10^{-7}$ m.

The refractive index of the glass for this light is 1·50.

The frequency of this light in the glass is

A $2{\cdot}10 \times 10^{-15}$ Hz

B $1{\cdot}26 \times 10^{2}$ Hz

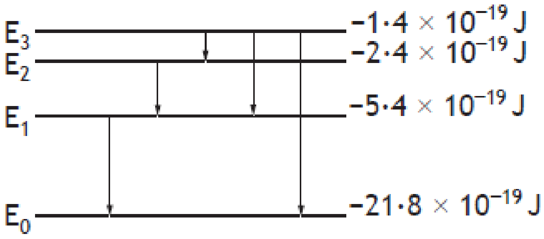
C $1{\cdot}89 \times 10^{2}$ Hz

D $4{\cdot}76 \times 10^{14}$ Hz

E $7{\cdot}14 \times 10^{14}$ Hz.

23

The diagram represents some electron transitions between energy levels in an atom.



The radiation emitted with the shortest wavelength is produced by an electron making transition

A E_1 to E_0

B E_2 to E_1

C E_3 to E_2

D E_3 to E_1

E E_3 to E_0.

24

The irradiance of light from a point source is $32\,W\,m^{-2}$ at a distance of 4·0 m from the source.

The irradiance of the light at a distance of 16 m from the source is

A $0{\cdot}125\,W\,m^{-2}$

B $0{\cdot}50\,W\,m^{-2}$

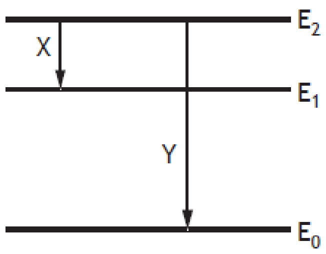
C $2{\cdot}0\,W\,m^{-2}$

D $8{\cdot}0\,W\,m^{-2}$

E $128\,W\,m^{-2}$.

25

Part of the energy level diagram for an atom is shown



X and Y represent two possible electron transitions.

A student makes the following statements about transitions X and Y.

I Transition Y produces photons of higher frequency than transition X

II Transition X produces photons of longer wavelength than transition Y

III When an electron is in the energy level E_0, the atom is ionised.

Which of the statements is/are correct?

A I only

B I and II only

C I and III only

D II and III only

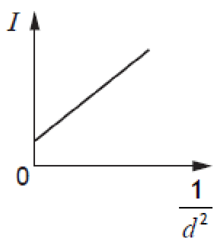
E I, II and III

26

A student carries out an experiment to investigate how irradiance varies with distance.

A small lamp is placed at a distance d away from a light meter. The irradiance I at this distance is displayed on the meter. This measurement is repeated for a range of different distances.

The student uses these results to produce the graph shown.



The graph indicates that there is a systematic uncertainty in this experiment.

Which of the following would be most likely to reduce the systematic uncertainty in this experiment?

A Repeating the readings and calculating mean values.

B Replacing the small lamp with a larger lamp.

C Decreasing the brightness of the lamp.

D Repeating the experiment in a darkened room.

E Increasing the range of distances.

27

A point source of light is 8·00 m away from a surface. The irradiance, due to the point source, at the surface is 50·0 mW m^{-2}. The point source is now moved to a distance of 12·0 m from the surface.

The irradiance, due to the point source, at the surface is now

A 22·2 mW m^{-2}

B 26·0 mW m^{-2}

C 33·3 mW m^{-2}

D 75·0 mW m^{-2}

E 267 mW m^{-2}.

28

The irradiance on a surface 0·50 m from a point source of light is I.

The irradiance on a surface 1·5 m from this source is

A 0·11I

B 0·33I

C 1·5I

D 3·0I

E 9·0I.

1	**D**	**11**	**A**	**21**	**D**
2	**B**	**12**	**B**	**22**	**D**
3	**A**	**13**	**D**	**23**	**E**
4	**A**	**14**	**D**	**24**	**C**
5	**E**	**15**	**A**	**25**	**B**
6	**B**	**16**	**C**	**26**	**D**
7	**E**	**17**	**E**	**27**	**A**
8	**C**	**18**	**E**	**28**	**A**
9	**D**	**19**	**E**		
10	**D**	**20**	**D**		

1

(a) The Standard Model classifies *force mediating particles* as bosons. Name the boson associated with the electromagnetic force. **1**

(b) In July 2012 scientists at CERN announced that they had found a particle that behaved in the way that they expected the Higgs boson to behave. Within a year this particle was confirmed to be a Higgs boson.

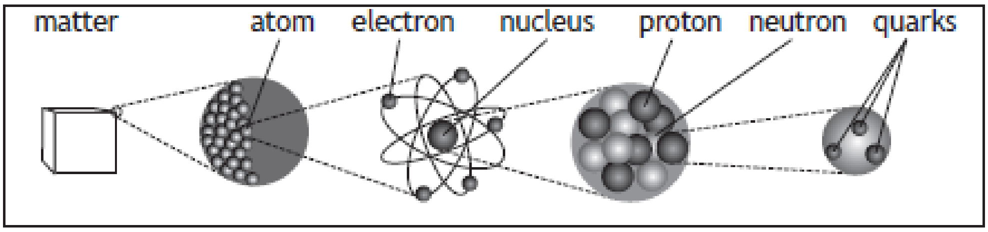
This Higgs boson had a mass-energy equivalence of 126 GeV.
($1\ \text{eV} = 1{\cdot}6 \times 10^{-19}\ \text{J}$)

(i) Show that the mass of the Higgs boson is $2{\cdot}2 \times 10^{-25}$ kg. **3**

(ii) Compare the mass of the Higgs boson with the mass of a proton in terms of orders of magnitude. **2**

2

The following diagram gives information on the Standard Model of fundamental particles.



(a) Explain why the proton and the neutron are not fundamental particles. **1**

(b) An extract from a data book contains the following information about three types of sigma (Σ) particles. Sigma particles are made up of three quarks.

Particle	*Symbol*	*Quark Content*	*Charge*	*Mean lifetime* (s)
sigma plus	Σ^+	up up strange	$+1e$	$8{\cdot}0 \times 10^{-11}$
neutral sigma	Σ^0	up down strange	0	$7{\cdot}4 \times 10^{-20}$
sigma minus	Σ^-	down down strange	$-1e$	$1{\cdot}5 \times 10^{-10}$

(i) A student makes the following statement.

All baryons are hadrons, but not all hadrons are baryons.

Explain why this statement is correct. **2**

(ii) The charge on an up quark is $+\frac{2}{3}e$.

Determine the charge on a strange quark. 1

(c) (i) State the name of the force that holds the quarks together in the sigma (Σ) particle. 1

(ii) State the name of the boson associated with this force. 1

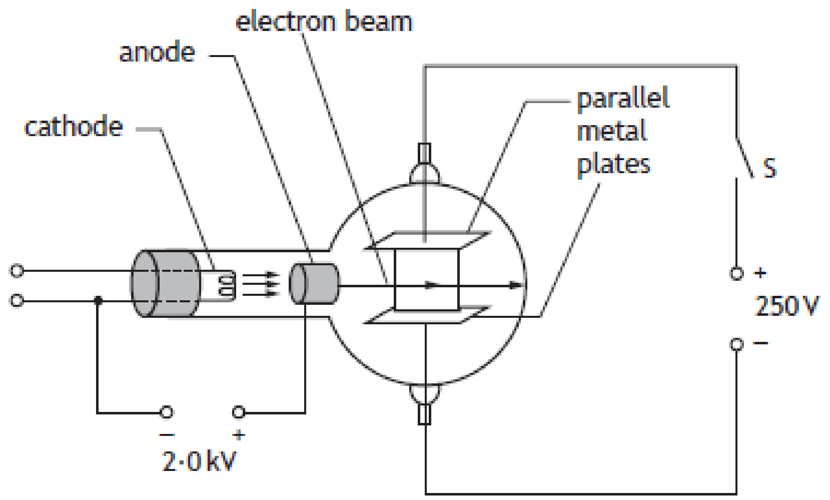
(d) Sigma minus (Σ^-) particles have a mean lifetime of $1\cdot5 \times 10^{-10}$ s in their frame of reference.

Σ^- are produced in a particle accelerator and travel at a speed of $0\cdot9c$ relative to a stationary observer.

Calculate the mean lifetime of the Σ^- particle as measured by this observer. 3

3

An experiment is set up to investigate the behaviour of electrons in electric fields.



