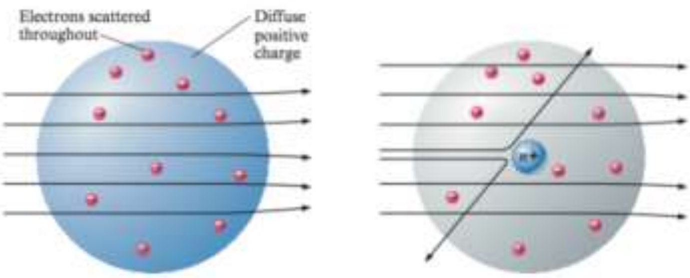
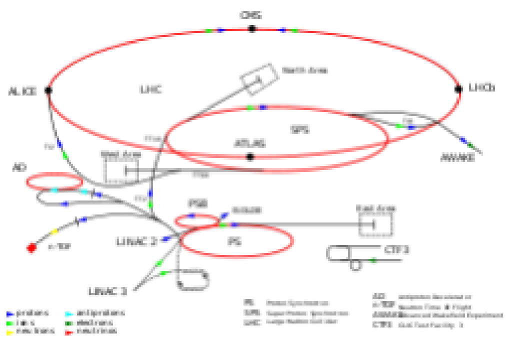
HIGHER PHYSICS

UNIT 2
Particles and Waves

WRITTEN QUESTIONS
2000—2018





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Unit 2 Homework

1. **The Standard Model**

   2013 Q27, 2014 Q26, 2015 Q26

2. **Forces on Charged Particles**

   2006 Q24, 2012 Q23, 2013 Q26

3. **Nuclear Reactions**

   2004 Q30, 2006 Q29, 2009 Q30

4. **Wave Particle Duality**

   2002 Q28, 2007 Q30, 2011 Q29

5. **Interference & Diffraction**

   2007 Q28, 2009 Q27, 2010 Q27

6. **Refraction of Light**

   2002 Q27, 2004 Q27, 2014 Q29

7. **Spectra**

   2000 Q28, 2006 Q26, 2012 Q30

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The Standard Model

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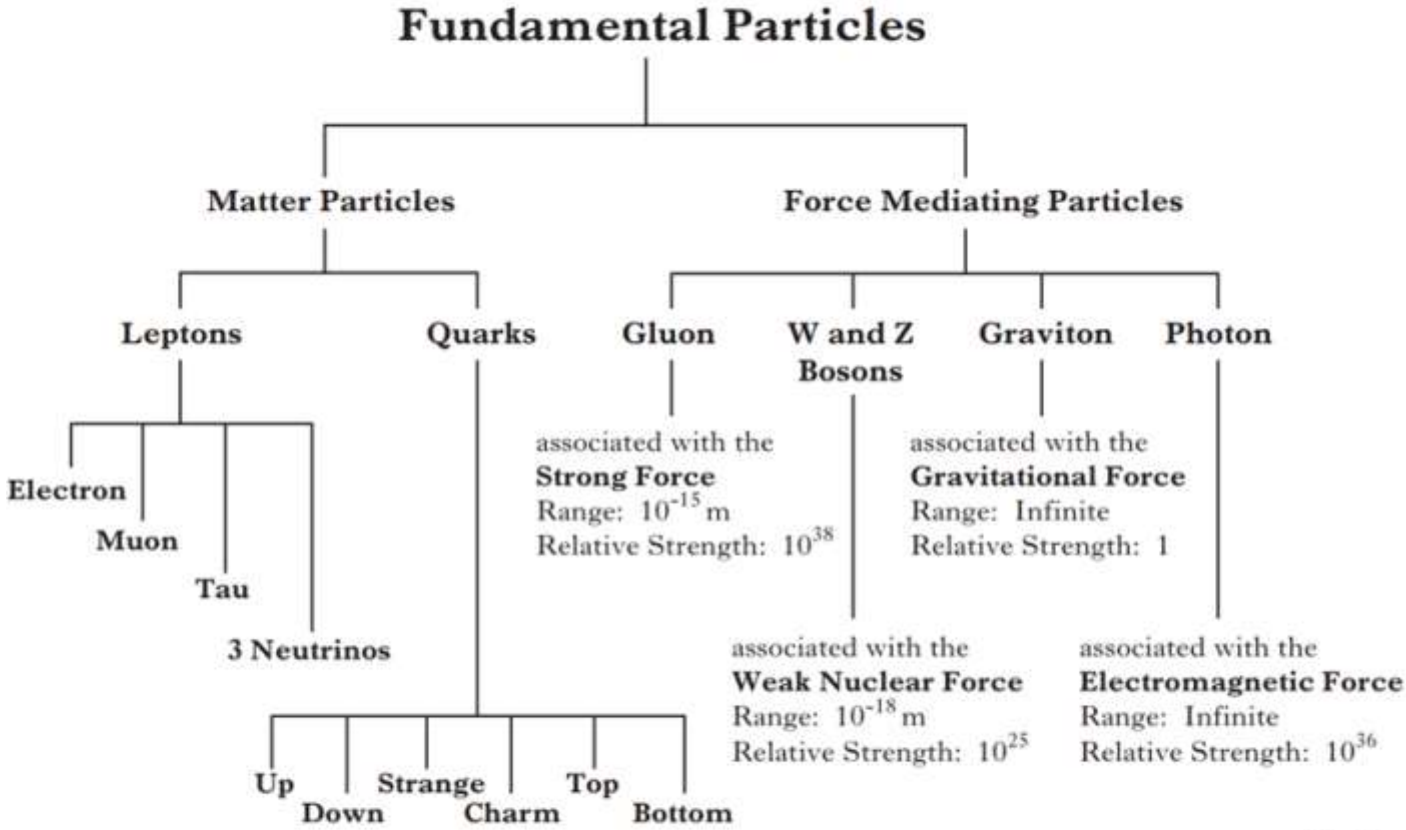
2012 RH

26. The following diagram gives information on the Standard Model of Fundamental Particles and Interactions.



Marks

Use information from the diagram and your knowledge of physics to answer the following questions.

(*a*) Explain why particles such as leptons and quarks are known as *Fundamental Particles*. **1**

(*b*) A particle called the sigma plus (Σ^+) has a charge of +1. It contains two different types of quark. It has two up quarks each having a charge of $+^2/_3$ and one strange quark.

What is the charge on the strange quark? **1**

(*c*) Explain why the gluon cannot be the force mediating particle for the gravitational force. **1**

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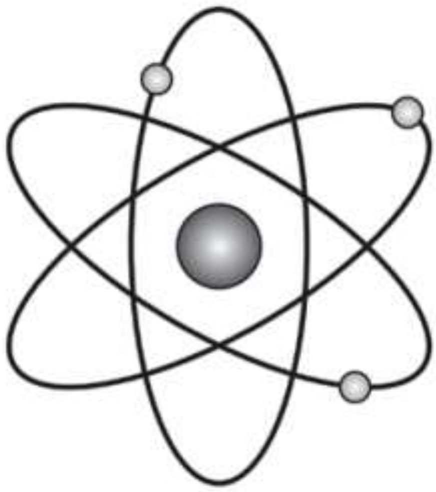
2013 RH

27. A science textbook contains the following diagram of an atom.



Use your knowledge of physics to comment on this diagram. **(3)**

2014 RH

26. Physicists study subatomic particles using particle accelerators.

(*a*) Pions are subatomic particles made up of two quarks.

There are three types of pion:

π^+ particles which have a charge of +1;
π^- particles which have a charge of −1;
and π^0 particles which have a zero charge.

The π^+ particle is made up of an up quark and an anti-down quark.

(i) Is a pion classed as a baryon or a meson?

Justify your answer. **1**

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

Determine the charge on an anti-down quark. **1**

(iii) The π^- particle is the antiparticle of the π^+ particle.

State the names of the quarks that make up a π^- particle. **1**

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2015 RH

26. (*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.
($1\ eV = 1{\cdot}6 \times 10^{-19}\ J$)

(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. **1**

(5)

2016

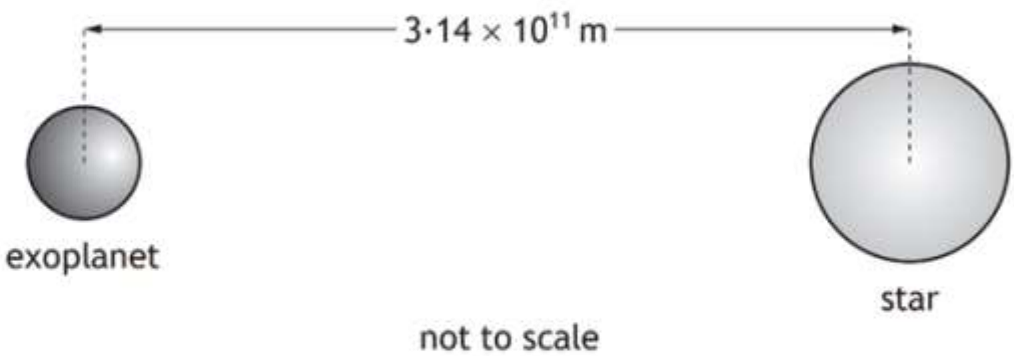
6. A website states "*Atoms are like tiny solar systems with electrons orbiting a nucleus like the planets orbit the Sun*".

Use your knowledge of physics to comment on this statement. **3**

2017

5. Planets outside our solar system are called exoplanets.

An exoplanet of mass $5{\cdot}69 \times 10^{27}$ kg orbits a star of mass $3{\cdot}83 \times 10^{30}$ kg.



(a) (i) Compare the mass of the star with the mass of the exoplanet in terms of orders of magnitude. **2**

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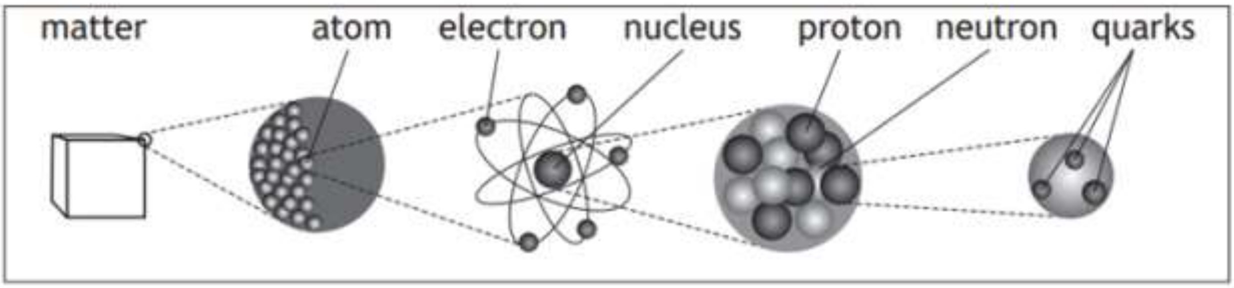
2017

7. 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**

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2017

7. (continued)

(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 $1{\cdot}5 \times 10^{-10}$ s in their frame of reference.

Σ^- are produced in a particle accelerator and travel at a speed of $0{\cdot}9c$ relative to a stationary observer.

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

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2019

7. Scientists have recently discovered a type of particle called a pentaquark. Pentaquarks are very short lived and contain five quarks.

A lambda b (Λ_b) pentaquark contains the following quarks: 2 up, 1 down, 1 charm, and 1 anticharm quark.

(a) Quarks and leptons are fundamental particles.

(i) Explain what is meant by the term *fundamental particle*. **1**

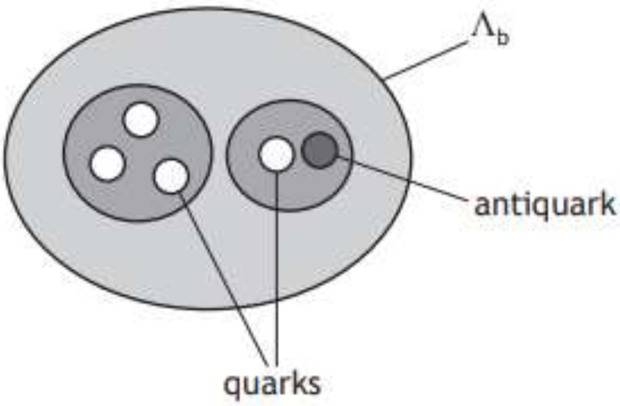
(ii) State the name given to the group of matter particles that contains quarks and leptons. **1**

(b) The table contains information about the charge on the quarks that make up the Λ_b pentaquark.

Type of quark	Charge
up	$+\frac{2}{3}e$
down	$-\frac{1}{3}e$
charm	$+\frac{2}{3}e$
anticharm	$-\frac{2}{3}e$

Determine the total charge on the Λ_b pentaquark. **2**

(c) One theory to explain the structure of the Λ_b pentaquark suggests that three of the quarks group together and one quark and the antiquark group together within the pentaquark.



(i) State the type of particle that is made of a quark-antiquark pair. **1**

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Forces On Charged Particles

2000 Q29 b

2001 Q23 b

2004 Q29 c

2006 Q24

2007 Q24

2012 Q23 a

2013 Q26

2014 Q26 b

2016 Q7

2016 Q8 c,d

2017 Q8

2018 Q6

2000

29. Radium (Ra) decays to radon (Rn) by the emission of an alpha particle.

Some energy is also released by this decay.

The decay is represented by the statement shown below.

(*b*) The alpha particle leaves the radium nucleus with a speed of $1{\cdot}5 \times 10^7\,\text{m s}^{-1}$.

The alpha particle is now accelerated through a potential difference of 25 kV.

Calculate the **final** kinetic energy, in joules, of the alpha particle. **3**

2001

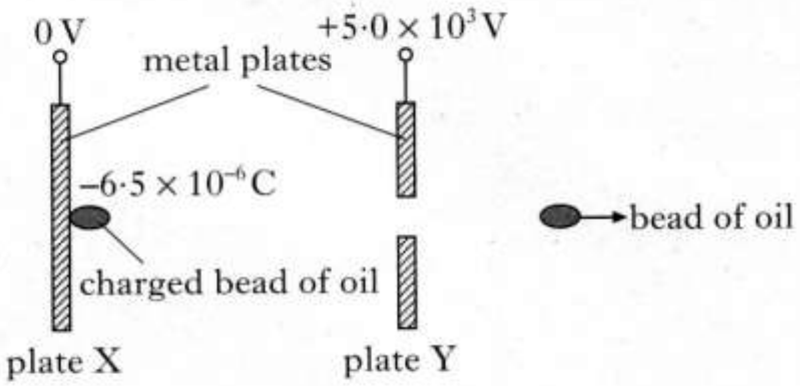
23. Beads of liquid moving at high speed are used to move threads in modern weaving machines.

(*b*) Another design of machine uses beads of oil and two metal plates X and Y.

The potential difference between these plates is $5{\cdot}0 \times 10^3$ V.

Each bead of oil has a mass of $4{\cdot}0 \times 10^{-5}$ kg and is given a negative charge of $6{\cdot}5 \times 10^{-6}$ C.

The bead accelerates from rest at plate X and passes through a hole in plate Y.



Neglecting air friction, calculate the speed of the bead at plate Y. **3**

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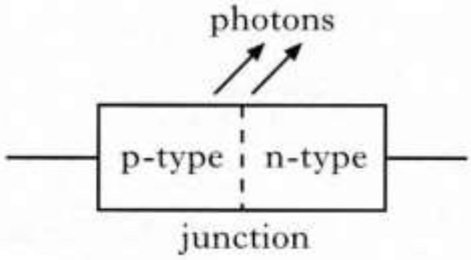
2004

29. An LED consists of a p-n junction as shown.



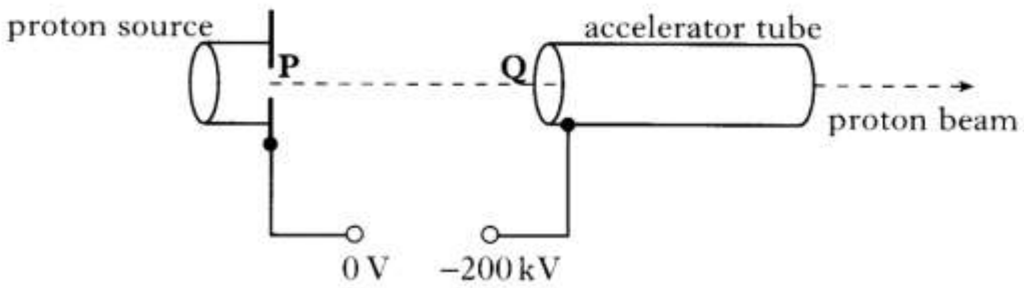
(*c*) The LED emits photons, of energy $3{\cdot}68 \times 10^{-19}$ J.