(a) Electrons are accelerated from rest between the cathode and the anode by a potential difference of 2·0 kV.

Calculate the kinetic energy gained by each electron as it reaches the anode. 3

(b) The electrons then pass between the two parallel metal plates.

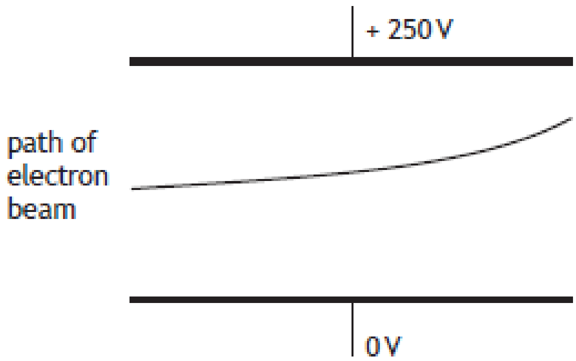
The electron beam current is 8·0 mA.

Determine the number of electrons passing between the metal plates in one minute. 4

(c) The switch S is now closed.

The potential difference between the metal plates is 250 V.

The path of the electron beam between the metal plates is shown.



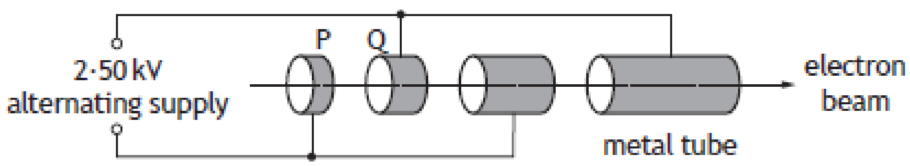
Complete the diagram to show the electric field pattern between the two metal plates. **1**

4

X-ray machines are used in hospitals.

An X-ray machine contains a linear accelerator that is used to accelerate electrons towards a metal target.

The linear accelerator consists of hollow metal tubes placed in a vacuum.



Electrons are accelerated across the gaps between the tubes by an alternating supply.

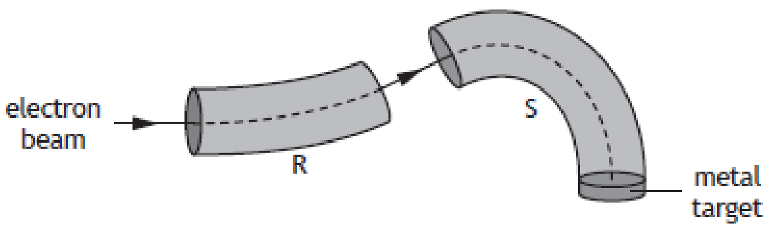
(a) (i) Calculate the work done on an electron as it accelerates from P to Q. 3

(ii) Explain why an alternating supply is used in the linear accelerator. **1**

(b) The electron beam is then passed into a "slalom magnet" beam guide. The function of the beam guide is to direct the electrons towards a metal target.

Inside the beam guides R and S, two different magnetic fields act on the electrons.

Electrons strike the metal target to produce high energy photons of radiation.



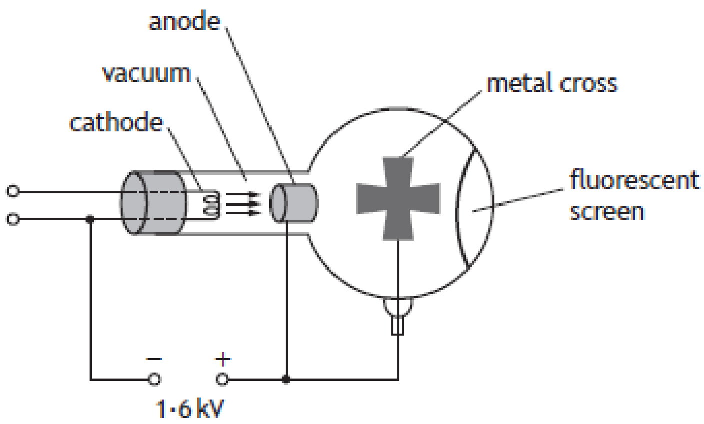
(i) Determine the direction of the magnetic field inside beam guide R. 1

(ii) State two differences between the magnetic fields inside beam guides R and S. 2

(c) Calculate the minimum speed of an electron that will produce a photon of energy $4{\cdot}16 \times 10^{-17}$ J. 3

5

An experiment is set up to demonstrate a simple particle accelerator.



(a) Electrons are accelerated from rest between the cathode and the anode by a potential difference of 1·6 kV.

(i) Show that the work done in accelerating an electron from rest is $2{\cdot}6 \times 10^{-16}$ J. 2

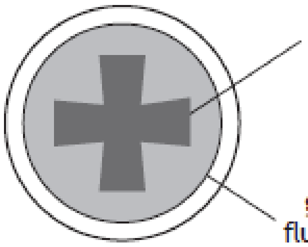
(ii) Calculate the speed of the electron as it reaches the anode. 3

(b) As the electrons travel through the vacuum towards the fluorescent screen they spread out.

In the path of the electrons there is a metal cross, which is connected to the positive terminal of the supply. The electrons that hit the cross are stopped by the metal.

Electrons that get past the metal cross hit a fluorescent screen at the far side of the tube.

When electrons hit the fluorescent screen, the screen glows.

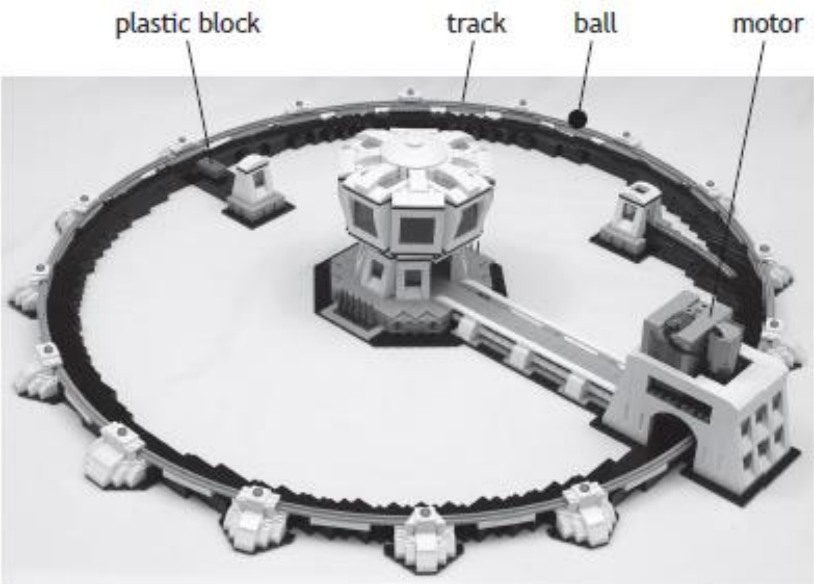


The potential difference between the anode and the cathode is now increased to 2·2 kV. This changes what is observed on the screen.

Suggest one change that is observed. 2

You must justify your answer.

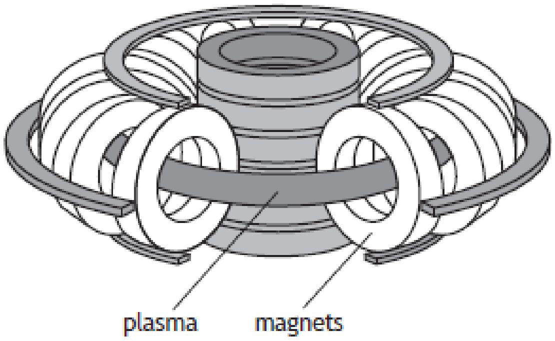
(c) A student builds a model of a particle accelerator. The model accelerates a small ball on a circular track. A battery-operated motor accelerates the ball each time it passes the motor. To cause a collision a plastic block is pushed onto the track. The ball then hits the block.



Using your knowledge of physics comment on the model compared to a real particle accelerator, such as the large hadron collider at CERN. 3

6

The diagram shows part of an experimental fusion reactor.



The following statement represents a reaction that takes place inside the reactor.

$$^{2}_{1}H + ^{3}_{1}H \rightarrow ^{4}_{2}He + ^{1}_{0}n$$

The masses of the particles involved in the reaction are shown in the table.

Particle	*Mass* (kg)
$^{2}_{1}H$	$3{\cdot}3436 \times 10^{-27}$
$^{3}_{1}H$	$5{\cdot}0083 \times 10^{-27}$
$^{4}_{2}He$	$6{\cdot}6465 \times 10^{-27}$
$^{1}_{0}n$	$1{\cdot}6749 \times 10^{-27}$

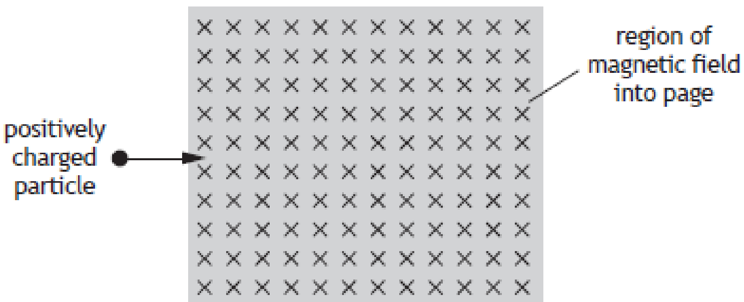
(a) Explain why energy is released in this reaction. **1**

(b) Calculate the energy released in this reaction. **4**

(c) Magnetic fields are used to contain the plasma inside the fusion reactor.

Explain why it is necessary to use a magnetic field to contain the plasma. **1**

(d) The plasma consists of charged particles. A positively charged particle enters a region of the magnetic field as shown.

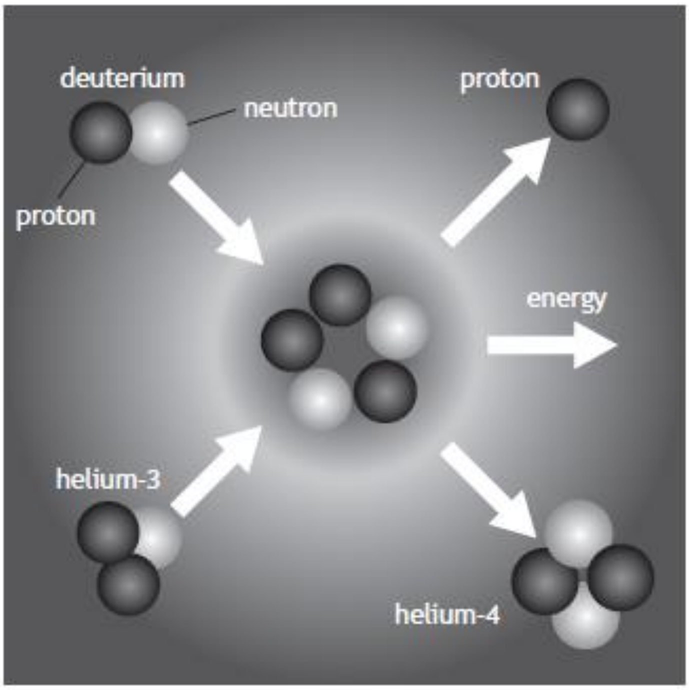


Determine the direction of the force exerted by the magnetic field on the positively charged particle as it enters the field. **1**

7.

A diagram from a 'How Things Work' website contains information about a nuclear fusion reaction.

Reaction of helium-3 with deuterium



(a) State what is meant by the term *nuclear fusion*. **1**

(b) The following statement represents this fusion reaction.

$$^{3}_{2}\text{He} + ^{2}_{1}\text{H} \rightarrow ^{4}_{2}\text{He} + ^{1}_{1}\text{p}$$

The mass of the particles involved in the reaction are shown in the table.

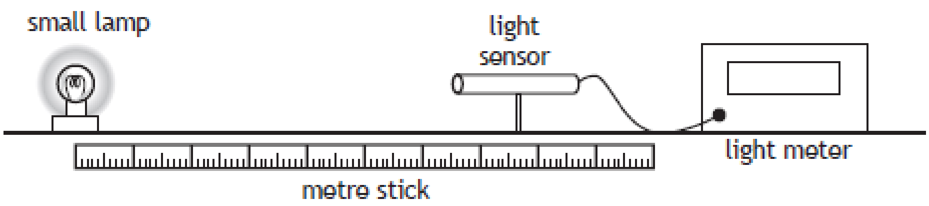
Particle	*Mass* (kg)
$^{3}_{2}\text{He}$	$5{\cdot}008 \times 10^{-27}$
$^{2}_{1}\text{H}$	$3{\cdot}344 \times 10^{-27}$
$^{4}_{2}\text{He}$	$6{\cdot}646 \times 10^{-27}$
$^{1}_{1}\text{p}$	$1{\cdot}673 \times 10^{-27}$

(i) Explain why energy is released in this reaction. **1**

(ii) Determine the energy released in this reaction. **4**

8.

A student investigates how irradiance I varies with distance d from a point source of light.



The distance between a small lamp and a light sensor is measured with a metre stick. The irradiance is measured with a light meter.

The apparatus is set up as shown in a darkened laboratory.

The following results are obtained.

d (m)	0·20	0·30	0·40	0·50
I ($W m^{-2}$)	134·0	60·5	33·6	21·8

(a) State what is meant by the term *irradiance*. 1

(b) Use all the data to establish the relationship between irradiance I and distance d. 3

(c) The lamp is now moved to a distance of 0·60 m from the light sensor.

Calculate the irradiance of light from the lamp at this distance. 3

Space for working and answer

(d) Suggest one way in which the experiment could be improved.

You must justify your answer. 2

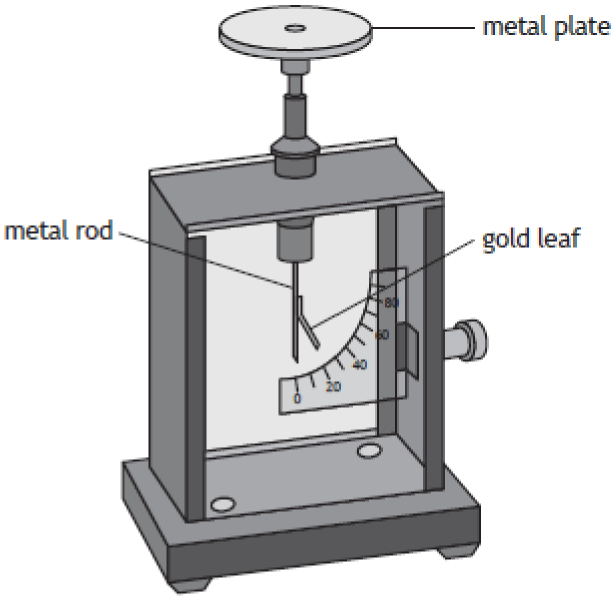
(e) The student now replaces the lamp with a different small lamp. The power output of this lamp is 24 W.

Calculate the irradiance of light from this lamp at a distance of 2·0 m. 4

9.

A student uses a gold-leaf electroscope to investigate the photoelectric effect. A deflection of the gold leaf on the electroscope shows that the metal plate is charged.

The student charges the metal plate on the electroscope and the gold leaf is deflected.



gold-leaf electroscope

(a) Ultraviolet light is shone onto the negatively charged metal plate. The gold-leaf electroscope does not discharge. This indicates that photoelectrons are not ejected from the surface of the metal.

Suggest one reason why photoelectrons are not ejected from the surface of the metal. **1**

(b) The student adjusts the experiment so that the gold-leaf electroscope now discharges when ultraviolet light is shone onto the plate.

The work function for the metal plate is $6 \cdot 94 \times 10^{-19}$ J.

(i) State what is meant by a *work function of* $6 \cdot 94 \times 10^{-19}$ *J*. **1**

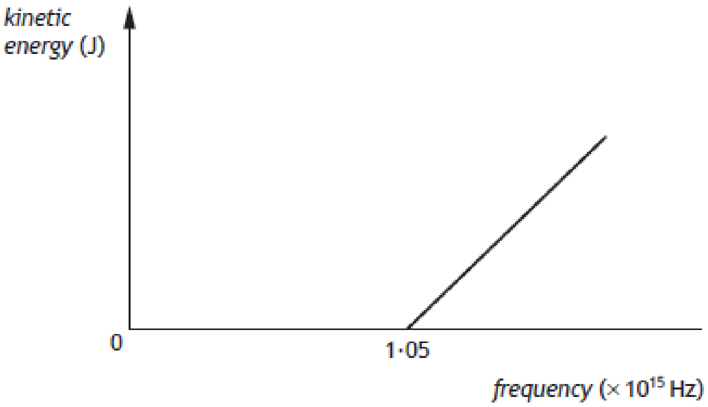
(ii) The irradiance of the ultraviolet light on the metal plate is reduced by increasing the distance between the gold-leaf electroscope and the ultraviolet light source.