(i) Calculate the wavelength of a photon of light from this LED.

(ii) Calculate the minimum potential difference across the p-n junction when it emits photons. **4**

2006

24. The diagram below shows the basic features of a proton accelerator. It is enclosed in an evacuated container.



Protons released from the proton source start from rest at **P**.
A potential difference of 200 kV is maintained between **P** and **Q**.

(*a*) What is meant by the term *potential difference of 200 kV*? **1**

(*b*) Explain why protons released at **P** are accelerated towards **Q**. **1**

(*c*) Calculate:

(i) the work done on a proton as it accelerates from **P** to **Q**; **2**

(ii) the speed of a proton as it reaches **Q**. **2**

(*d*) The distance between **P** and **Q** is now halved.

What effect, if any, does this change have on the speed of a proton as it reaches **Q**? Justify your answer. **2**

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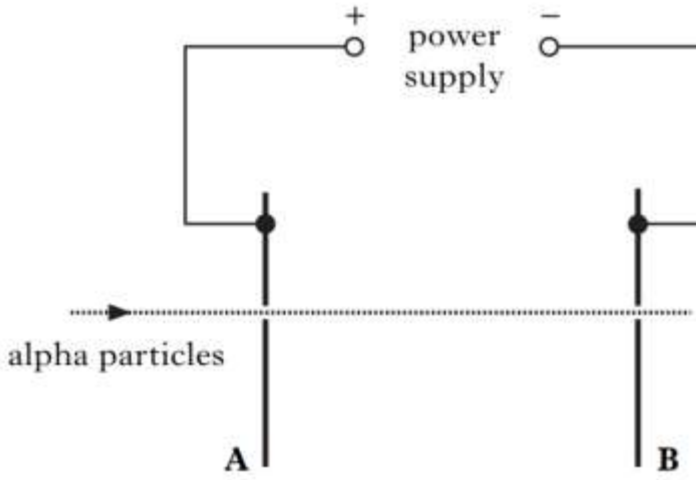
2007

24. The apparatus shown in the diagram is designed to accelerate alpha particles.



An alpha particle travelling at a speed of $2{\cdot}60 \times 10^{6}\,m\,s^{-1}$ passes through a hole in plate A. The mass of an alpha particle is $6{\cdot}64 \times 10^{-27}\,kg$ and its charge is $3{\cdot}2 \times 10^{-19}\,C$.

(*a*) When the alpha particle reaches plate B, its kinetic energy has increased to $3{\cdot}05 \times 10^{-14}\,J$.

Show that the work done on the alpha particle as it moves from plate A to plate B is $8{\cdot}1 \times 10^{-15}\,J$. **2**

(*b*) Calculate the potential difference between plates A and B. **2**

(*c*) The apparatus is now adapted to accelerate **electrons** from A to B through the same potential difference.

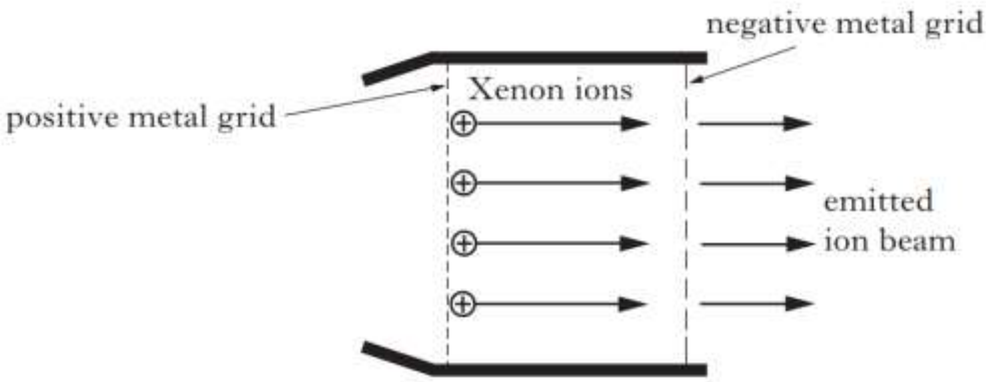
How does the increase in the kinetic energy of an electron compare with the increase in kinetic energy of the alpha particle in part (*a*)?

Justify your answer. **2**

2012 RH

23. An ion propulsion engine can be used to propel spacecraft to areas of deep space.

A simplified diagram of a Xenon ion engine is shown.



The Xenon ions are accelerated as they pass through an electric field between the charged metal grids. The emitted ion beam causes a force on the spacecraft in the opposite direction.

The spacecraft has a total mass of 750 kg.

The mass of a Xenon ion is $2{\cdot}18 \times 10^{-25}$ kg and its charge is $1{\cdot}60 \times 10^{-19}$ C. The potential difference between the charged metal grids is 1·22 kV.

(*a*) (i) Show that the work done on a Xenon ion as it moves through the electric field is $1{\cdot}95 \times 10^{-16}$ J. **1**

(ii) Assuming the ions are accelerated from rest, calculate the speed of a Xenon ion as it leaves the engine. **2**

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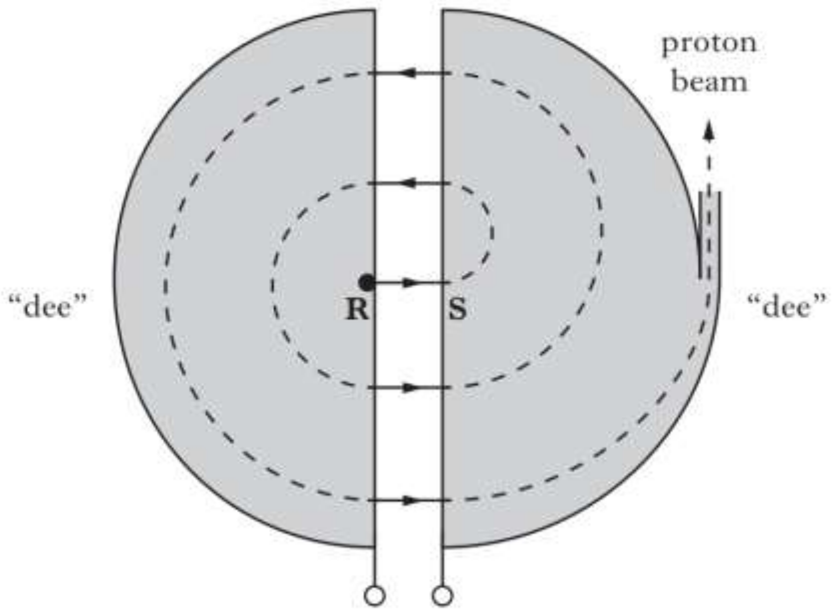
2013 RH

26. A cyclotron is used in a hospital to accelerate protons that are then targeted to kill cancer cells.

The cyclotron consists of two D-shaped, hollow metal structures called "dees", placed in a vacuum. The diagram shows the cyclotron viewed from above.



Protons are released from rest at **R** and are accelerated across the gap between the "dees" by a voltage of 55 kV.

(*a*) (i) Show that the work done on a proton as it accelerates from **R** to **S** is $8{\cdot}8 \times 10^{-15}$ J. **1**

(ii) Calculate the speed of a proton as it reaches **S**. **2**

(*b*) Inside the "dees" a uniform magnetic field acts on the protons.

Determine the direction of this magnetic field. **1**

(*c*) Explain why an alternating voltage is used in the cyclotron. **2**

2014 RH

26. Physicists study subatomic particles using particle accelerators.

(*b*) Explain how particle accelerators, such as the Large Hadron Collider at CERN, are able to:

(i) accelerate charged particles; **1**

(ii) deflect charged particles. **1**

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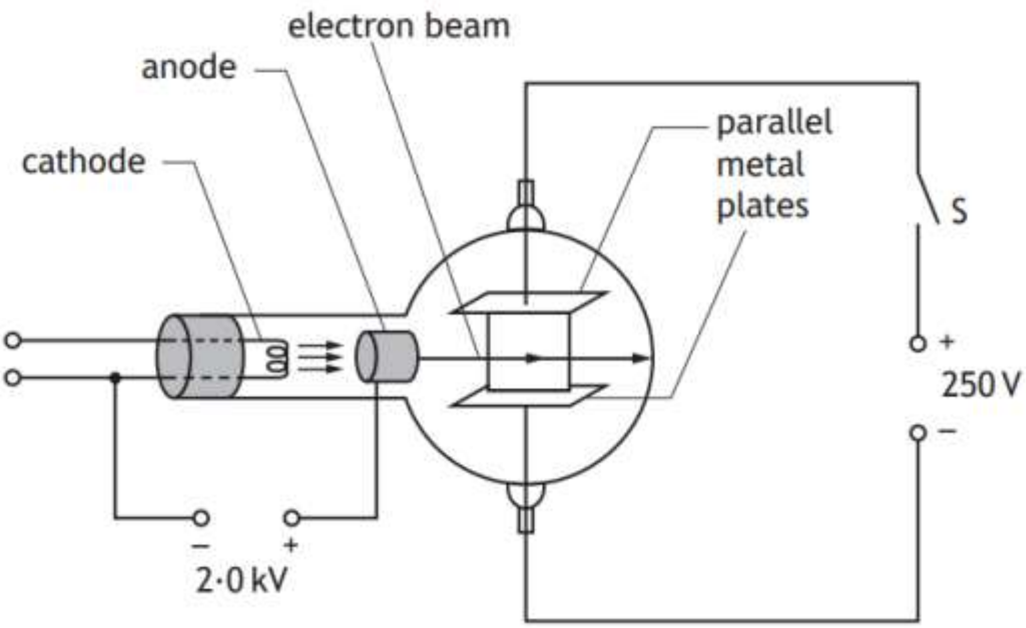
2016

7. 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**

Space for working and answer

(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**

Space for working and answer

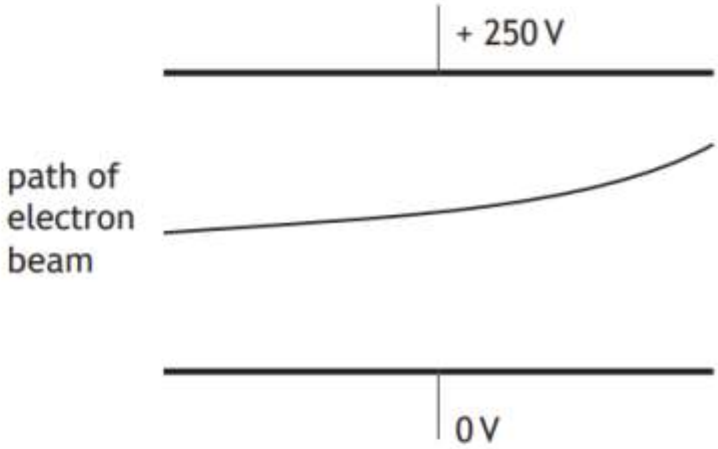
2016

7. (continued)

(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**

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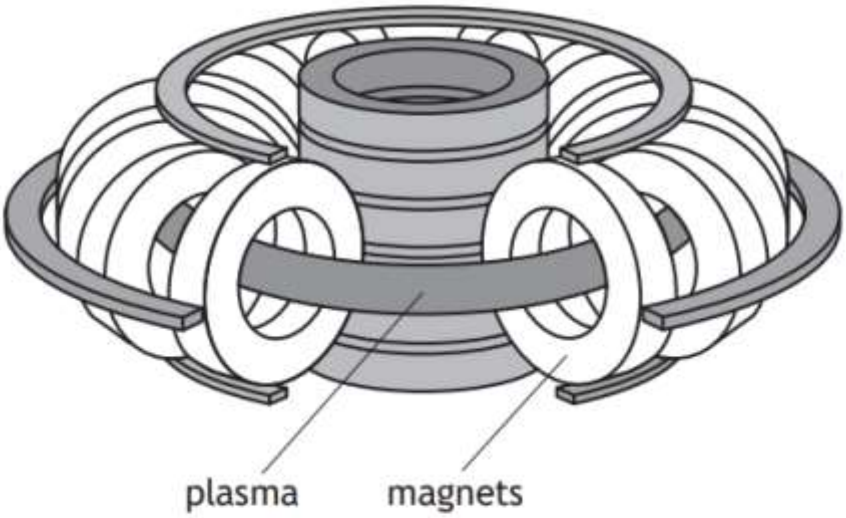
2016

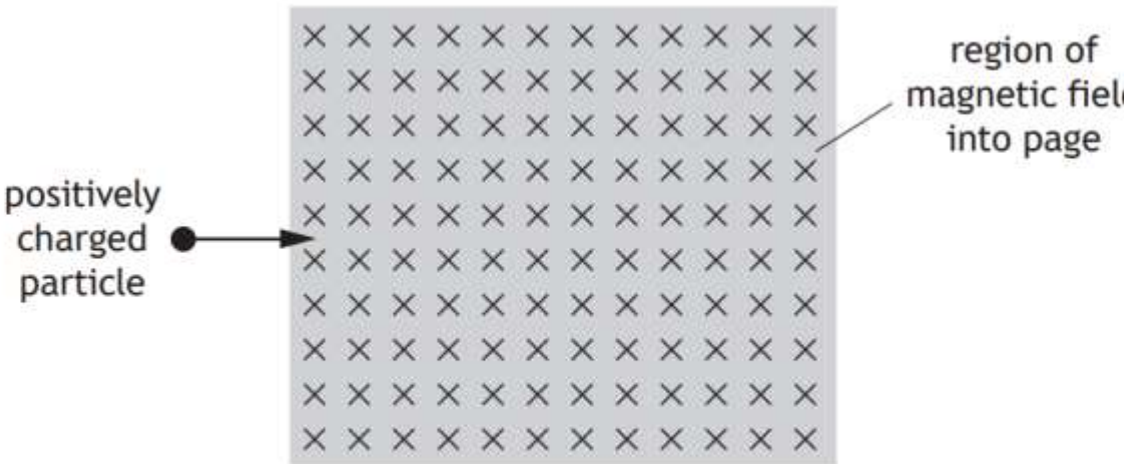
8. The diagram shows part of an experimental fusion reactor.



(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**

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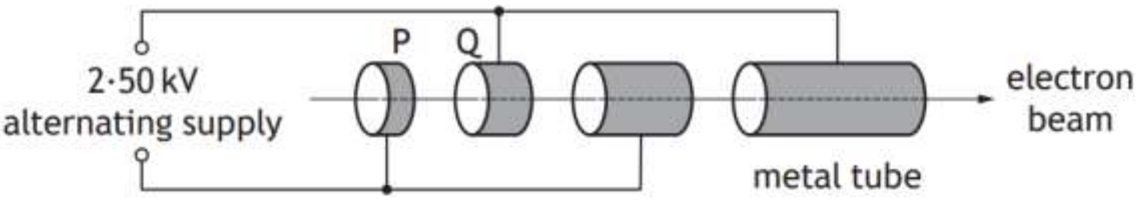
2017

8. 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**

Space for working and answer

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

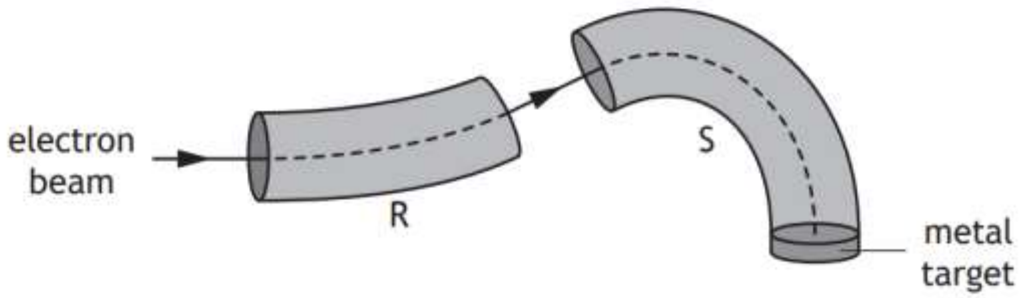
Return to Forces on Charged Particles Contents

8. (continued)

(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.