State what effect, if any, this has on the maximum kinetic energy of the photoelectrons ejected from the surface of the metal. **2**

Justify your answer.

(c) The graph shows how the kinetic energy of the photoelectrons ejected from the metal plate varies as the frequency of the incident radiation increases.

The threshold frequency for the metal plate is $1{\cdot}05 \times 10^{15}$ Hz.



The metal plate is now replaced with a different metal plate made of aluminium.

The aluminium has a threshold frequency of $0{\cdot}99 \times 10^{15}$ Hz.

Add a line to the graph to show how the kinetic energy of the photoelectrons ejected from the aluminium plate varies as the frequency of the incident radiation increases. 2

(An additional graph, if required, can be found on *page 45*.)

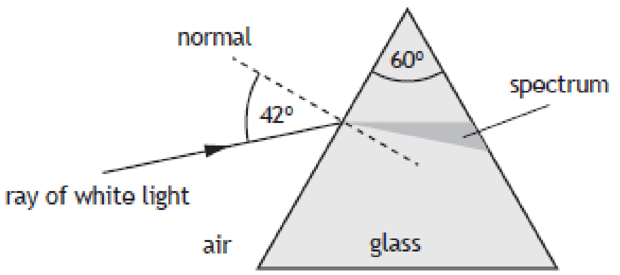
(d) Explain why the photoelectric effect provides evidence for the particle nature of light. 1

10.

A student carries out two experiments to investigate the spectra produced from a ray of white light.

(a) In the first experiment, a ray of white light is incident on a glass prism as shown.

not to scale

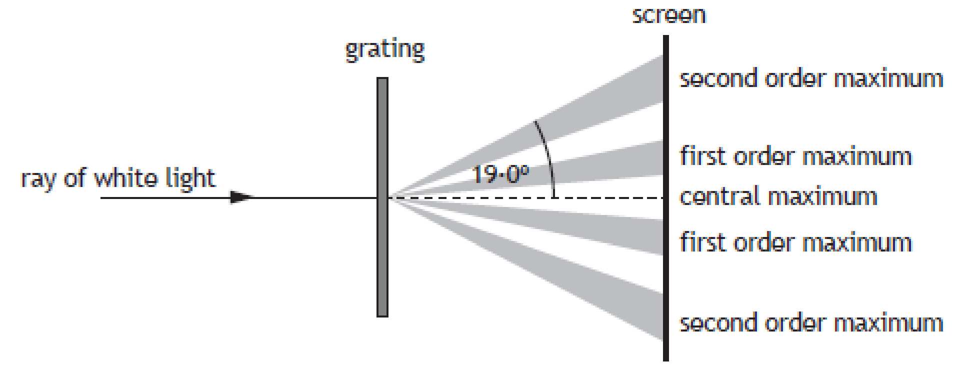


(i) Explain why a spectrum is produced in the glass prism. 1

(ii) The refractive index of the glass for red light is 1·54.

Calculate the speed of red light in the glass prism. 3

(b) In the second experiment, a ray of white light is incident on a grating.



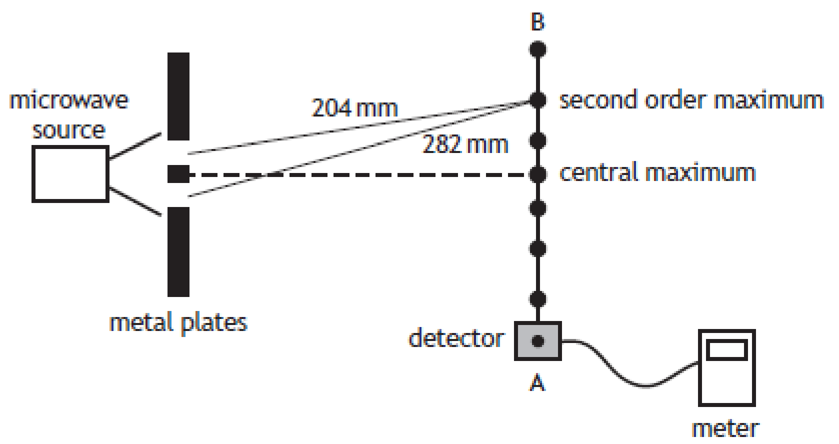
The angle between the central maximum and the second order maximum for red light is 19·0°.
The frequency of this red light is $4{\cdot}57 \times 10^{14}$ Hz.

(i) Calculate the distance between the slits on this grating. 5

(ii) Explain why the angle to the second order maximum for blue light is different to that for red light. 3

11

A student carries out an experiment to measure the wavelength of microwave radiation. Microwaves pass through two gaps between metal plates as shown.



As the detector is moved from A to B, a series of maxima and minima are detected.

(a) The microwaves passing through the gaps are coherent.

State what is meant by the term *coherent*. 1

(b) Explain, in terms of waves, how a maximum is produced. 1

(c) The measurements of the distance from each gap to the second order maximum are shown in the diagram above.

Calculate the wavelength of the microwaves. 3

(d) The distance separating the two gaps is now increased.

State what happens to the path difference to the second order maximum.

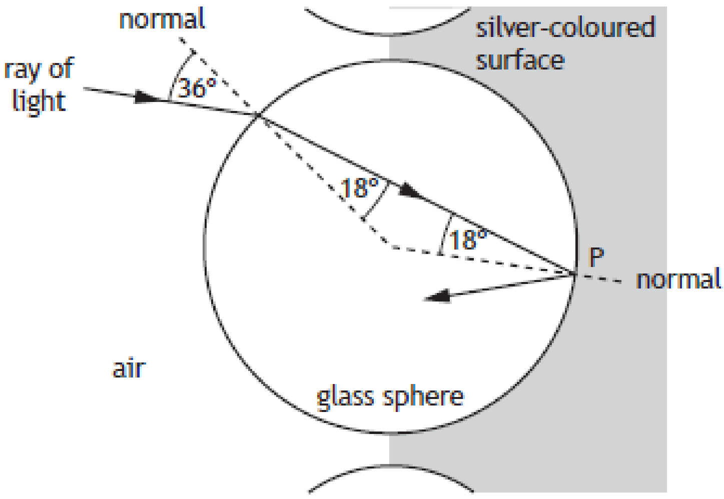
Justify your answer. 2

12

Retroflective materials reflect light to enhance the visibility of clothing.

One type of retroflective material is made from small glass spheres partially embedded in a silver-coloured surface that reflects light.

A ray of monochromatic light follows the path shown as it enters one of the glass spheres.



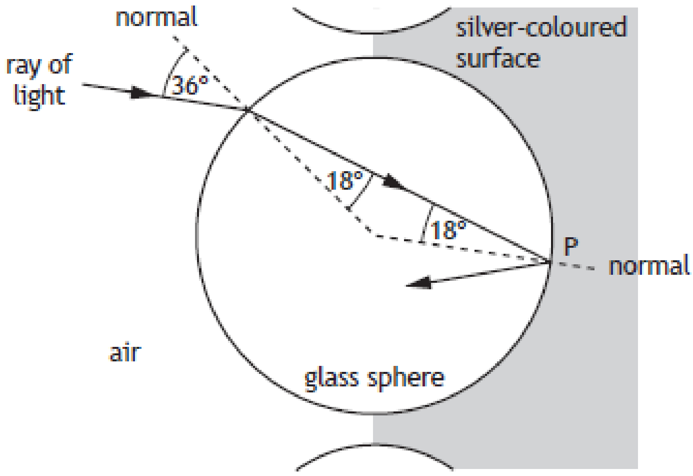
(a) Calculate the refractive index of the glass for this light. 3

(b) Calculate the critical angle for this light in the glass. 3

Space for working and answer

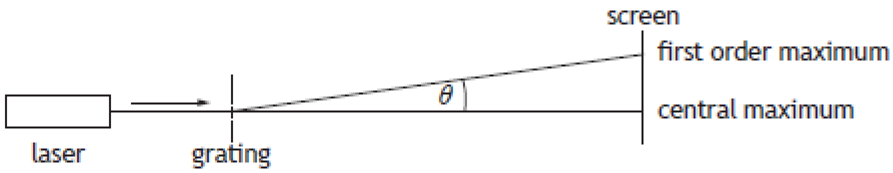
(c) The light is reflected at point P.

Complete the diagram below to show the path of the ray as it passes through the sphere and emerges into the air. 1



13

An experiment is carried out to determine the wavelength of light from a laser.



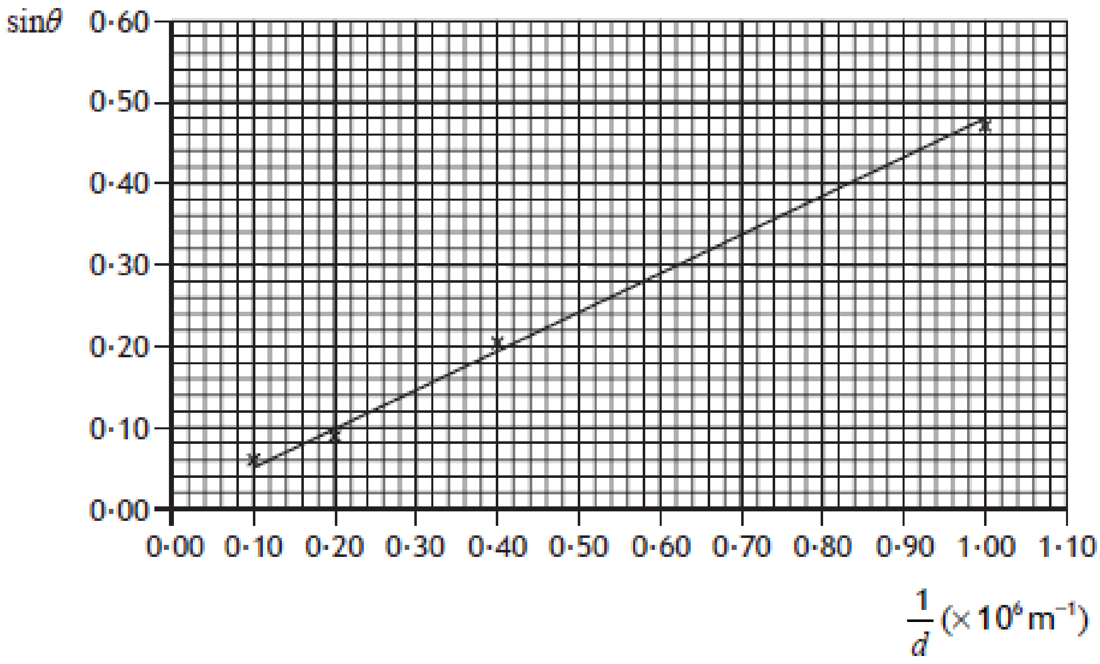
(a) Explain, in terms of waves, how a maximum is formed. 1

(b) The experiment is carried out with four gratings.

The separation of the slits d is different for each grating.

The angle between the central maximum and the first order maximum θ, produced by each grating, is measured.

The results are used to produce a graph of $\sin\theta$ against $\frac{1}{d}$.



(i) Determine the wavelength of the light from the laser used in this experiment. 3

Space for working and answer

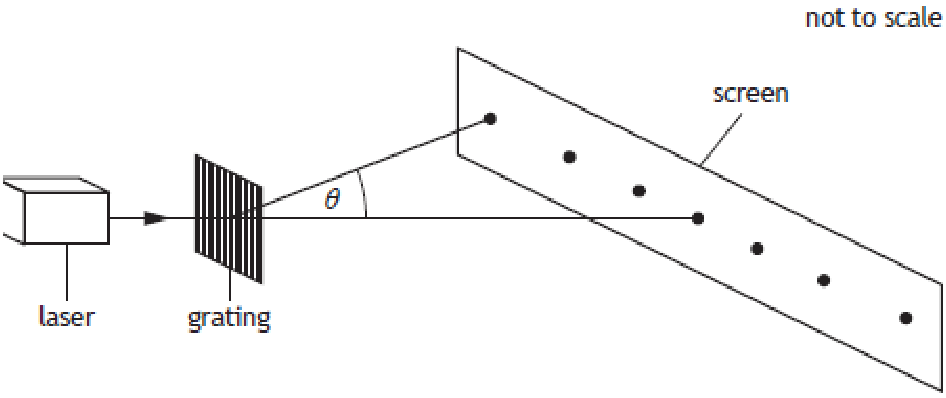
(ii) Determine the angle θ produced when a grating with a spacing d of $2{\cdot}0 \times 10^{-6}$ m is used with this laser. 3

Space for working and answer

(c) Suggest two improvements that could be made to the experiment to improve reliability. 2

14.

A student investigates interference of light by directing laser light of wavelength 630 nm onto a grating as shown.



(a) A pattern of bright spots is observed on a screen.

(i) Explain, in terms of waves, how bright spots are produced on the screen. 1

(ii) The grating has 250 lines per millimetre.

Calculate the angle θ between the central maximum and the third order maximum. 3

(iii) The grating is now replaced by one which has 600 lines per millimetre.

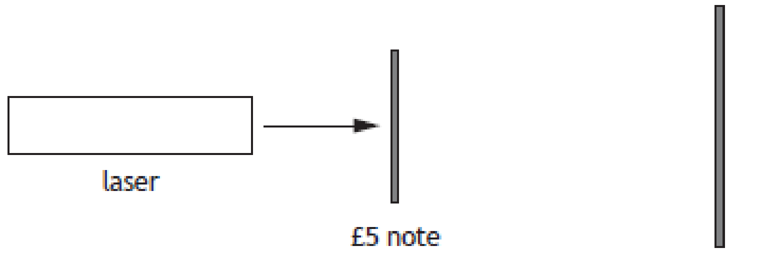
State the effect of this change on the pattern observed. 2

Justify your answer.

(iv) The interference pattern is produced by coherent light.

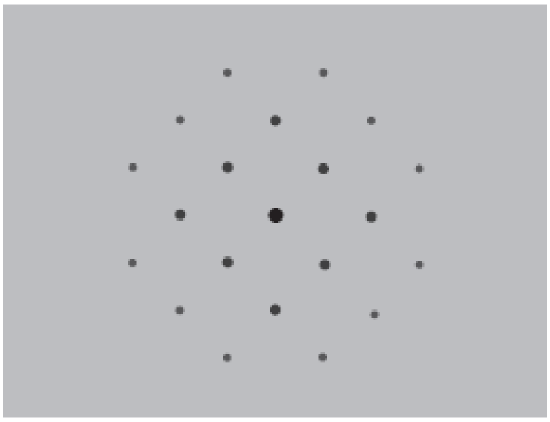
State what is meant by the term *coherent*. 1

(b) The student now shines light from the laser onto a £5 note.



When it is shone through the transparent section of the note the student observes a pattern of bright spots on the screen.

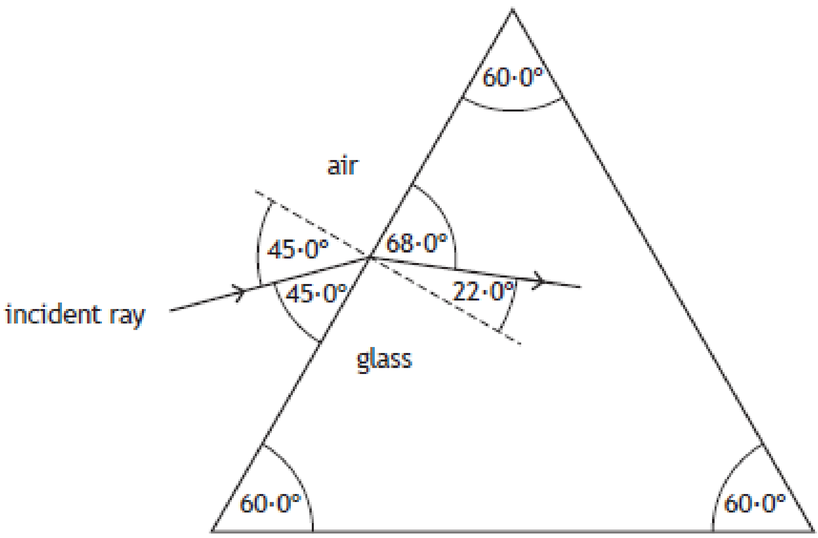
The diagram below shows the pattern that the student observes on the screen.



Suggest a reason for the difference in the pattern produced using the £5 note and the pattern produced using the grating. **1**

15

A ray of monochromatic light is incident on a glass prism as shown.