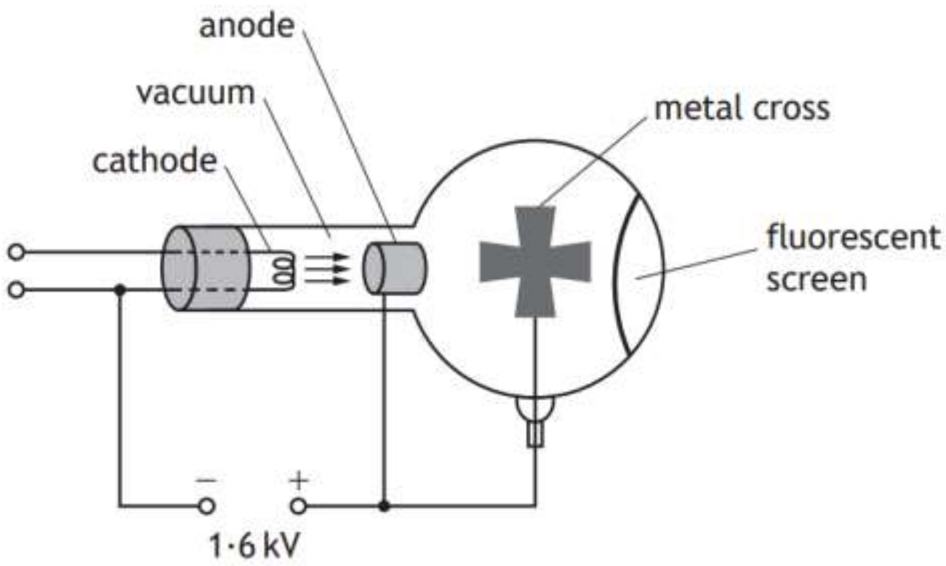
(i) Determine the direction of the magnetic field inside beam guide R. **1**

(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**

2018

6. 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**

Space for working and answer

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

Return to Forces on Charged Particles Contents

6. (continued)

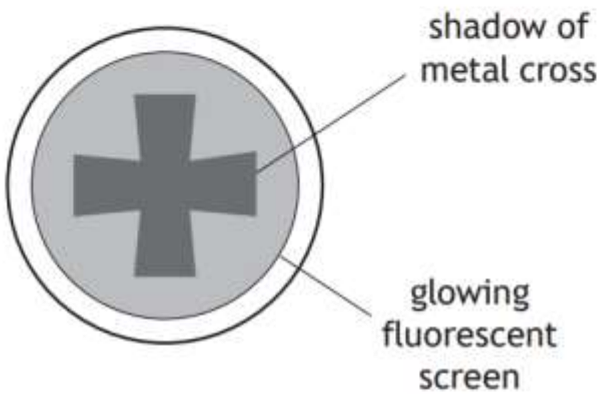
2018

(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.

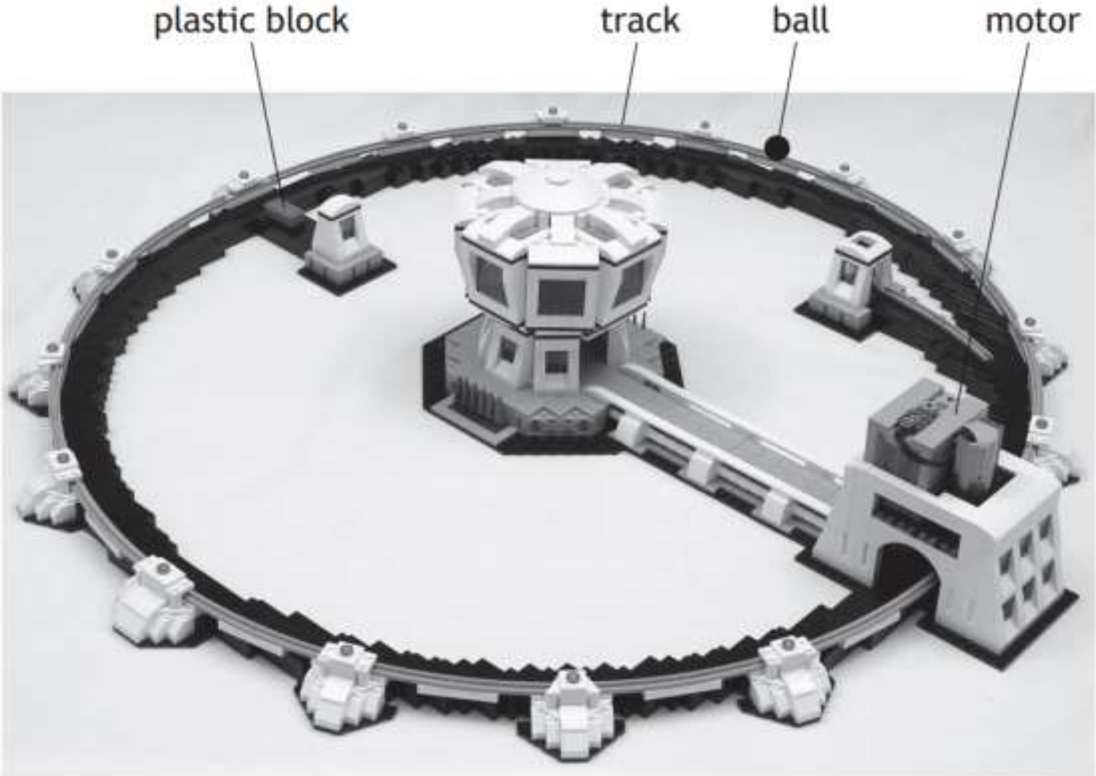
Suggest one change that is observed. **2**

Return to Forces on Charged Particles Contents

6. (continued)

2018

(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**

Return to Forces on Charged Particles Contents

Nuclear Reactions

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2000

29. Radium (Ra) decays to radon (Rn) by the emission of an alpha particle. Some energy is also released by this decay. The decay is represented by the statement shown below.

$$^{226}_{88}\text{Ra} \longrightarrow {}^{x}_{y}\text{Rn} + {}^{4}_{2}\text{He}$$

The masses of the nuclides involved are as follows.

Mass of $^{226}_{88}\text{Ra}$ = $3{\cdot}75428 \times 10^{-25}$ kg

Mass of $^{x}_{y}\text{Rn}$ = $3{\cdot}68771 \times 10^{-25}$ kg

Mass of $^{4}_{2}\text{He}$ = $6{\cdot}64832 \times 10^{-27}$ kg

(*a*) (i) What are the values of x and y for the nuclide $^{x}_{y}\text{Rn}$?

(ii) Why is energy released by this decay?

(iii) Calculate the energy released by one decay of this type. **5**

2001

29. (*a*) The following statement represents a nuclear reaction.

$$^{239}_{94}\text{Pu} + {}^{1}_{0}\text{n} \longrightarrow {}^{137}_{52}\text{Te} + {}^{100}_{42}\text{Mo} + 3\,{}^{1}_{0}\text{n} + \text{energy}$$

The total mass of the particles before the reaction is $3{\cdot}9842 \times 10^{-27}$ kg and the total mass of the particles after the reaction is $3{\cdot}9825 \times 10^{-27}$ kg.

(i) State and explain whether this reaction is spontaneous or induced.

(ii) Calculate the energy, in joules, released by this reaction. **3**

Return to Nuclear Reactions Contents

2003

29. A technician is studying samples of radioactive substances.

(*a*) The following statement describes a nuclear decay in one of the samples used by the technician.

$$^{238}_{92}U \rightarrow ^{234}_{90}Th + ^{4}_{2}He$$

(i) What type of particle is emitted during this decay?

(ii) In this sample $7{\cdot}2 \times 10^5$ nuclei decay in two minutes.

Calculate the average activity of the sample during this time. **3**

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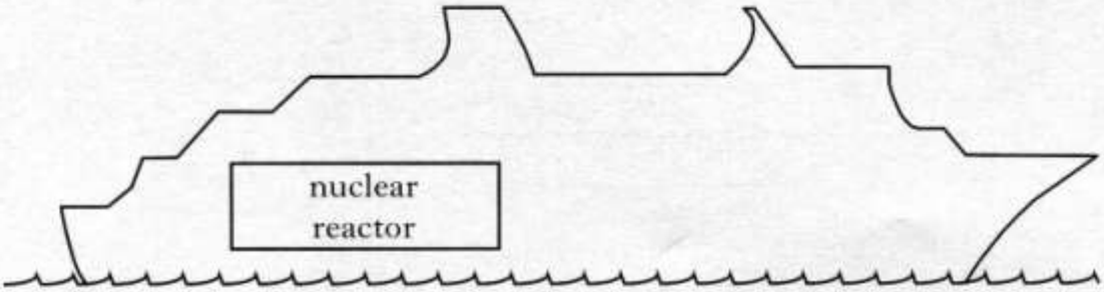
2004

30. A ship is powered by a nuclear reactor.



One reaction that takes place in the core of the nuclear reactor is represented by the statement below.

$$^{235}_{92}\text{U} + ^{1}_{0}\text{n} \rightarrow ^{140}_{58}\text{Ce} + ^{94}_{40}\text{Zr} + 2^{1}_{0}\text{n} + 6^{0}_{-1}\text{e}$$

(*a*) The symbol for the Uranium nucleus is $^{235}_{92}\text{U}$.

What information about the nucleus is provided by the following numbers?

(i) 92

(ii) 235 **2**

(*b*) Describe how neutrons produced during the reaction can cause further nuclear reactions. **1**

(*c*) The masses of particles involved in the reaction are shown in the table.

Particles	*Mass*/kg
$^{235}_{92}\text{U}$	$390{\cdot}173 \times 10^{-27}$
$^{140}_{58}\text{Ce}$	$232{\cdot}242 \times 10^{-27}$
$^{94}_{40}\text{Zr}$	$155{\cdot}884 \times 10^{-27}$
$^{1}_{0}\text{n}$	$1{\cdot}675 \times 10^{-27}$
$^{0}_{-1}\text{e}$	negligible

Calculate the energy released in the reaction. **3**

(6)

Return to Nuclear Reactions Contents

2006

29. (continued)

(*b*) A nuclear fission reaction is represented by the following statement.

$$^{235}_{92}\text{U} + {}^{1}_{0}\text{n} \rightarrow {}^{137}_{r}\text{Cs} + {}^{s}_{37}\boldsymbol{T} + 4{}^{1}_{0}\text{n}$$

(i) Is this a spontaneous or an induced reaction? You must justify your answer. **1**

(ii) Determine the numbers represented by the letters ***r*** and ***s*** in the above reaction. **1**

(iii) Use the data booklet to identify the element represented by ***T***. **1**

(iv) The masses of the nuclei and particles in the reaction are given below.

	Mass/kg
$^{235}_{92}\text{U}$	$390{\cdot}219 \times 10^{-27}$
$^{137}_{r}\text{Cs}$	$227{\cdot}292 \times 10^{-27}$
$^{s}_{37}\boldsymbol{T}$	$157{\cdot}562 \times 10^{-27}$
$^{1}_{0}\text{n}$	$1{\cdot}675 \times 10^{-27}$

Calculate the energy released in the reaction. **3**

Return to Nuclear Reactions Contents

29. (continued)

2006

(*b*) A nuclear fission reaction is represented by the following statement.

$$^{235}_{92}\mathrm{U} + {}^{1}_{0}\mathrm{n} \rightarrow {}^{137}_{r}\mathrm{Cs} + {}^{s}_{37}\boldsymbol{T} + 4\,{}^{1}_{0}\mathrm{n}$$

(i) Is this a spontaneous or an induced reaction? You must justify your answer. **1**

(ii) Determine the numbers represented by the letters ***r*** and ***s*** in the above reaction. **1**

(iii) Use the data booklet to identify the element represented by ***T***. **1**

(iv) The masses of the nuclei and particles in the reaction are given below.

	Mass/kg
$^{235}_{92}\mathrm{U}$	$390{\cdot}219 \times 10^{-27}$
$^{137}_{r}\mathrm{Cs}$	$227{\cdot}292 \times 10^{-27}$
$^{s}_{37}\boldsymbol{T}$	$157{\cdot}562 \times 10^{-27}$
$^{1}_{0}\mathrm{n}$	$1{\cdot}675 \times 10^{-27}$

Calculate the energy released in the reaction. **3**

2007

31. (*a*) The following statement represents a nuclear reaction.

$$^{240}_{94}\mathrm{Pu} \longrightarrow {}^{236}_{92}\mathrm{U} + {}^{4}_{2}\mathrm{He}$$

The table shows the masses of the particles involved in this reaction.

Particle	*Mass*/kg
$^{240}_{94}\mathrm{Pu}$	$398{\cdot}626 \times 10^{-27}$
$^{236}_{92}\mathrm{U}$	$391{\cdot}970 \times 10^{-27}$
$^{4}_{2}\mathrm{He}$	$6{\cdot}645 \times 10^{-27}$

Calculate the energy released in this reaction. **3**

Return to Nuclear Reactions Contents

2009

30. (*a*) Some power stations use nuclear fission reactions to provide energy for generating electricity. The following statement represents a fission reaction.

$$^{235}_{92}U \;+\; ^{1}_{0}n \;\rightarrow\; ^{139}_{57}La \;+\; ^{\boldsymbol{r}}_{42}Mo \;+\; 2\,^{1}_{0}n \;+\; \boldsymbol{s}\,^{0}_{-1}e$$

(i) Determine the numbers represented by the letters ***r*** and ***s*** in the above statement. **1**

(ii) Explain why a nuclear fission reaction releases energy. **1**

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

Particle	*Mass*/kg
$^{235}_{92}U$	$390{\cdot}173 \times 10^{-27}$
$^{139}_{57}La$	$230{\cdot}584 \times 10^{-27}$
$^{\boldsymbol{r}}_{42}Mo$	$157{\cdot}544 \times 10^{-27}$
$^{1}_{0}n$	$1{\cdot}675 \times 10^{-27}$
$^{0}_{-1}e$	negligible

Calculate the energy released in this reaction. **3**

Return to Nuclear Reactions Contents

2010

30. A smoke alarm contains a very small sample of the radioactive isotope Americium-241, represented by the symbol

$$^{241}_{95}\text{Am}$$

(*a*) How many neutrons are there in a nucleus of this isotope? **1**

(*b*) This isotope decays by emitting alpha particles as shown in the following statement.

$$^{241}_{95}\text{Am} \longrightarrow \, ^{\boldsymbol{s}}_{\boldsymbol{r}}\boldsymbol{T} + \alpha$$

(i) Determine the numbers represented by the letters ***r*** and ***s***. **1**

(ii) Use the data booklet to identify the element ***T***. **1**

2011

30. (*a*) The Sun is the source of most of the energy on Earth. This energy is produced by nuclear reactions which take place in the interior of the Sun.

One such reaction can be described by the following statement.

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

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

Particle	*Mass*/kg
$^{3}_{1}\text{H}$	$5{\cdot}005 \times 10^{-27}$
$^{2}_{1}\text{H}$	$3{\cdot}342 \times 10^{-27}$
$^{4}_{2}\text{He}$	$6{\cdot}642 \times 10^{-27}$
$^{1}_{0}\text{n}$	$1{\cdot}675 \times 10^{-27}$

(i) Name this type of nuclear reaction. **1**

(ii) Calculate the energy released in this reaction. **3**

Return to Nuclear Reactions Contents

2013 TH

31. (*a*) The following statement represents a nuclear reaction.

$$^{A}_{Z}\mathbf{X} \quad + \quad ^{2}_{1}\mathrm{H} \quad \longrightarrow \quad 2\,^{4}_{2}\mathrm{He} \quad + \quad ^{1}_{0}\mathrm{n} \quad + \quad \text{energy}$$

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

Particle	*Mass*/kg
$^{2}_{1}\mathrm{H}$	$3{\cdot}342 \times 10^{-27}$
$^{4}_{2}\mathrm{He}$	$6{\cdot}642 \times 10^{-27}$
$^{1}_{0}\mathrm{n}$	$1{\cdot}675 \times 10^{-27}$

(i) Use the data booklet to identify the element **X**. **1**

(ii) The energy released in this reaction is $2{\cdot}97 \times 10^{-12}$ J.

Calculate the mass of the nucleus $^{A}_{Z}\mathbf{X}$. **3**

2015 TH

31. (*a*) In a certain star, one of the fusion reactions taking place is represented by the following statement.

$$^{1}_{1}\mathrm{H} + {}^{15}_{7}\mathrm{N} \rightarrow {}^{12}_{6}\mathrm{C} + {}^{4}_{2}\mathrm{He}$$

The energy released by this reaction is $7{\cdot}96662 \times 10^{-13}$ J.

The table shows the masses of three of the particles.