(a) Show that the refractive index of the glass for this ray of light is 1·89. **2**

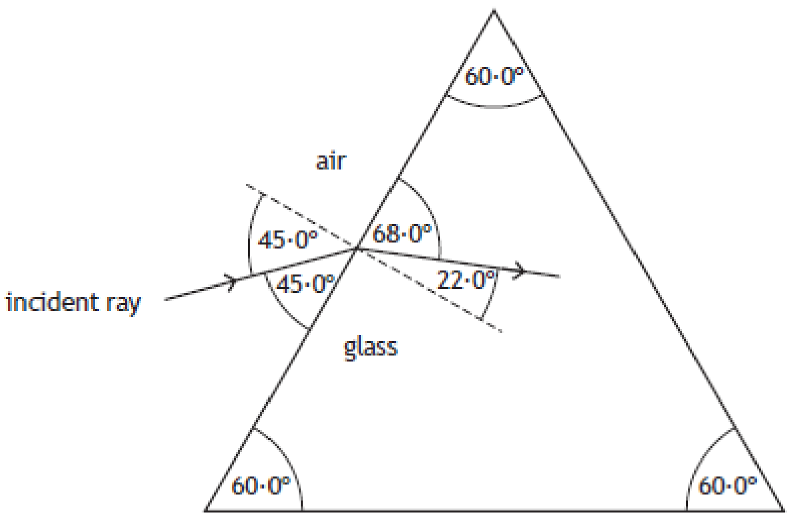
(b) (i) State what is meant by the term *critical angle*. 1

(ii) Calculate the critical angle for this light in the prism. 3

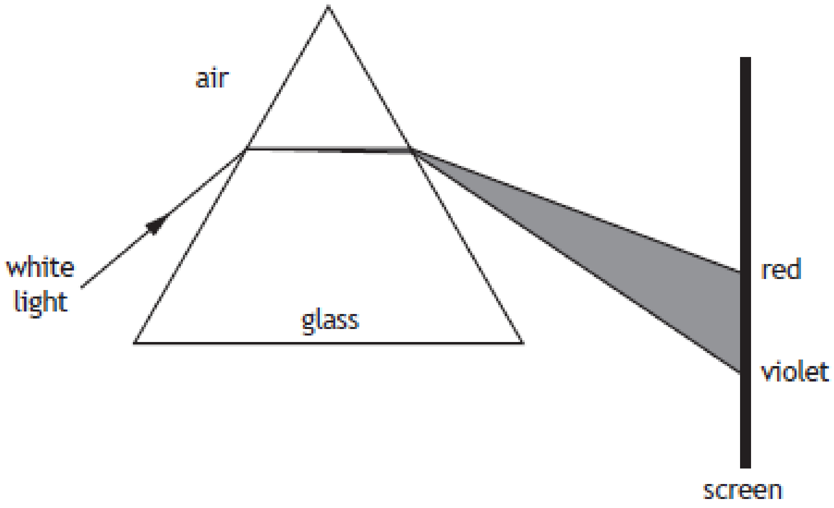
Space for working and answer

(iii) Complete the diagram below to show the path of the ray as it passes through the prism and emerges into the air.

Mark on the diagram the values of all relevant angles. 4



(c) A ray of white light is shone through the prism and a spectrum is observed as shown.



The prism is now replaced with another prism made from a different type of glass with a lower refractive index.

Describe one difference in the spectrum produced by this prism compared to the spectrum produced by the first prism. **1**

1

(a)		Photon	1	
(b)	(i)	$126 \text{ GeV} = 126 \times 10^{9} \times (1{\cdot}6 \times 10^{-19})$ **(1)** $= 2{\cdot}0 \times 10^{-8}$ (J) $E = mc^2$ **(1)** $2{\cdot}0 \times 10^{-8} = m \times (3 \times 10^{8})^2$ **(1)** $m = 2{\cdot}2 \times 10^{-25}$ (kg)	3	If candidate does not show this line, either separately or in the formula, then max 2 marks may be awarded. -anywhere Alternative: $E = mc^2$ **(1)** $126 \times 10^{9} \times (1{\cdot}6 \times 10^{-19}) = m \times (3 \times 10^{8})^2$ **(1)** $m = 2{\cdot}2 \times 10^{-25}$ (kg) Max 2 marks if final answer not given
	(ii)	$(2{\cdot}2 \times 10^{-25} / 1{\cdot}673 \times 10^{-27} =)130$ **(1)** (Higgs boson is) <u>2</u> orders of magnitude <u>bigger</u> **(1)**	2	or $10^{-25}/10^{-27} = 100$ or $2{\cdot}2 \times 10^{-25} / 1{\cdot}67 \times 10^{-27} =$ or $2{\cdot}2 \times 10^{-25} / 1{\cdot}7 \times 10^{-27} =$ or $2{\cdot}24 \times 10^{-25} / 1{\cdot}673 \times 10^{-27} =$ etc

2

(a)		They are composed of other particles/quarks, (fundamental particles are not).	1	Accept they are composite particles.
(b)	(i)	Baryons are (hadrons as they are) composed of (three) quarks. 1 Mesons/some hadrons are made from a quark - anti-quark pair so are not baryons. 1	2	For first mark, a correct statement that baryons consist of quarks. For second mark, a correct statement that there are other hadrons that have a different quark-count from baryons. Accept two quarks in place of quark-anti-quark pair.
	(ii)	- 1/3(e)	1	
(c)	(i)	strong (nuclear force)	1	
	(ii)	gluon	1	Or consistent with (c)(i). A carry forward mark is only accessible if one of the four fundamental forces is identified in (c)(i).
(d)		$t' = \frac{t}{\sqrt{1-\left(\frac{v}{c}\right)^2}}$ 1 $t' = \frac{1{\cdot}5\times10^{-10}}{\sqrt{1-\frac{(0{\cdot}9c)^2}{c^2}}}$ 1 $t' = 3{\cdot}4\times10^{-10}$ s 1	3	Accept: 3, 3·44, 3·441 Accept: $\frac{1{\cdot}5\times10^{-10}}{\sqrt{1-0{\cdot}9^2}}$

3

(a)		$W = QV$ (1) $= 1{\cdot}6 \times 10^{-19} \times 2000$ (1) $= 3{\cdot}2 \times 10^{-16}$ J (1)	3	Sig figs: Accept 3×10^{-16}, $3{\cdot}20 \times 10^{-16}$, $3{\cdot}200 \times 10^{-16}$, Ignore negative sign for charge.
(b)		$Q = It$ (1) $= 0{\cdot}008 \times 60$ (1) $= 0{\cdot}48$ (C) (1) $number = \frac{0{\cdot}48}{1{\cdot}6 \times 10^{-19}}$ $= 3{\cdot}0 \times 10^{18}$ (1)	4	Sig figs: Accept 3×10^{18} If the response stops at 0·48 then a correct unit is required. Candidates can arrive at this answer by alternative methods eg P=IV and E=Pt OR Q=It to calculate the time for 1 electron.
(c)		Straight lines with arrows pointing downwards.	1	spacing should be approximately equal (ignore end effect) Field lines must start and finish on the plates Lines at right angles to the plates

4

(a)	(i)	W or $E_W = QV$ 1 $= 1{\cdot}60 \times 10^{-19} \times 2{\cdot}50 \times 10^{3}$ 1 $= 4{\cdot}00 \times 10^{-16}$ J 1	3	Suspend significant figure rule and accept 4×10^{-16} J. Ignore negative sign for charge.
	(ii)	Particle (always) accelerates in the same direction/forwards OR Force on particle/electron is always in same direction OR Ensure the direction of the electric field is correct when particle/electron passes between (alternate) gaps	1	Candidate must make some implication of 'same direction'.
(b)	(i)	Out of page	1	Do not accept: 'upwards' on its own, OR 'out of the page' with other comments such ad 'circular' 'clockwise'.