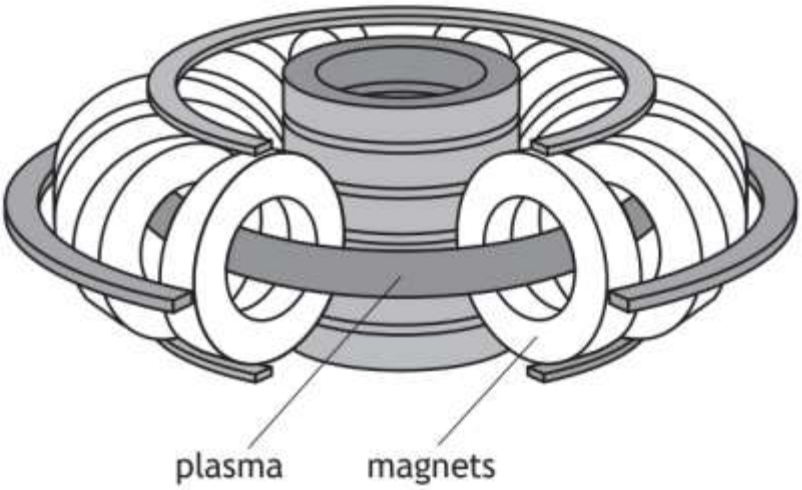
Particle	*Mass*/kg
$^{1}_{1}\mathrm{H}$	$1{\cdot}68706 \times 10^{-27}$
$^{12}_{6}\mathrm{C}$	$20{\cdot}1031 \times 10^{-27}$
$^{4}_{2}\mathrm{He}$	$6{\cdot}69944 \times 10^{-27}$

Calculate the mass of the nitrogen nucleus. **3**

Return to Nuclear Reactions Contents

2016

8. 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**

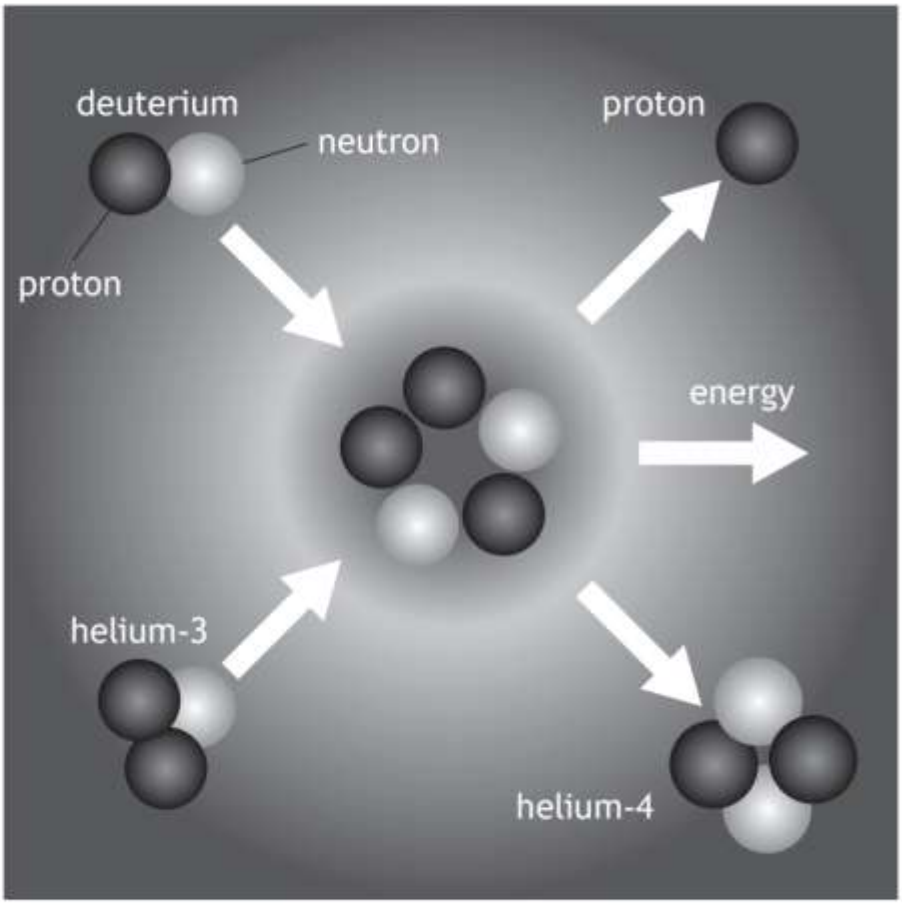
Space for working and answer

Return to Nuclear Reactions Contents

2017

9. 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**

Return to Nuclear Reactions Contents

2017

9. (continued)

(b) The following statement represents this fusion reaction.

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

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

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

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

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

Space for working and answer

Return to Nuclear Reactions Contents

2019

7. (continued)

(d) The Λ_b pentaquark has a mass-energy equivalence of 4450 MeV.

One eV is equal to $1 \cdot 60 \times 10^{-19}$ J.

(i) Determine the energy, in joules, of the Λ_b pentaquark. **1**

(ii) Calculate the mass of the Λ_b pentaquark. **3**

2019

8. The Sun emits energy at an average rate of $4 \cdot 1 \times 10^{26}$ J s^{-1}. This energy is produced by nuclear reactions taking place inside the Sun.

The following statement shows one reaction that takes place inside the Sun.

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

(a) State the name given to this type of nuclear reaction. **1**

(b) The mass of the particles involved in this reaction are shown in the table.

Particle	Mass (kg)
$^{2}_{1}H$	$3 \cdot 3436 \times 10^{-27}$
$^{3}_{2}He$	$5 \cdot 0082 \times 10^{-27}$
$^{1}_{0}n$	$1 \cdot 6749 \times 10^{-27}$

Determine the energy released in this reaction. **4**

(c) Determine the number of these reactions that would be required per second to produce the Sun's average energy output. **2**

Return to Nuclear Reactions Contents

Wave Particle Duality

2000 Q28 a

2002 Q28

2004 Q29 c

2005 Q29

2006 Q27 a

2007 Q30

2008 Q29

2009 Q29

2011 Q29

2014 Q27

2015 Q28

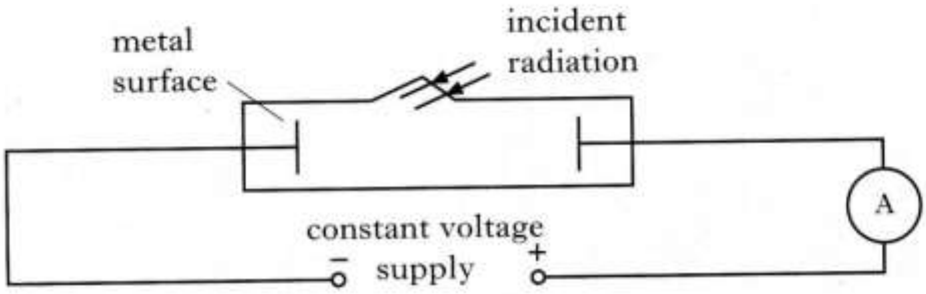
2018 Q7

Return to Homework Contents

2000

28. (*a*) The apparatus shown below is used to investigate photoelectric emission from a metal surface when electromagnetic radiation is shone on the surface.

The intensity and frequency of the incident radiation can be varied as required.



(i) Explain what is meant by *photoelectric emission* from a metal.

(ii) What is the name given to the minimum frequency of the radiation that produces a current in the circuit?

(iii) A particular source of radiation produces a current in the circuit.

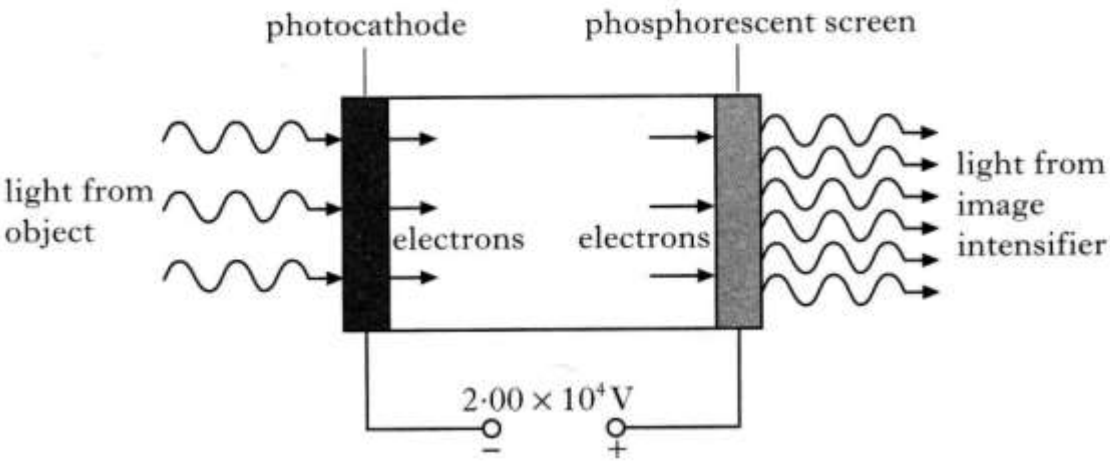
Explain why the current in the circuit increases as the intensity of the incident radiation increases. **4**

Return to Wave Particle Duality Contents

2002

28. An image intensifier is used to improve night vision. It does this by amplifying the light from an object.

Light incident on a photocathode causes the emission of photoelectrons. These electrons are accelerated by an electric field and strike a phosphorescent screen causing it to emit light. This emitted light is of a greater intensity than the light that was incident on the photocathode.



The voltage between the photocathode and the phosphorescent screen is $2{\cdot}00 \times 10^4$ V.

The minimum frequency of the incident light that allows photoemission to take place is $3{\cdot}33 \times 10^{14}$ Hz.

(*a*) What name is given to the minimum frequency of the light required for photoemission to take place? **1**

(*b*) (i) Show that the work function of the photocathode material is $2{\cdot}21 \times 10^{-19}$ J.

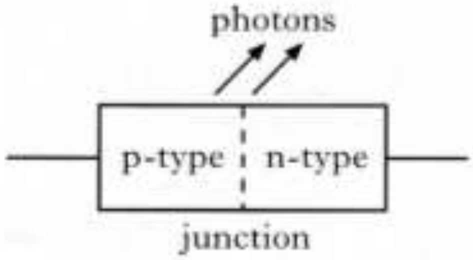
(ii) Light of frequency $5{\cdot}66 \times 10^{14}$ Hz is incident on the photocathode. Calculate the maximum kinetic energy of an electron emitted from the photocathode.

(iii) Calculate the kinetic energy gained by an electron as it is accelerated from the photocathode to the phosphorescent screen. **6**

Return to Wave Particle Duality Contents

2004

29. An LED consists of a p-n junction as shown.



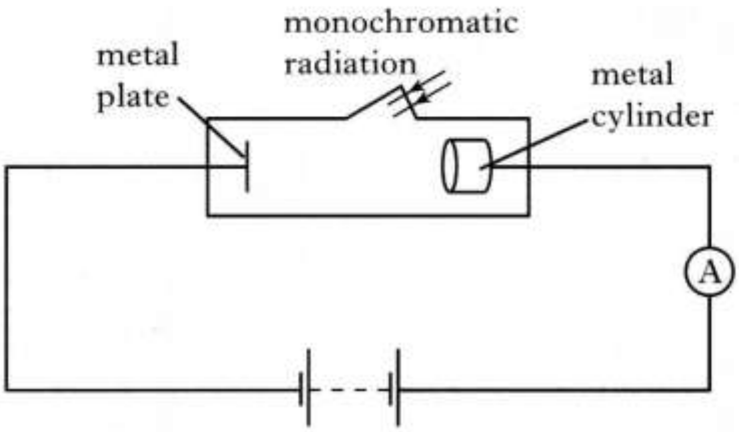
(*c*) The LED emits photons, of energy $3{\cdot}68 \times 10^{-19}$ J.

(i) Calculate the wavelength of a photon of light from this LED.

(ii) Calculate the minimum potential difference across the p-n junction when it emits photons. **4**

2005

29. In 1902, P. Lenard set up an experiment similar to the one shown below.



There is a constant potential difference between the metal plate and the metal cylinder.

Monochromatic radiation is directed onto the plate.

Photoelectrons produced at the plate are collected by the cylinder.

The frequency and the intensity of the radiation can be altered independently.

The frequency of the radiation is set at a value above the threshold frequency.

(*a*) The intensity of the radiation is slowly increased.

Sketch a graph of the current against intensity of radiation. **1**

(*b*) The metal of the plate has a work function of $3{\cdot}11 \times 10^{-19}$ J. The wavelength of the radiation is 400 nm.

(i) Calculate the maximum kinetic energy of a photoelectron. **3**

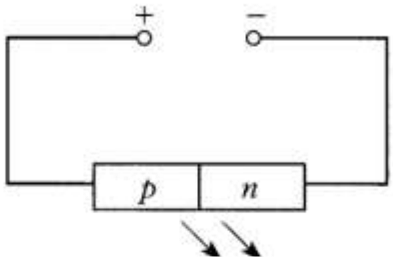
(ii) The battery connections are now reversed.

Explain why there could still be a reading on the ammeter. **1**

Return to Wave Particle Duality Contents

2006

27. (*a*) Light of frequency $6{\cdot}7 \times 10^{14}$ Hz is produced at the junction of a light emitting diode (LED).



(iii) The table below gives the values of the work function for three metals.

Metal	*Work function*/ J
caesium	$3{\cdot}4 \times 10^{-19}$
strontium	$4{\cdot}1 \times 10^{-19}$
magnesium	$5{\cdot}9 \times 10^{-19}$

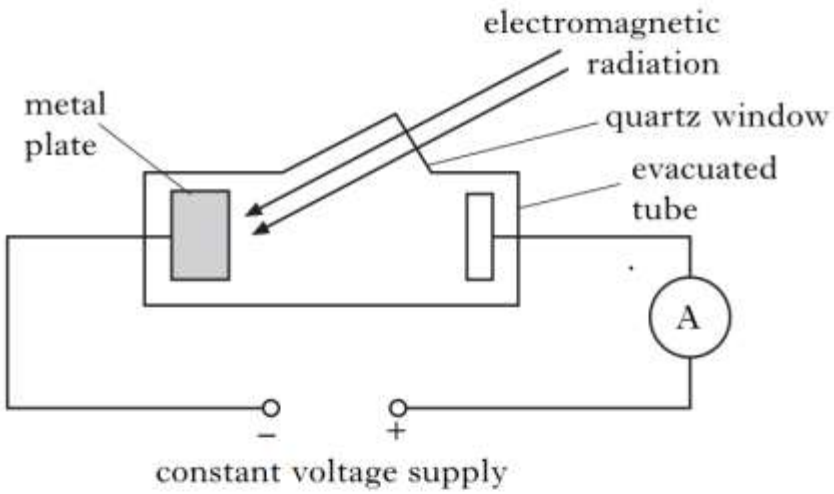
Light from the LED is now incident on these metals in turn.

Show by calculation which of these metals, if any, release(s) photoelectrons with this light. **3**

Return to Wave Particle Duality Contents

2007

30. A metal plate emits electrons when certain wavelengths of electromagnetic radiation are incident on it.



When light of wavelength 605 nm is incident on the metal plate, electrons are released with zero kinetic energy.

(*a*) Show that the work function of this metal is $3{\cdot}29 \times 10^{-19}$ J. **2**

(*b*) The wavelength of the incident radiation is now altered. Photons of energy $5{\cdot}12 \times 10^{-19}$ J are incident on the metal plate.

(i) Calculate the maximum kinetic energy of the electrons just as they leave the metal plate. **1**

(ii) The irradiance of this radiation on the metal plate is now decreased.

State the effect this has on the ammeter reading.

Justify your answer. **2**

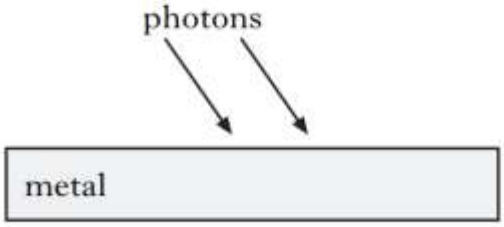
Return to Wave Particle Duality Contents

2008

29. To explain the photoelectric effect, light can be considered as consisting of tiny bundles of energy. These bundles of energy are called photons.

(*a*) Sketch a graph to show the relationship between photon energy and frequency. **1**

(*b*) Photons of frequency $6 \cdot 1 \times 10^{14}$ Hz are incident on the surface of a metal.



This releases photoelectrons from the surface of the metal.

The maximum kinetic energy of any of these photoelectrons is $6 \cdot 0 \times 10^{-20}$ J.

Calculate the work function of the metal. **3**

(*c*) The irradiance due to these photons on the surface of the metal is now reduced.

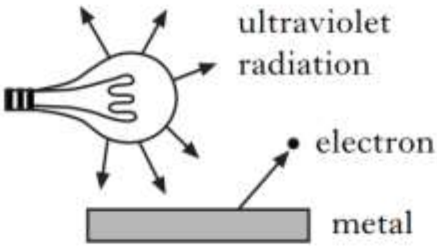
Explain why the maximum kinetic energy of each photoelectron is unchanged. **1**

Return to Wave Particle Duality Contents

2009

29. Ultraviolet radiation from a lamp is incident on the surface of a metal.

This causes the release of electrons from the surface of the metal.



The energy of each photon of ultraviolet light is $5{\cdot}23 \times 10^{-19}$ J.

The work function of the metal is $2{\cdot}56 \times 10^{-19}$ J.

(*a*) Calculate:

(i) the maximum kinetic energy of an electron released from this metal by this radiation; **1**

(ii) the maximum speed of an emitted electron. **2**

(*b*) The source of ultraviolet radiation is now moved further away from the surface of the metal.

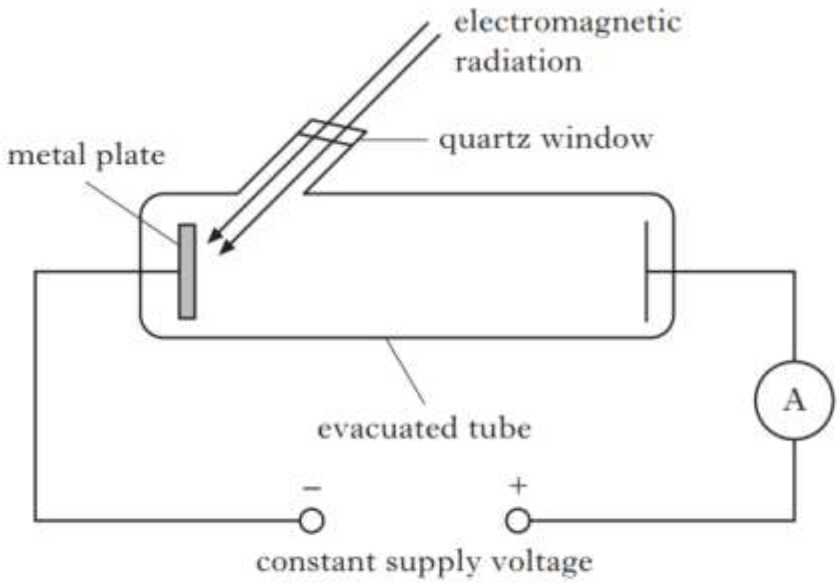
State the effect, if any, this has on the maximum speed of an emitted electron.

Justify your answer. **2**

Return to Wave Particle Duality Contents

2011

29. A metal plate emits electrons when certain wavelengths of electromagnetic radiation are incident on it. *Marks*



The work function of the metal is $2{\cdot}24 \times 10^{-19}$ J.

(*a*) Electrons are released when electromagnetic radiation of wavelength 525 nm is incident on the surface of the metal plate.

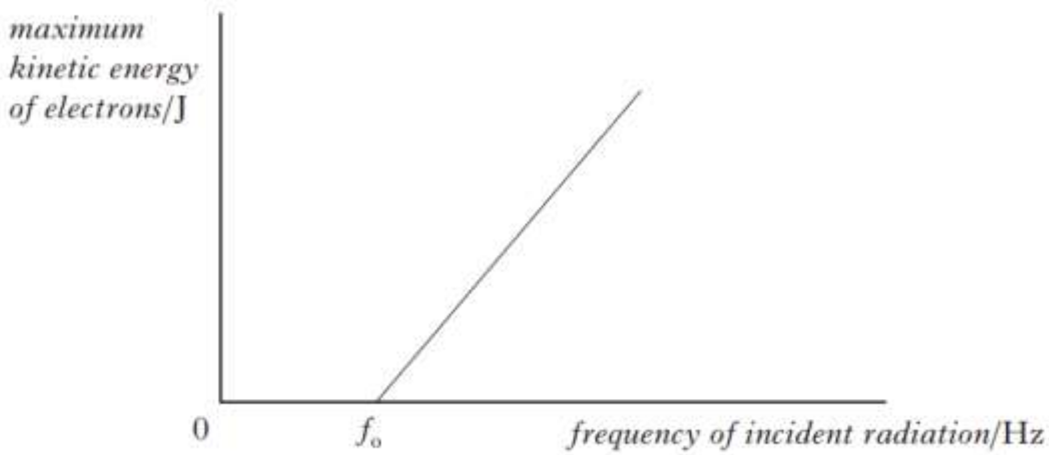
(i) Show that the energy of each photon of the incident radiation is $3{\cdot}79 \times 10^{-19}$ J. **2**

(ii) Calculate the maximum kinetic energy of an electron released from the surface of the metal plate. **1**

(*b*) The frequency of the incident radiation is now varied through a range of values.

The maximum kinetic energy of electrons leaving the metal plate is determined for each frequency.

A graph of this maximum kinetic energy against frequency is shown.



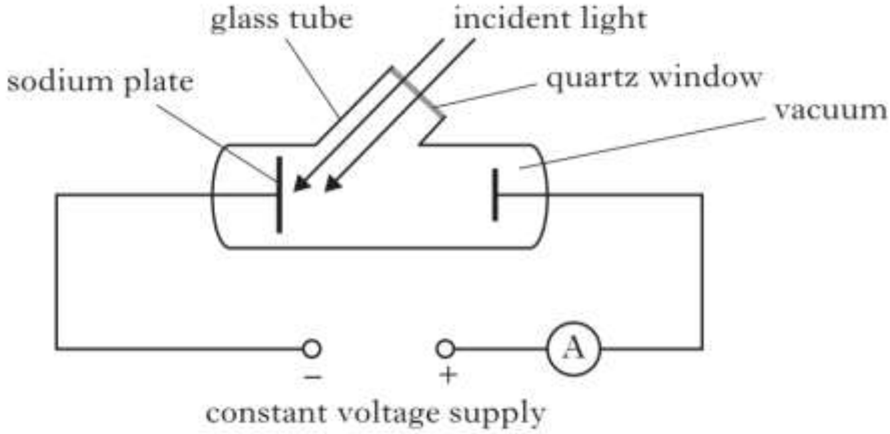
(i) Explain why the kinetic energy of the electrons is zero below the frequency f_o. **1**

(ii) Calculate the value of the frequency f_o. **2**

Return to Wave Particle Duality Contents

2014 RH

27. The following apparatus is set up in a physics laboratory to investigate the photoelectric effect.



The work function of sodium is $3{\cdot}78 \times 10^{-19}$ J.

Light of frequency $6{\cdot}74 \times 10^{14}$ Hz is incident on the sodium plate and photoelectrons are emitted.

(*a*) (i) Calculate the maximum kinetic energy of a photoelectron just as it is emitted from the sodium plate. **2**

(ii) Calculate the maximum velocity of a photoelectron just as it is emitted from the sodium plate. **2**

(*b*) The irradiance of this incident light is now decreased.

Explain how this affects the maximum velocity of a photoelectron just as it is emitted from the sodium plate. **2**

Return to Wave Particle Duality Contents

2015 RH

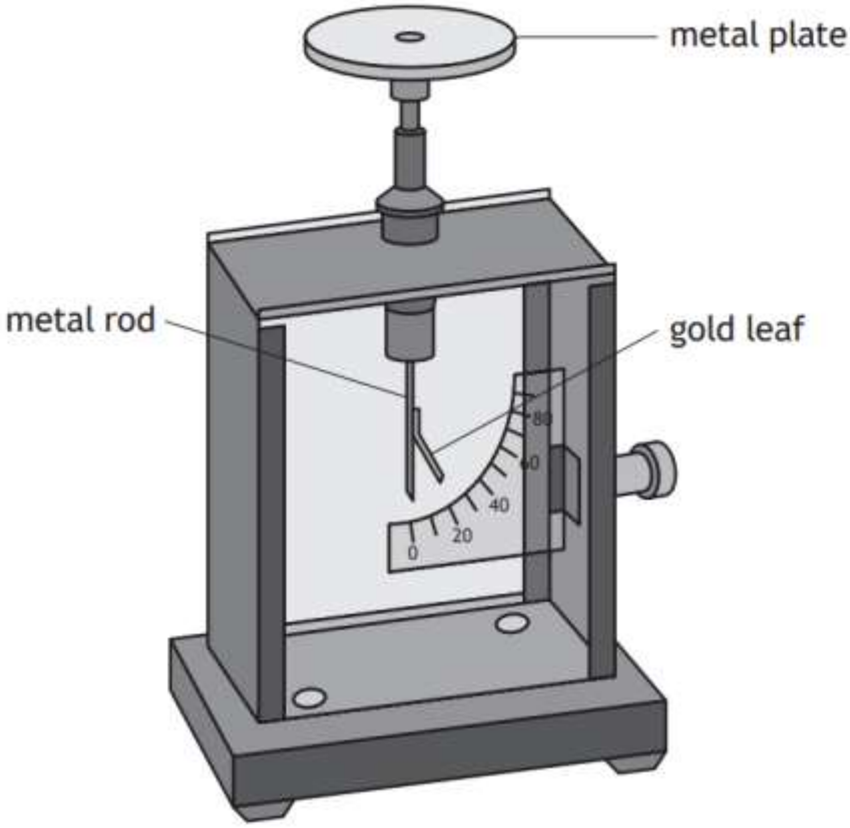
28. The use of analogies from everyday life can help better understanding of physics concepts. Throwing different balls at a coconut shy to dislodge a coconut is an analogy which can help understanding of the photoelectric effect.

Use your knowledge of physics to comment on this analogy **(3)**

2018

7. 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**

Return to Wave Particle Duality Contents

2018

7. (continued)

(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**

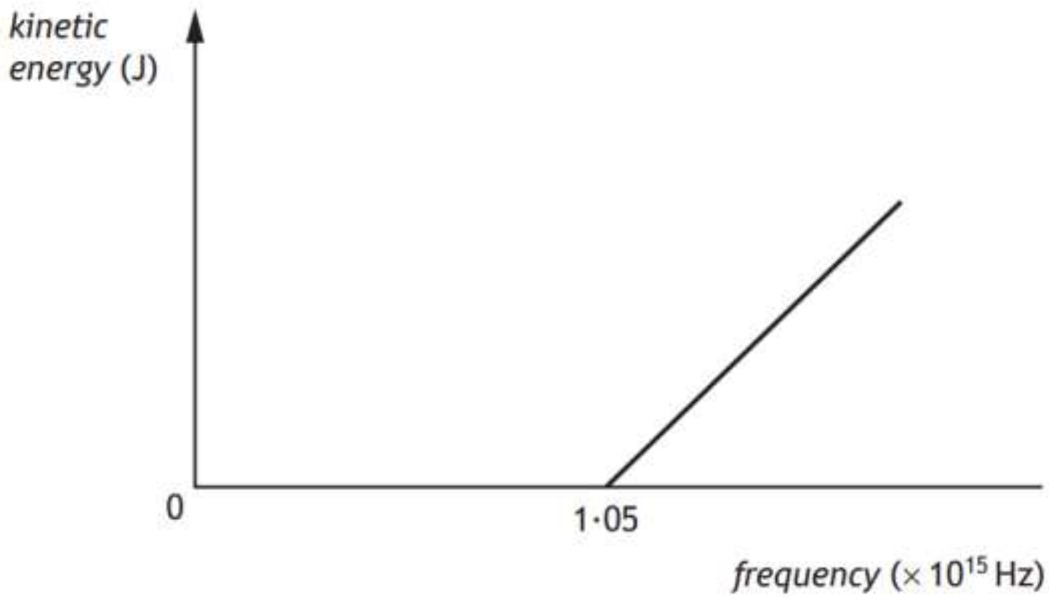
Justify your answer.

Return to Wave Particle Duality Contents

7. (continued)

(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**

Interference & Diffraction

2002 Q29 b(ii)

2003 Q28 a

2004 Q28 b

2005 Q28 b

2006 Q27 b

2007 Q28

2009 Q27

2010 Q27

2010 Q29 d

2011 Q28

2012 Q27

2013 Q28

2014 Q28

2015 Q29 b

2016 Q9

2017 Q10

2018 Q8

2019 Q10

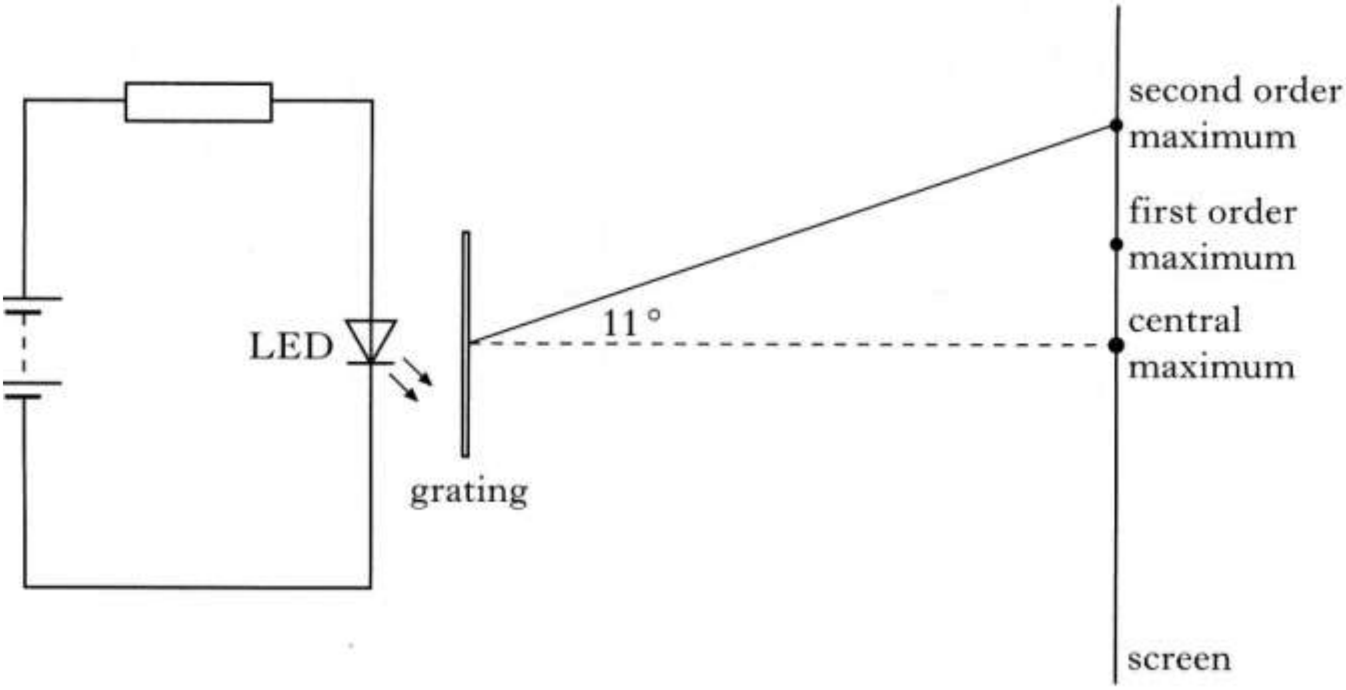
Return to Homework Contents

29.

2002

(ii) Monochromatic light from the LED is incident on a grating as shown.

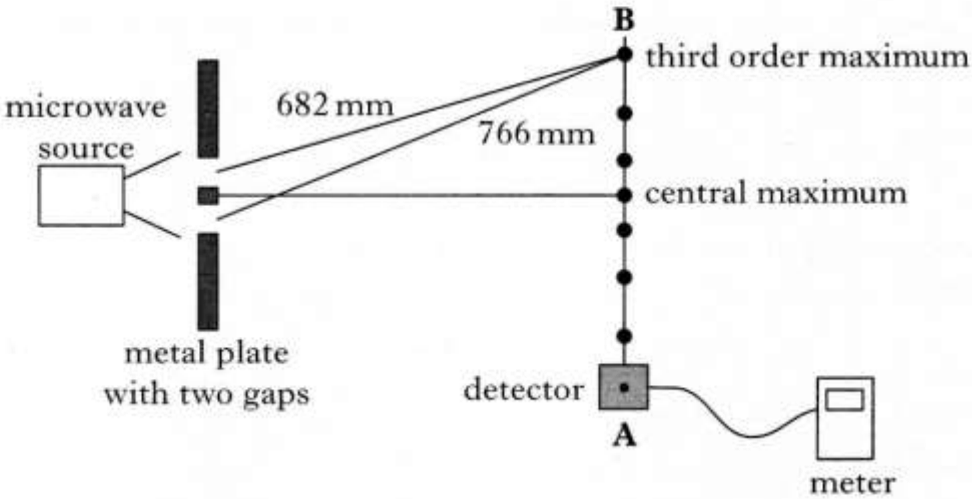
The spacing between lines in the grating is $5{\cdot}0 \times 10^{-6}$ m.