	(ii)	(Magnetic fields are in) <u>opposite</u> directions 1 (Magnetic field in) S is <u>stronger</u> than (field in) R 1	2	Independent marks Or consistent with (b)(i) for first mark as long as a <u>linear</u> field is described. Accept statement referring to direction of (magnetic field in) S alone ONLY if (b)(i) has been answered. Do not accept: 'different directions' 'force in S is opposite to force in R' alone.
(c)		$E_K = \frac{1}{2}mv^2$ 1 $4{\cdot}16 \times 10^{-17} = \frac{1}{2} \times 9{\cdot}11 \times 10^{-31} \times v^2$ 1 $v = 9{\cdot}56 \times 10^6$ ms^{-1} 1	3	Accept: 9·6, 9·557, 9·5566

5

(a)	(i)	$W = QV$ (1) $W = 1{\cdot}60 \times 10^{-19} \times 1600$ (1) $W = 2{\cdot}6 \times 10^{-16}$ J	2	"SHOW" question
	(ii)	$E_K = \frac{1}{2}mv^2$ (1) $2{\cdot}6 \times 10^{-16} = \frac{1}{2} \times 9{\cdot}11 \times 10^{-31} \times v^2$ (1) $v = 2{\cdot}4 \times 10^7$ m s^{-1} (1)	3	Accept: 2, 2·39, 2·389
(b)		Screen will be brighter/increase glow. (1) Electrons will gain more energy/move faster. OR Increase in number of electrons <u>per second</u>. (1)	2	Look for correct statement of effect first - if incorrect or missing then 0 marks. Accept: Circle of brightness on fluorescent screen is reduced. (1) Greater force of attraction on the electrons due to the cross. (1) OR Cross on screen is sharper. (1) Greater force of attraction on the electrons due to the cross. (1) 'increase in current' alone is insufficient for the justification. Any correct statement followed by wrong physics, 0 marks. Any correct statement followed by no justification, 0 marks.

6

(a)		mass is converted into energy	1	There must be a link between mass and energy. Mass is lost on its own - 0 marks Mass defect is wrong physics - 0 marks Energy is released or equivalent is not sufficient.
(b)		$m_{before} = 3 \cdot 3436 \times 10^{-27} + 5 \cdot 0083 \times 10^{-27}$ $= 8 \cdot 3519 \times 10^{-27}$ (kg) $m_{after} = 6 \cdot 6465 \times 10^{-27} + 1 \cdot 6749 \times 10^{-27}$ $= 8 \cdot 3214 \times 10^{-27}$ (kg) $\Delta m = 3 \cdot 0500 \times 10^{-29}$ (kg) (1) $E = mc^2$ (1) $= 3 \cdot 0500 \times 10^{-29} \times (3 \cdot 00 \times 10^8)^2$ (1) $= 2 \cdot 75 \times 10^{-12}$ J (1)	4	$E = mc^2$ anywhere - 1 mark. If mass before and after not used to 5 significant figures from table then stop marking - maximum 1 mark for formula Arithmetic mistake can be carried forward Truncation error in mass before and/or mass after- maximum 1 mark for formula Sig figs: $2 \cdot 7$, $2 \cdot 745$, $2 \cdot 7450$ If finding $E = mc^2$ for each particle, then $E = mc^2$ (1) All substitutions (1) Subtraction (1) Final answer (1)
(c)		Plasma would cool down if it came too close to the sides (and reaction would stop)	1	(Reaction requires very high temperature), so plasma would melt the sides of the reactor **OR** High temperature plasma could damage/ destroy the container
(d)		Up the page	1	Accept up and upwards Arrow drawn pointing up the page is acceptable If upwards arrow is drawn on the original diagram, it must be on the left hand edge The path of the particle on its own is not acceptable

7

(a)		(Two) small nuclei combine to form a larger nucleus	1	Accept: 'light' and 'heavy'. Accept: 'fuse', 'join' Do not accept: Atoms/molecules/particles/ isotopes/elements. Do not accept: 'react' in place of 'combine' or equivalent of 'combining'.
(b)	(i)	(Some) mass (is lost and) converted to energy	1	There must be an indication of mass being converted (or an equivalent term) to energy e.g. transformed, becomes, changed to etc…

(b)	(ii)	Mass before: $5{\cdot}008 \times 10^{-27} + 3{\cdot}344 \times 10^{-27}$ $= 8{\cdot}352 \times 10^{-27}$ Mass after: $6{\cdot}646 \times 10^{-27} + 1{\cdot}673 \times 10^{-27}$ $= 8{\cdot}319 \times 10^{-27}$ Mass "lost": $0{\cdot}033 \times 10^{-27}$ (kg) 1 $E = mc^2$ 1 $E = 0{\cdot}033 \times 10^{-27} \times (3{\cdot}00 \times 10^8)^2$ 1 $E = 2{\cdot}97 \times 10^{-12}$ J 1	4	$E = mc^2$ anywhere, 1 mark. Accept: 3·0, 2·970, 2·9700 Do not accept 3. Check for correct substitutions of values in calculation of mass "lost". If values are incorrect, maximum 1 mark for formula, even if final answer is correct. If mass before and after not used to 4 significant figures from table then stop marking - maximum 1 mark for formula. Ignore inappropriate reference to mass defect. Arithmetic mistake can be carried forward. Truncation error in mass before and/or mass after - maximum 1 mark for formula. If finding $E = mc^2$ for each particle, then $E = mc^2$ 1 All substitutions 1 Subtraction 1 Final answer 1

8

(a)		The power per unit area (incident on a surface)	1	Accept power per square metre (m^2)
(b)		$134 \times 0{\cdot}2^2 = 5{\cdot}4$ $60{\cdot}5 \times 0{\cdot}3^2 = 5{\cdot}4$ $33{\cdot}6 \times 0{\cdot}4^2 = 5{\cdot}4$ $21{\cdot}8 \times 0{\cdot}5^2 = 5{\cdot}5$ (2) Statement of $I \times d^2$ = constant (1)	3	If only 3 sets of data used correctly then maximum 2 marks. If 2 sets of data used correctly then maximum 1 mark (for relationship) If only 1 set of data used award 0 marks. Must be clear how the candidate has used the data to obtain the relationship. Ignore inappropriate averaging in this case. Accept straight line graph proof A sketch graph is not acceptable. 1 mark for all 4 points plotted correctly and best fit line 1 mark for correct axes including scales and labels ie I and $1/d^2$ (ignore units) 1 mark for statement of $I \times d^2$ = constant only if some or all data has been used $I \times d^2$ is equivalent to $I \propto 1/d^2$ Accept $I_1 d_1^{\,2} = I_2 d_2^{\,2}$
(c)		$I \times d^2 = 5{\cdot}4$ (1) $I \times 0{\cdot}60^2 = 5{\cdot}4$ (1) $I = 15\ \text{W m}^{-2}$ (1)	3	Can use $I_1 d_1^{\,2} = I_2 d_2^{\,2}$ Watch for a variation in answers due to data used.

(d)		Smaller lamp (1) Will be more like a point source (1) or Black cloth on bench (1) to reduce reflections (1)	2	Accept Use a more precise instrument to reduce the (absolute) uncertainty. Must provide justification which is not wrong physics, otherwise 0 marks Do not accept 'repeat it' (since there is little variation in the calculated value of the constant/ spread of points from best fit line)
(e)		$A = 4\pi r^2 = 4\pi \times 2^2 = 50{\cdot}265$ (1) $I = \frac{P}{A}$ (1) $I = 24/50{\cdot}265$ (1) $I = 0{\cdot}48\ \text{W m}^{-2}$ (1)	4	-anywhere Accept $0{\cdot}5$, $0{\cdot}477$, $0{\cdot}4775$

9

(a)		Frequency of UV/photons/light is not high enough. OR Frequency of UV/photons/light is less than threshold frequency. OR Energy of photons (of UV light) is not high enough. OR Energy of photons (of UV light) is less than work function. OR May not be a 'clean plate'.	1	Do not accept "gold" for metal plate.
(b)	(i)	$6{\cdot}94 \times 10^{-19}$ joules of energy is the minimum energy required for (photo) electrons to be emitted/ejected/ photoemission (of electrons).	1	Do not accept "to cause photoelectric effect" alone.
	(ii)	No change (to the kinetic energy). (1) As the irradiance does not affect the energy of the photons/ $E = hf$ is unchanged. (1)	2	Look for this first - if incorrect or missing then 0 marks.
(c)		Lower starting frequency. (1) Same gradient. (1)	2	Independent marks Do not accept: Additional line starting at origin.
(d)		Each photon contains a fixed/discrete amount of energy. OR Each photon removes one electron.	1	Some indication of quantisation of energy. If light was a wave then the photoelectric effect would occur regardless of the frequency of the light, it would just take longer for electrons to absorb the energy required to be ejected.

10.