What is the wavelength of the light emitted by the LED? **4**

2003

28. (*a*) An experiment with microwaves is set up as shown below.



(i) As the detector is moved from **A** to **B**, the reading on the meter increases and decreases several times.

Explain, in terms of waves, how the pattern of maxima and minima is produced.

(ii) The measurements of the distance from each gap to a third order maximum are shown. Calculate the wavelength of the microwaves. **3**

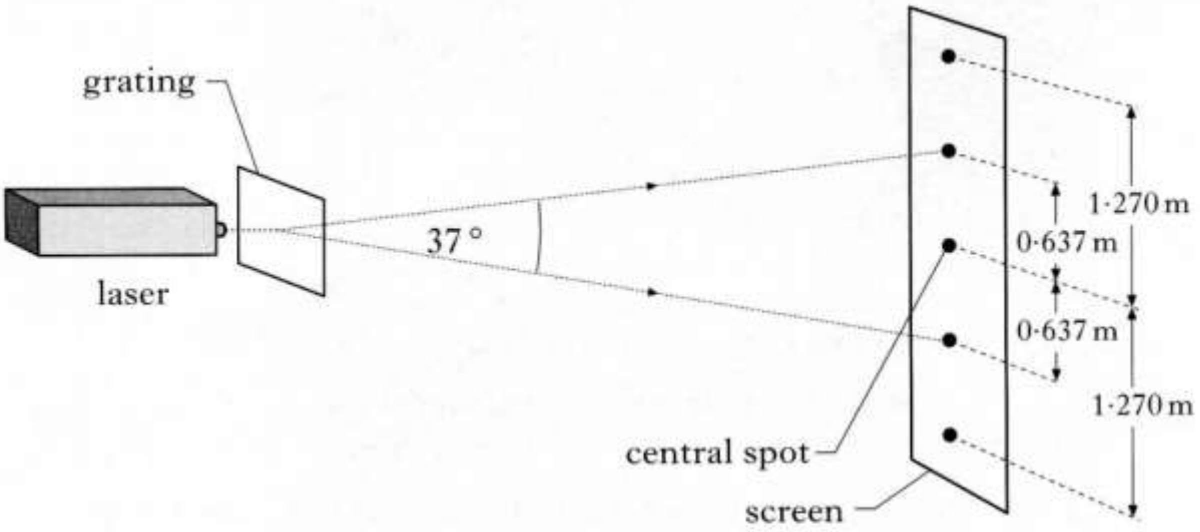
Return to Interference Contents

2004

28. The term LASER is short for "Light Amplification by the Stimulated Emission of Radiation".

(*b*) In an experiment, laser light of wavelength 633 nm is incident on a grating.

A series of bright spots are seen on a screen placed some distance from the grating. The distance between these spots and the central spot is shown.



Calculate the number of lines per metre on the grating. **3**

(*c*) The laser is replaced with another laser and the experiment repeated. With this laser the bright spots are closer together.

How does the wavelength of the light from this laser compare with that from the original laser?

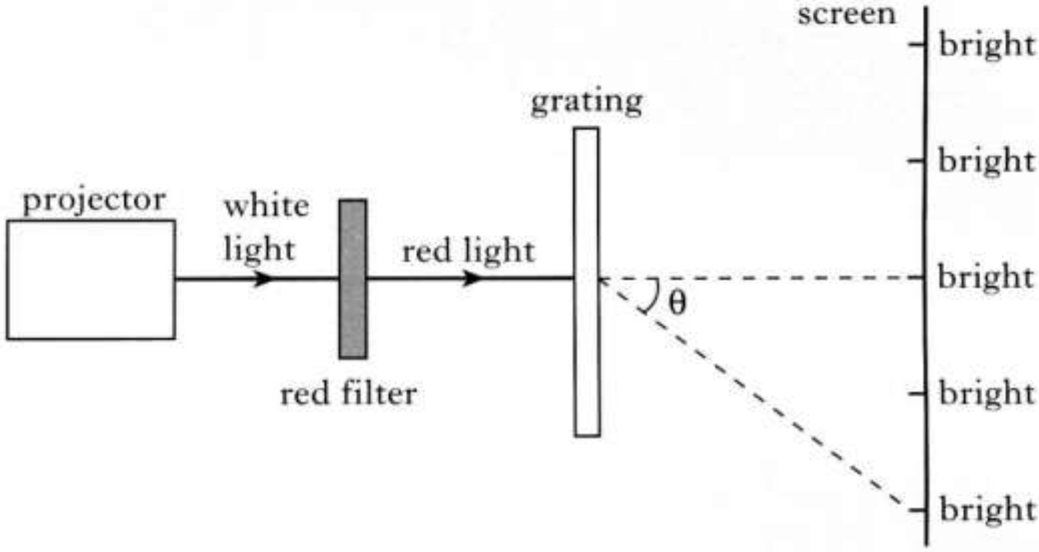
You must justify your answer. **2**

Return to Interference Contents

2005

28. A physics student investigates what happens when monochromatic light passes through a glass prism or a grating.

(*b*) The apparatus for the second experiment is shown below.



A pattern of bright and dark fringes is observed on the screen.

The grating has 300 lines per millimetre and the wavelength of the red light is 650 nm.

(i) Explain how the bright fringes are produced. **1**

(ii) Calculate the angle θ of the second order maximum. **2**

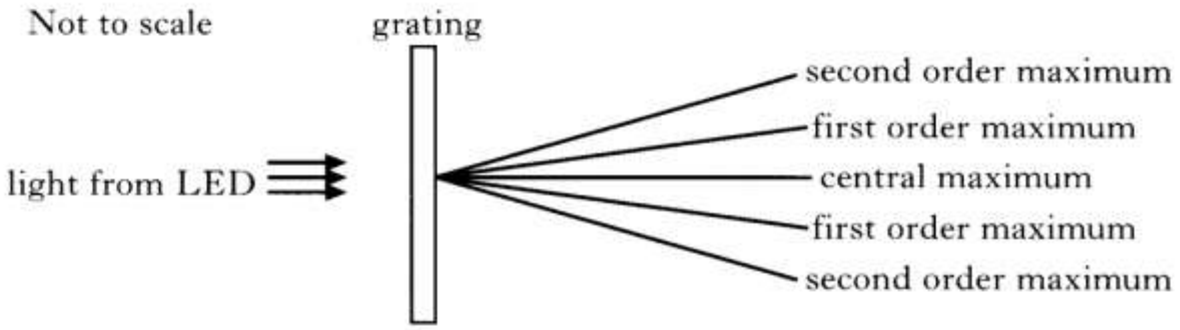
(iii) The red filter is replaced by a blue filter. Describe the effect of this change on the pattern observed.
Justify your answer. **1**

Return to Interference Contents

2006

27.

(*b*) Light from a different LED is passed through a grating as shown below.



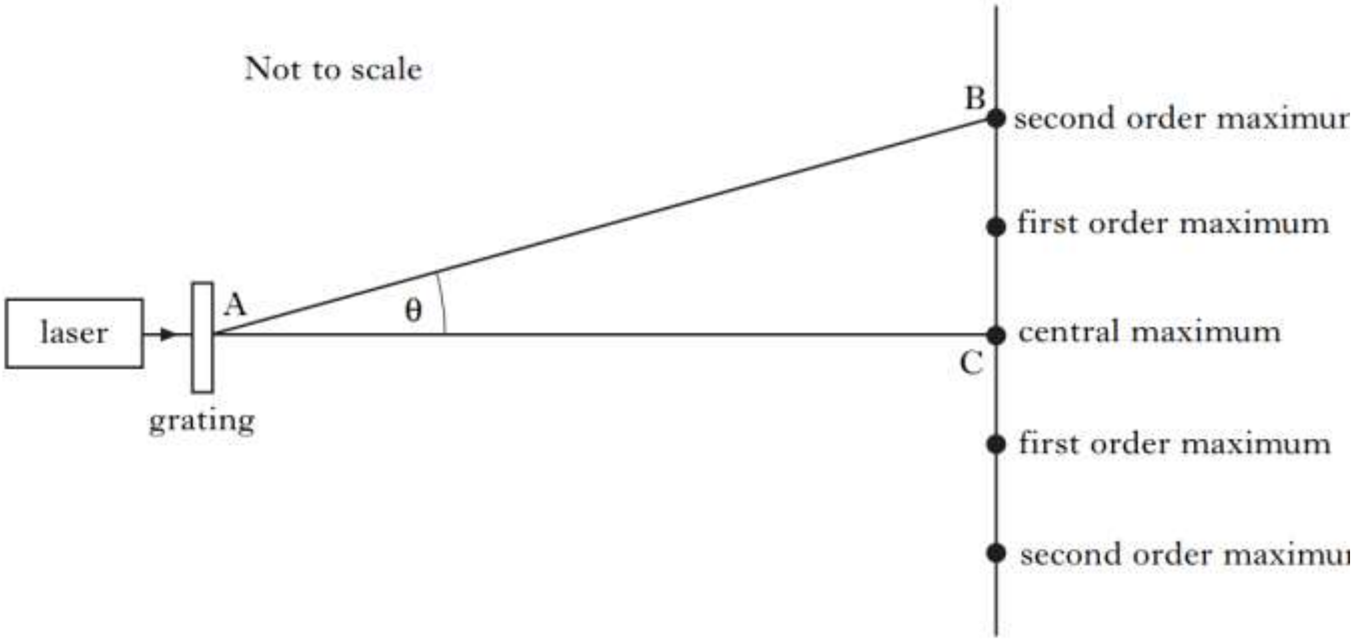
Light from this LED has a wavelength of $6{\cdot}35 \times 10^{-7}$ m. The spacing between lines in the grating is $5{\cdot}0 \times 10^{-6}$ m.

Calculate the angle between the central maximum and the **second** order maximum. **2**

Return to Interference Contents

2007

28. An experiment to determine the wavelength of light from a laser is shown.



A **second** order maximum is observed at point B.

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

(*b*) Distance AB is measured six times.

The results are shown.

1·11 m 1·08 m 1·10 m 1·13 m 1·11 m 1·07 m

(i) Calculate:

(A) the mean value for distance AB; **1**

(B) the approximate random uncertainty in this value. **1**

(ii) Distance BC is measured as (270 ± 10) mm.

Show whether AB or BC has the larger percentage uncertainty. **2**

(iii) The spacing between the lines on the grating is $4{\cdot}00 \times 10^{-6}$ m.

Calculate the wavelength of the light from the laser.

Express your answer in the form

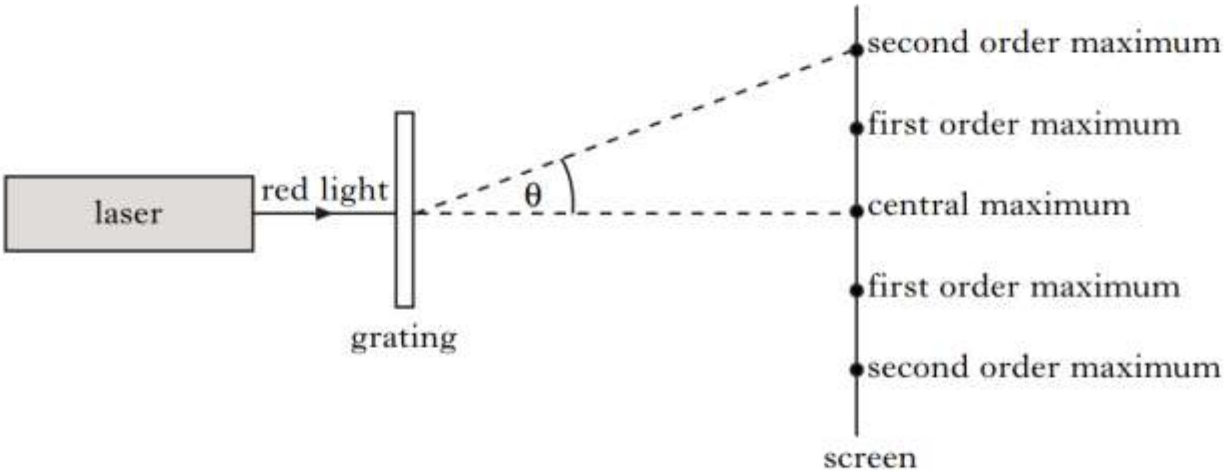
wavelength ± **absolute** uncertainty **3**

Return to Interference Contents

2009

27. A laser produces a narrow beam of monochromatic light.

(*a*) Red light from a laser passes through a grating as shown.



A series of maxima and minima is observed.

Explain in terms of waves how a **minimum** is produced. **1**

(*b*) The laser is now replaced by a second laser, which emits blue light.

Explain why the observed maxima are now closer together. **1**

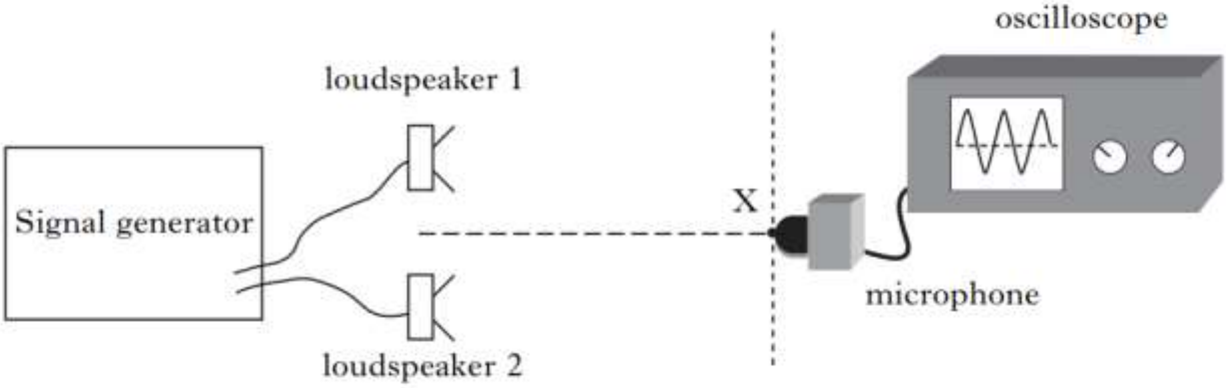
(*c*) The wavelength of the blue light from the second laser is $4{\cdot}73 \times 10^{-7}$ m. The spacing between the lines on the grating is $2{\cdot}00 \times 10^{-6}$ m.

Calculate the angle between the central maximum and the second order maximum. **2**

Return to Interference Contents

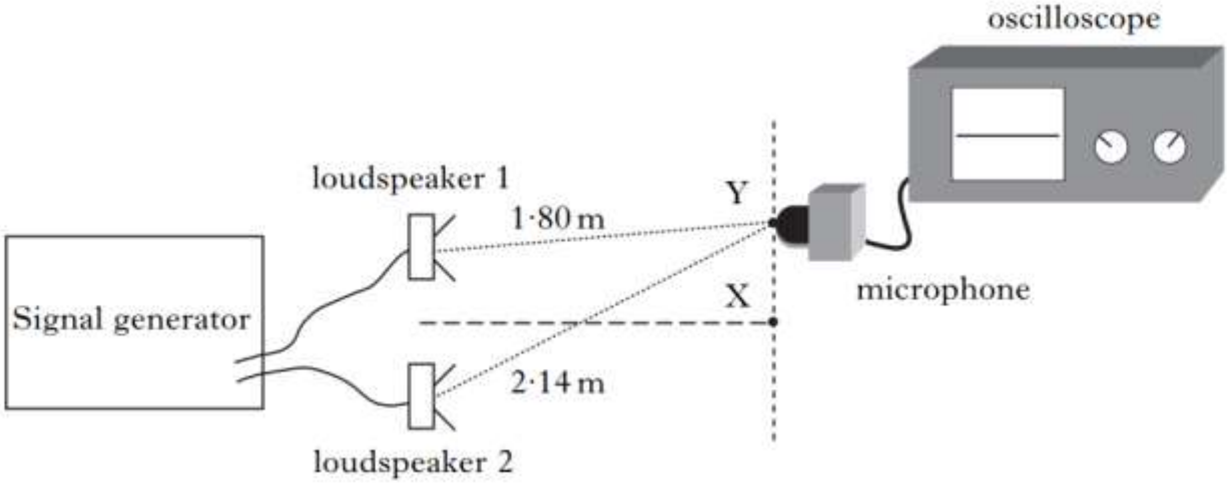
2010

27. A student is carrying out an experiment to investigate the interference of sound waves. She sets up the following apparatus.



The microphone is initially placed at point X which is the same distance from each loudspeaker. A maximum is detected at X.

(*a*) The microphone is now moved to the first minimum at Y as shown.



Calculate the wavelength of the sound waves. **2**

(*b*) Loudspeaker 1 is now disconnected.

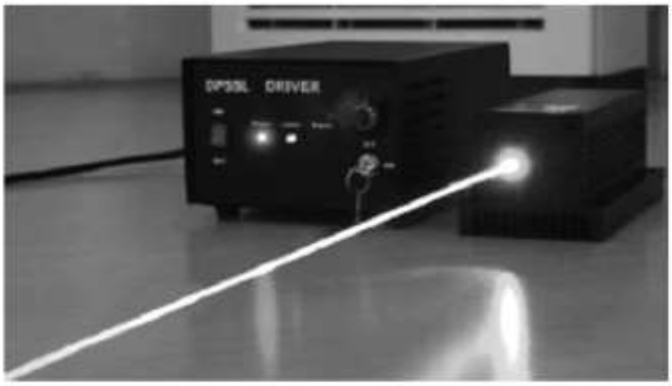
What happens to the amplitude of the sound detected by the microphone at Y?

Explain your answer. **2**

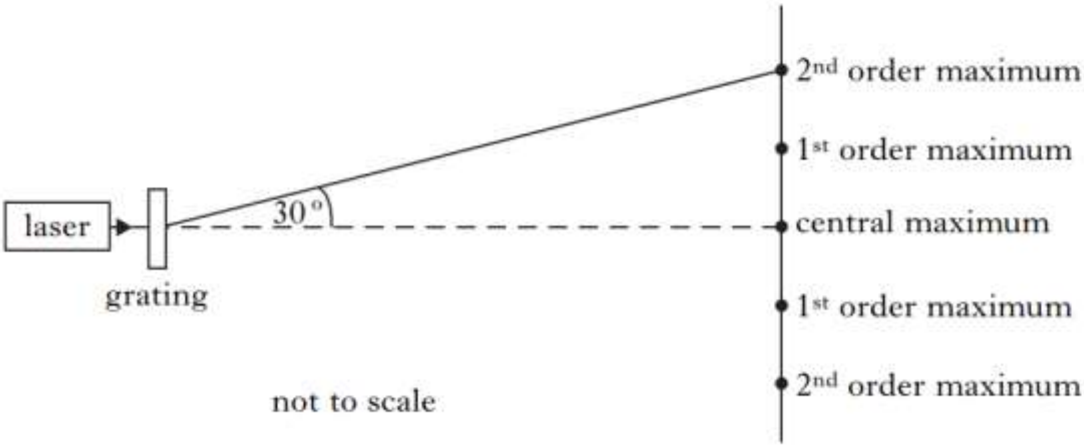
Return to Interference Contents

2010

29. A laser produces a beam of light with a frequency of $4{\cdot}74 \times 10^{14}$ Hz.



(*d*) This laser beam is now incident on a grating as shown below.



The second order maximum is detected at an angle of 30° from the central maximum.

Calculate the separation of the slits on the grating. **3**

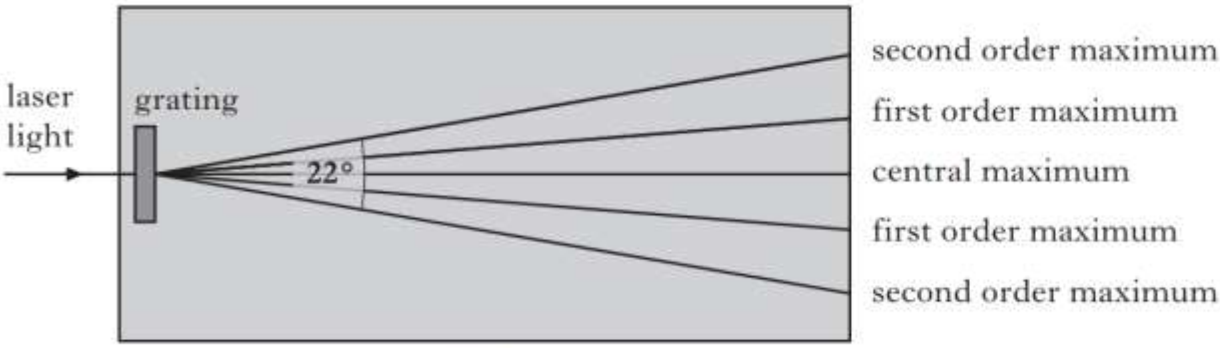
Return to Interference Contents

2011

28. (*a*) The first demonstration of the interference of light was performed by Thomas Young in 1801.

What does the demonstration of interference prove about light? **1**

(*b*) A grating is placed in a colourless liquid in a container. Laser light is incident on the grating along the normal. The spacing between the lines on the grating is $5{\cdot}0 \times 10^{-6}$ m. Interference occurs and the maxima produced are shown in the diagram.



container filled with a colourless liquid

(i) Calculate the wavelength of the laser light in the liquid. **2**

(ii) The refractive index of the colourless liquid decreases as the temperature of the liquid increases.

The liquid is now heated.

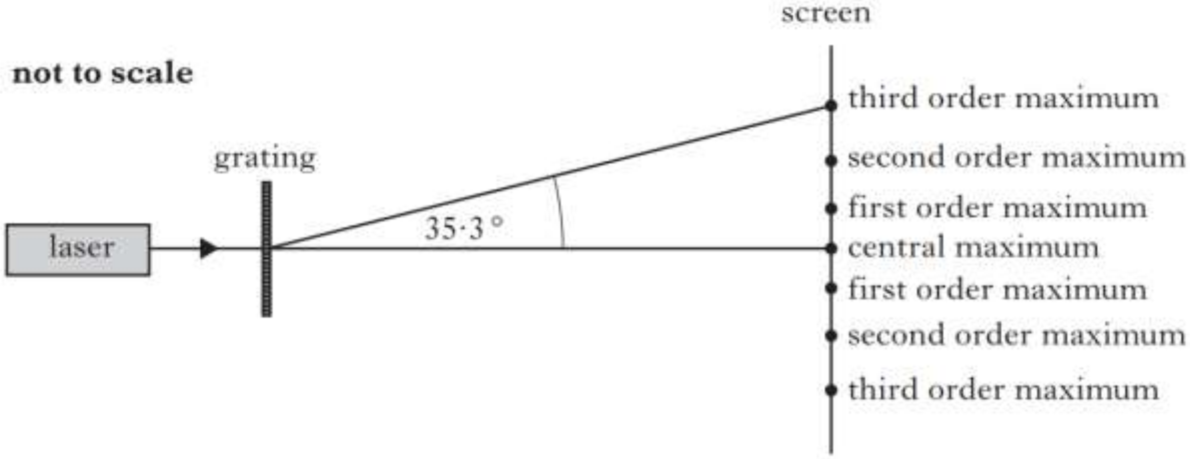
What effect does this have on the spacing between the maxima?

You must justify your answer. **2**

Return to Interference Contents

2012 RH

27. A manufacturer claims that a grating consists of $3{\cdot}00 \times 10^5$ lines per metre and is accurate to ± 2·0%. A technician decides to test this claim. She directs laser light of wavelength 633 nm onto the grating.



She measures the angle between the central maximum and the third order maximum to be 35·3 °.

(*a*) Calculate the value she obtains for the slit separation for this grating. **2**

(*b*) What value does she determine for the number of lines per metre for this grating? **1**

(*c*) Does the technician's value for the number of lines per metre agree with the manufacturer's claim of $3{\cdot}00 \times 10^5$ lines per metre ± 2·0%?

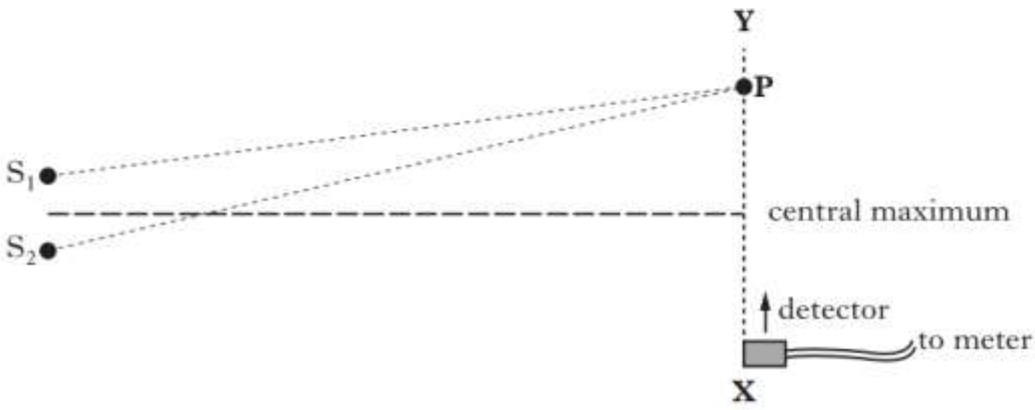
You must justify your answer by calculation. **2**

Return to Interference Contents

2013 RH

28. A student is using different types of electromagnetic radiation to investigate interference.

(*a*) In the first experiment, two identical sources of microwaves, S_1 and S_2, are positioned a short distance apart as shown.



(i) The student moves a microwave detector from X towards Y. The reading on the meter increases and decreases regularly.

Explain, in terms of waves, what causes the minimum readings to occur. **1**

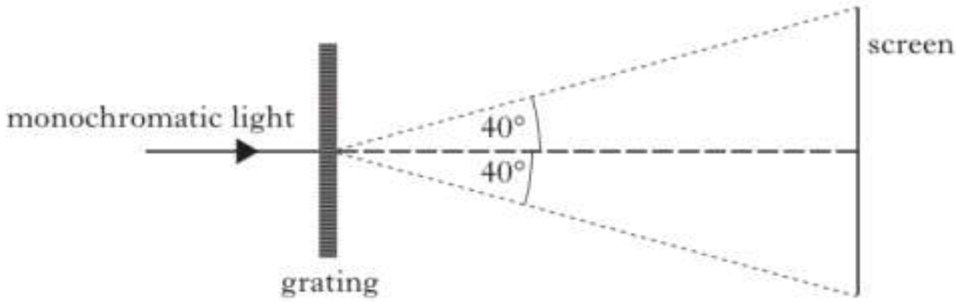
(ii) The **third** maximum from the central maximum is located at P.

The distance from S_1 to P is 620 mm.

The wavelength of the waves is 28 mm.

Calculate the distance from S_2 to P. **2**

(*b*) (i) In the second experiment, a beam of parallel, monochromatic light is incident on a grating. An interference pattern is produced on a screen. The edges of the screen are at an angle of 40° to the centre of the grating as shown.



The wavelength of the light is 420 nm and the separation of the slits on the grating is $3{\cdot}27 \times 10^{-6}$ m.

Determine the total number of maxima visible on the screen. **3**

(ii) The experiment is now repeated using a source of monochromatic red light.

How does the total number of maxima visible on the screen compare to the answer to part (*b*)(i)?

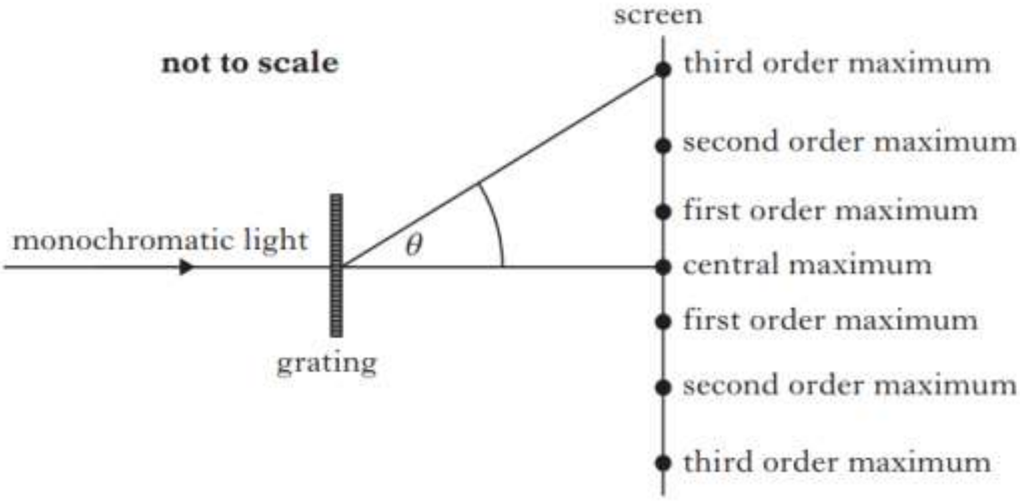
Justify your answer. **2**

Return to Interference Contents

2014 RH

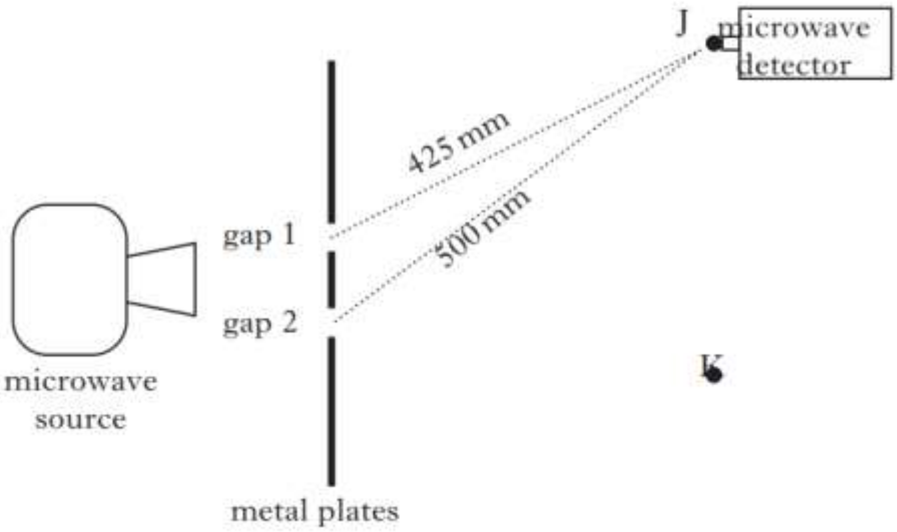
28. Two experiments are carried out to study the interference of waves.

(*a*) In the first experiment, monochromatic light of wavelength 589 nm passes through a grating. The distance between the slits on the grating is $5{\cdot}0 \times 10^{-6}$ m.



Calculate the angle θ between the central maximum and the third order maximum. **2**

(*b*) In the second experiment, microwaves of wavelength 30 mm pass through two gaps between metal plates as shown.



(i) The distances from each of the gaps to point J are shown in the diagram.

Use this information to determine whether J is a point of constructive or destructive interference.

You must justify your answer by calculation. **2**

(ii) The microwave detector is now moved to K, which is a point of destructive interference.

Gap 1 is then covered with a sheet of metal.

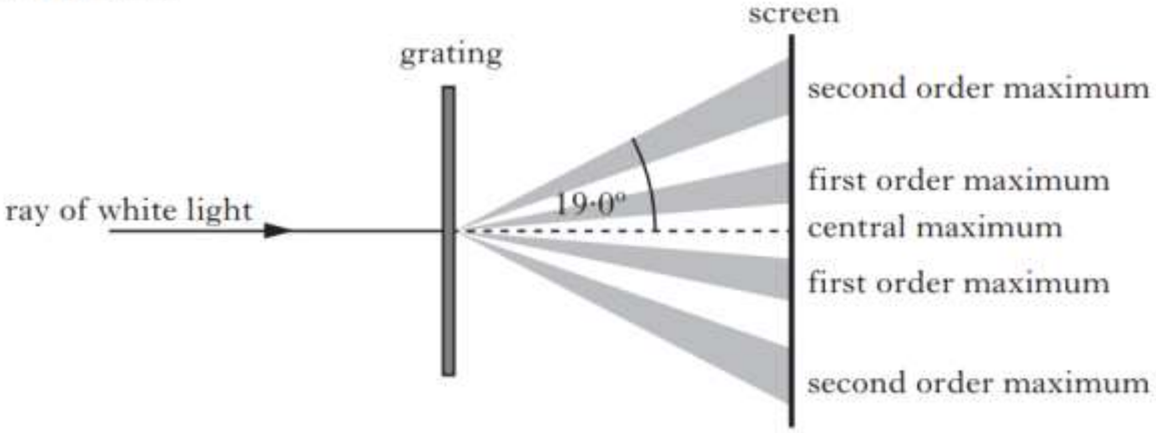
Does the strength of the signal detected at K increase, decrease or stay the same? You must justify your answer. **2**

Return to Interference Contents

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

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

not to scale



The angle between the central maximum and the second order maximum for red light is 19·0°.