(a)	(i)	• Different frequencies/ colours have different <u>refractive indices</u> (1) or • Different frequencies/ colours are <u>refracted</u> through different angles (1)	1	Do NOT accept "bending" on its own but ignore it if follows 'refraction' Do not accept 'different amounts'. Not wavelength or speed on its own but ignore if reference made to frequency or colour. A correct answer followed by 'diffract' or 'defract', *0 marks*
	(ii)	$n = \frac{v_1}{v_2}$ (1) $1 \cdot 54 = \frac{3 \cdot 00 \times 10^8}{v_2}$ (1) $v_2 = 1 \cdot 95 \times 10^8 \text{ m s}^{-1}$ (1)	3	Accept 1·9, 1·948, 1·9481 Example of inappropriate intermediate rounding: $n = \frac{\sin\theta_1}{\sin\theta_2}$ $1 \cdot 54 = \frac{\sin 42}{\sin\theta_2}$ $\theta_2 = 25 \cdot 75^\circ = 26^\circ$ $\frac{v_1}{v_2} = \frac{\sin\theta_1}{\sin\theta_2}$ $\frac{3 \cdot 00 \times 10^8}{v_2} = \frac{\sin 42}{\sin 26}$ $v_2 = 2 \cdot 0 \times 10^8 \text{ ms}^{-1}$ (max 2 marks)

(b)	(i)	$v = f\lambda$ (1) $3 \cdot 00 \times 10^8 = 4 \cdot 57 \times 10^{14} \times \lambda$ (1) $\lambda = 656 \cdot 5 \times 10^{-9}$ $m\lambda = d\sin\theta$ (1) $2 \times 656 \cdot 5 \times 10^{-9} = d \times \sin 19 \cdot 0$ (1) $d = 4 \cdot 03 \times 10^{-6}$ m (1)	5	-anywhere Inappropriate intermediate rounding eg 660, treat as arithmetic error max 4 marks -anywhere Accept 4·0, 4·033, 4·0327 If candidates go on to calculate 1/d then do not award the final mark for answer
	(ii)	• different colours have different λ (1) • $m\lambda = d\sin\theta$ (1) • (*m* and *d* are the same) • θ is different for different λ (1) or • different colours have different λ (1) • Path difference = $m\lambda$ (1) • (for the same m) • PD is different for different λ (1)	3	Any answer using different colours/wavelengths diffract/ refracts different amounts as the explanation is wrong physics, award 0 marks Any answer using wrong physics, award 0 marks. $2\lambda = d\sin\theta$ is ok Path difference = 2λ is ok Can be done by recalculation but must include the first statement else maximum 2 marks.

11.

(a)		The waves from the two sources have a constant phase relationship (and have the same frequency, wavelength, and velocity).	1	"In phase" is not sufficient
(b)		Waves meet in phase OR Crest meets crest OR Trough meets trough OR Path difference = mλ	1	Accept peak for crest Can be shown by diagram eg  Diagram must imply addition of two waves in phase
(c)		Path Difference = $m\lambda$ (1) $0{\cdot}282 - 0{\cdot}204 = 2 \times \lambda$ (1) $\lambda = 0{\cdot}0390\text{m}$ (1) (39 mm)	3	Sig figs: 0·039 m 0·03900 m 0·039000 m Not: 0·04 m
(d)		The path difference stays the same OR The path difference is still 2λ (1) because the wavelength has not changed (1)	2	Look for this statement first - if incorrect then 0 marks. The path difference stays the same OR The path difference is still 2λ on its own - 1 mark Any wrong physics in justification then maximum 1 mark (for the statement)

12.

(a)		$n = \sin i/\sin r$ (1) $= \sin36/\sin18$ (1) $= 1{\cdot}9$ (1)	3	Sig figs: Accept 2, 1·90, 1·902
(b)		$\sin\theta_C = 1/n$ (1) $= 1/1{\cdot}9$ (1) $= 0{\cdot}5263$ $\theta_C = 32°$ (1)	3	Or consistent with 10(a).
(c)		Completed diagram, showing light emerging (approximately) parallel to the incident ray	1	The normal is not required

13.

(a)		Waves <u>meet</u> in phase OR Crest <u>meets</u> crest OR Trough <u>meets</u> trough OR Path difference = mλ	1	Accept 'peak' for 'crest'. Can be shown by diagram:  Do not accept 'join' or 'merge' alone.
(b)	(i)	statement that λ = gradient or link λ to the gradient (1) subs to calculate gradient (1) $\lambda = 4 \cdot 8 \times 10^{-7}$ m (1)	3	Acceptable range using the 'gradient' method, 4·7 to $5 \cdot 0 \times 10^{-7}$ m, but intermediate steps still need to be checked. If any of the plotted points on the graph ('x') are used, then maximum 1 for formula. $m\lambda = d \sin\theta$ (1) Accept : $\lambda = d \sin\theta$ in this case Subs of values <u>from line</u> (1) $\lambda = 4 \cdot 8 \times 10^{-7}$ m (1)
	(ii)	($d = 2 \times 10^{-6}$ gives:) $\frac{1}{d} = 0.50 \times 10^{6}$ (1) $sin\theta = 0 \cdot 24$ from graph (1) $\theta = 14^{\circ}$ (1)	3	Sig figs: Accept 10, 13·9, 13·89 Alternative method - $m\lambda = d \sin\theta$ (1) Accept: $\lambda = d \sin\theta$ in this case $1 \times 4 \cdot 8 \times 10^{-7} = 2 \cdot 0 \times 10^{-6} \times \sin\theta$ (1) θ = 14° (1) Or consistent with (b)(i).
(c)		Any two correct answers from: Repeat measurements Use additional gratings Move screen further away Use second order maxima to determine θ Measure angle from first order to first order	2	Independent marks For the first point opposite, it must be clear that the candidate is implying that the measurements are being repeated. Do not accept: 'repeat the experiment' 'different sizes of slits/gratings' 'darkened room' Any <u>additional</u> improvements stated (beyond two) that <u>reduce reliability</u>, then ± rule applies.

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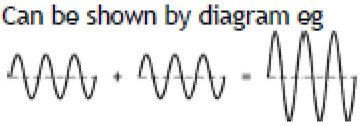
(a)	(i)	Waves meet in phase. OR Crest meets crest. OR Trough meets trough. OR Path difference = $m\lambda$	1	Accept: peak for crest. Can be shown by diagram eg  Diagram must imply addition of two waves in phase. Do not accept: 'join' or 'merge' alone.
	(ii)	$m\lambda = d\sin\theta$ (1) $3\times630\times10^{-9} = \frac{1}{250\ 000}\sin\theta$ (1) $\theta = 28^{\circ}$ (1)	3	Accept: 30°, 28·2°, 28·20° Note: d = 4×10^{-6} m Alternative substitution: $m\lambda = d\sin\theta$ (1) $3\times630\times10^{-9} = \frac{1\times10^{-3}}{250}\sin\theta$ (1) $\theta = 28^{\circ}$ (1)
	(iii)	Spots will be further apart. OR Angle θ is greater. (1) Slit separation d of new grating is smaller than the previous grating. (1)	2	Look for correct statement of effect first - if incorrect or missing then 0 marks. Accept: fewer/less spots on the screen. Justification can be done by calculation. If calculation is carried out using m = 3, candidate will obtain an invalid answer. This implies fewer/less spots (five) on the screen.
	(iv)	(The waves from the laser have a) constant phase relationship (and have the same frequency, wavelength, and velocity).	1	"In phase" is not sufficient.
(b)		(Polymer) note has vertical and horizontal or crossed lines/grid/grating.	1	Accept: crosshatch, mesh Accept: diagram to aid description There are vertical and horizontal spots so there are vertical and horizontal lines or a grid of lines.

15.

(a)		$n = \frac{\sin\theta_1}{\sin\theta_2}$ (1) $n = \frac{\sin 45\cdot 0}{\sin 22\cdot 0}$ (1) $n = 1\cdot 89$	2	"SHOW" question Accept: $\frac{n_2}{n_1} = \frac{\sin\theta_1}{\sin\theta_2}$ (1) $\frac{n_2}{1} = \frac{\sin 45\cdot 0}{\sin 22\cdot 0}$ (1) $n = 1\cdot 89$
(b)	(i)	The angle of incidence such that the angle of refraction is 90°.	1	Accept a description of the incident ray as an alternative to the word 'incidence'. Do not accept: The minimum angle of incidence that causes total internal reflection.
	(ii)	$\sin\theta_C = \frac{1}{n}$ (1) $\sin\theta_C = \frac{1}{1\cdot 89}$ (1) $\theta_C = 31\cdot 9^\circ$ (1)	3	Accept: 32°, 31·94°, 31·945°