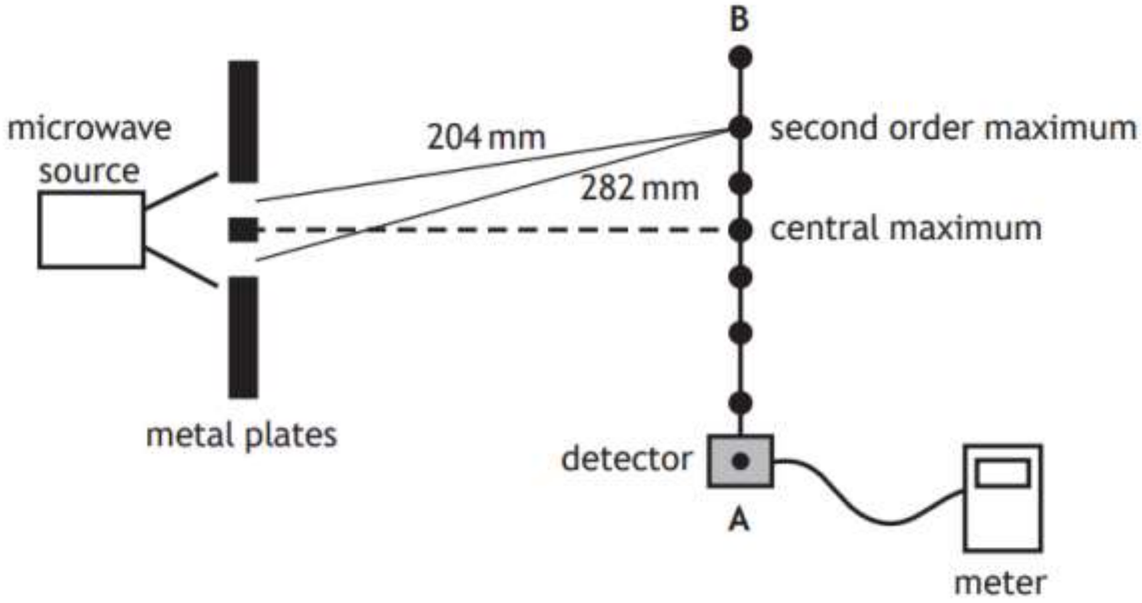
The frequency of this red light is $4{\cdot}57 \times 10^{14}$ Hz.

(i) Calculate the distance between the slits on this grating. **3**

(ii) Explain why the angle to the second order maximum for blue light is different to that for red light. **2**

2016

9. 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.

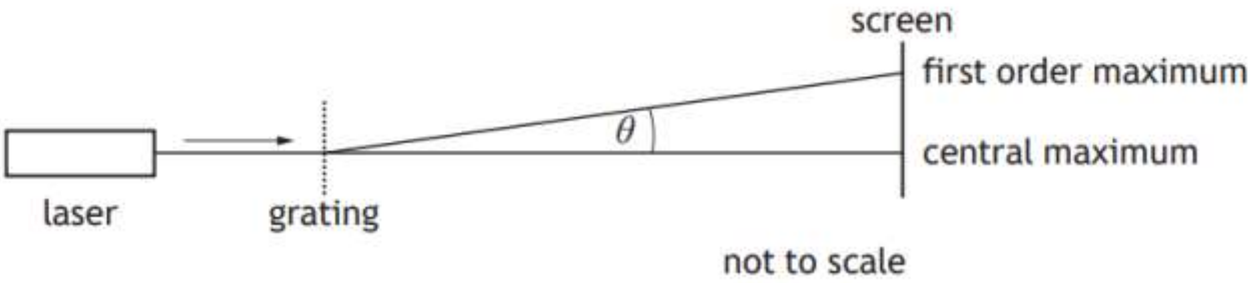
State what happens to the path difference to the second order maximum.

Justify your answer. **2**

Return to Interference Contents

2017

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



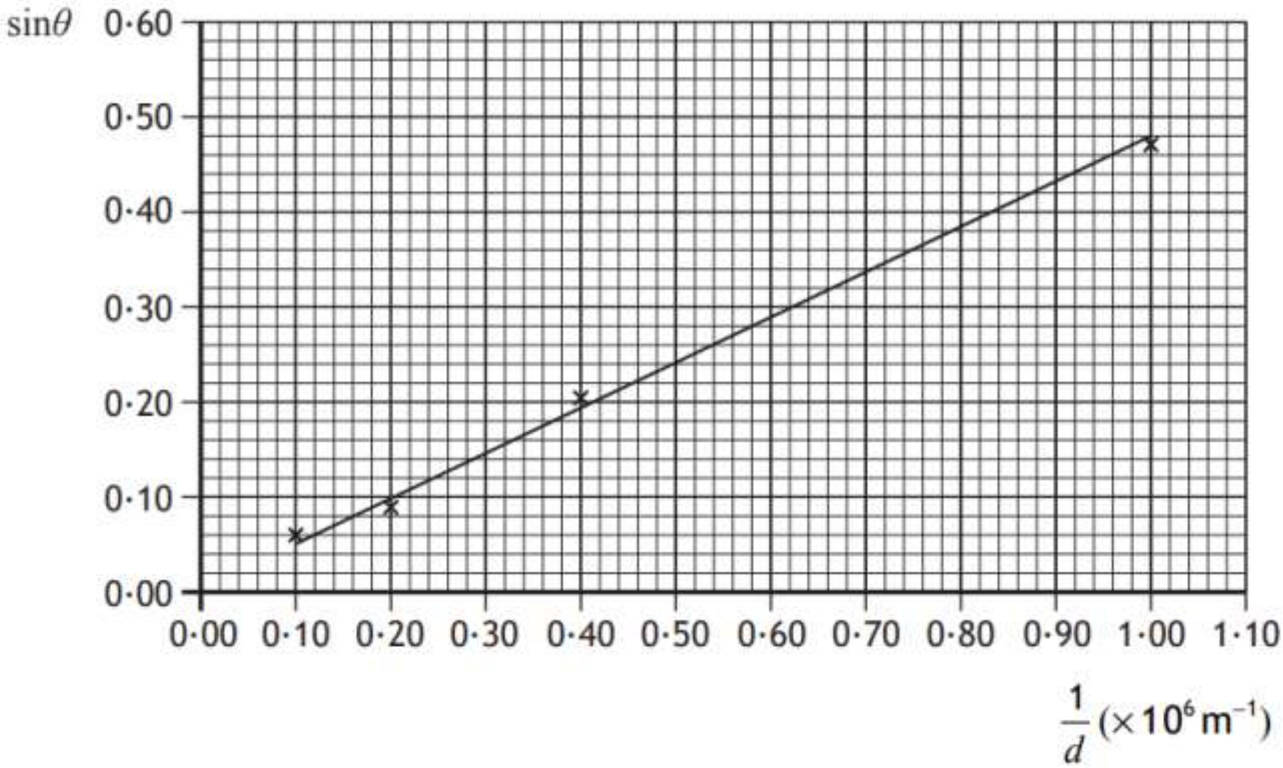
(a) Explain, in terms of waves, how a maximum is formed.

(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 $\frac{1}{d}$.



Return to Interference Contents

2017

10. (b) (continued)

(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**

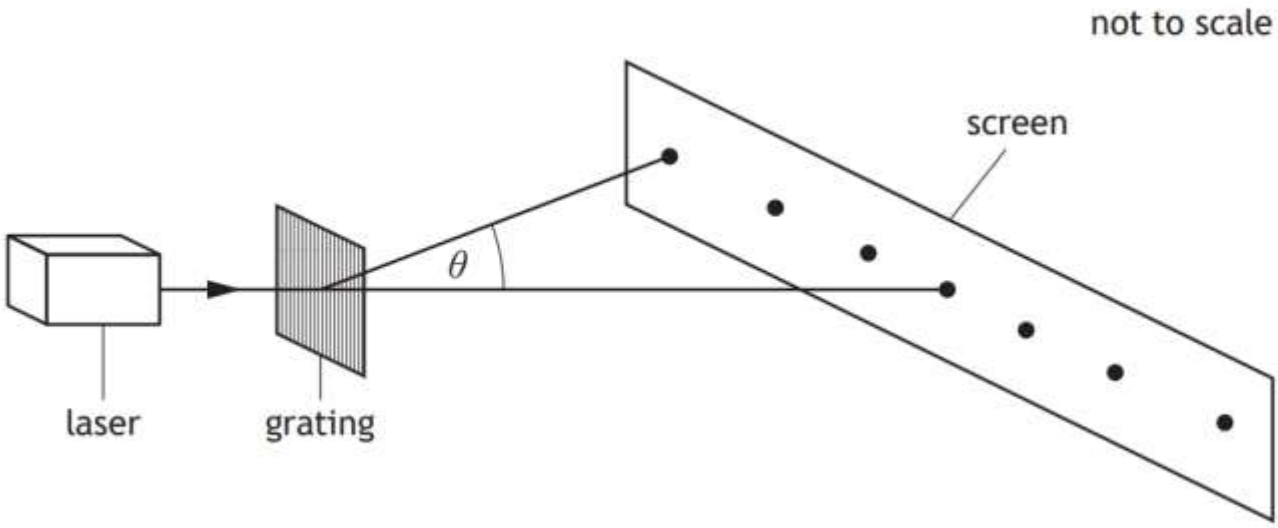
Space for working and answer

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

Return to Interference Contents

2018

8. 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**

2018

8. (a) (continued)

(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**

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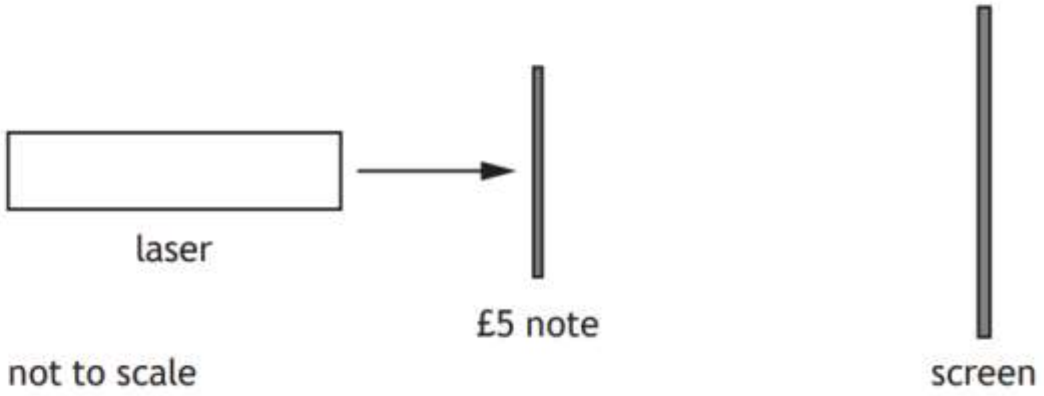
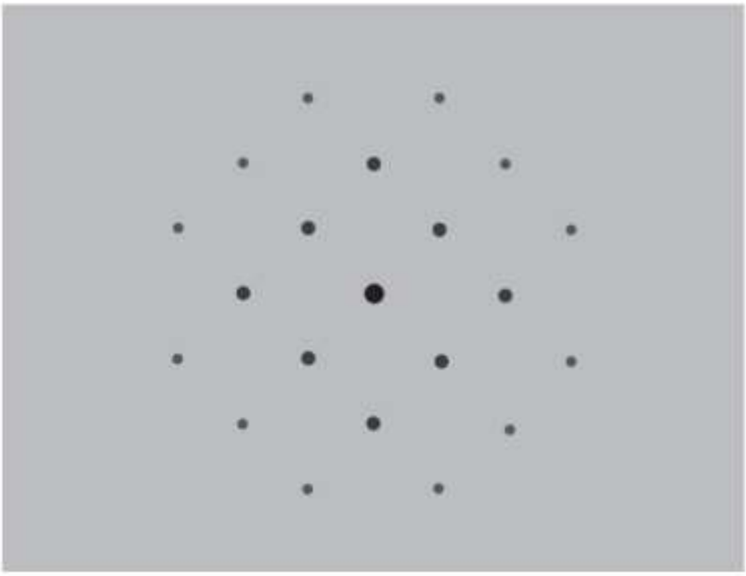
2018

(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.

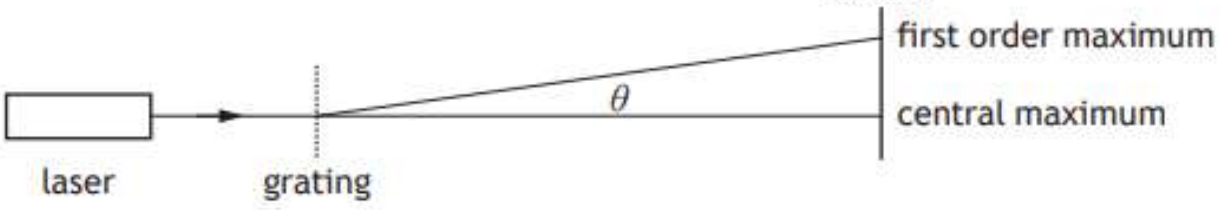


Suggest a reason for the difference in the pattern produced using the £5 note and the pattern produced using the grating. **1**

Return to Interference Contents

2019

10. A student carries out an experiment to investigate the effect of a grating on beams of light from three different lasers.



The three different lasers produce red, green and blue light respectively.

Each laser beam is directed in turn towards the grating.

The grating has a slit separation of $3{\cdot}3 \times 10^{-6}$ m.

(a) State which of these three colours of laser light would produce the smallest angle θ between the central maximum and the first order maximum.

Justify your answer. **3**

(b) The angle θ between the central maximum and the first order maximum for light from one of the lasers is $8{\cdot}9°$.

(i) Calculate the wavelength of this light. **3**

(ii) Determine the colour of the light from this laser. **1**

(iii) Another student suggests that a more accurate value for the wavelength of this laser light can be found if a grating with a slit separation of $5{\cdot}0 \times 10^{-6}$ m is used.

Explain why this suggestion is incorrect. **2**

Return to Interference Contents

Refraction of Light

2000 Q27

2001 Q27 b

2002 Q27

2003 Q27 b

2004 Q27

2005 Q28 a

2007 Q29

2008 Q27

2009 Q28 b

2010 Q28 b

2011 Q27

2012 Q29

2013 Q29

2014 Q29

2015 Q29 a

2016 Q10

2017 Q11

2018 Q9

2019 Q11

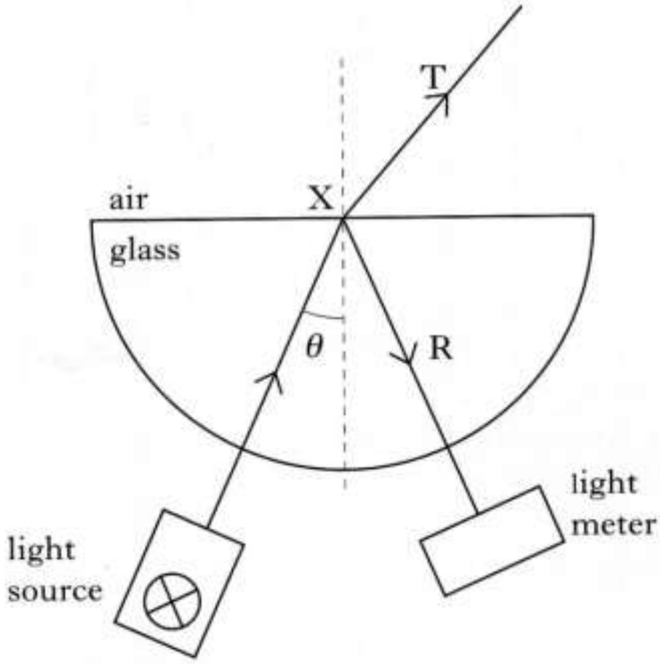
Return to Homework Contents

2000

27. A student is investigating the effect that a semicircular glass block has on a ray of monochromatic light.

She observes that at point X the incident ray splits into two rays:

T — a transmitted ray
R — a reflected ray.



The student uses a light meter to measure the intensity of ray R as angle θ is changed.

(*a*) State what is meant by the *intensity* of a radiation. **1**

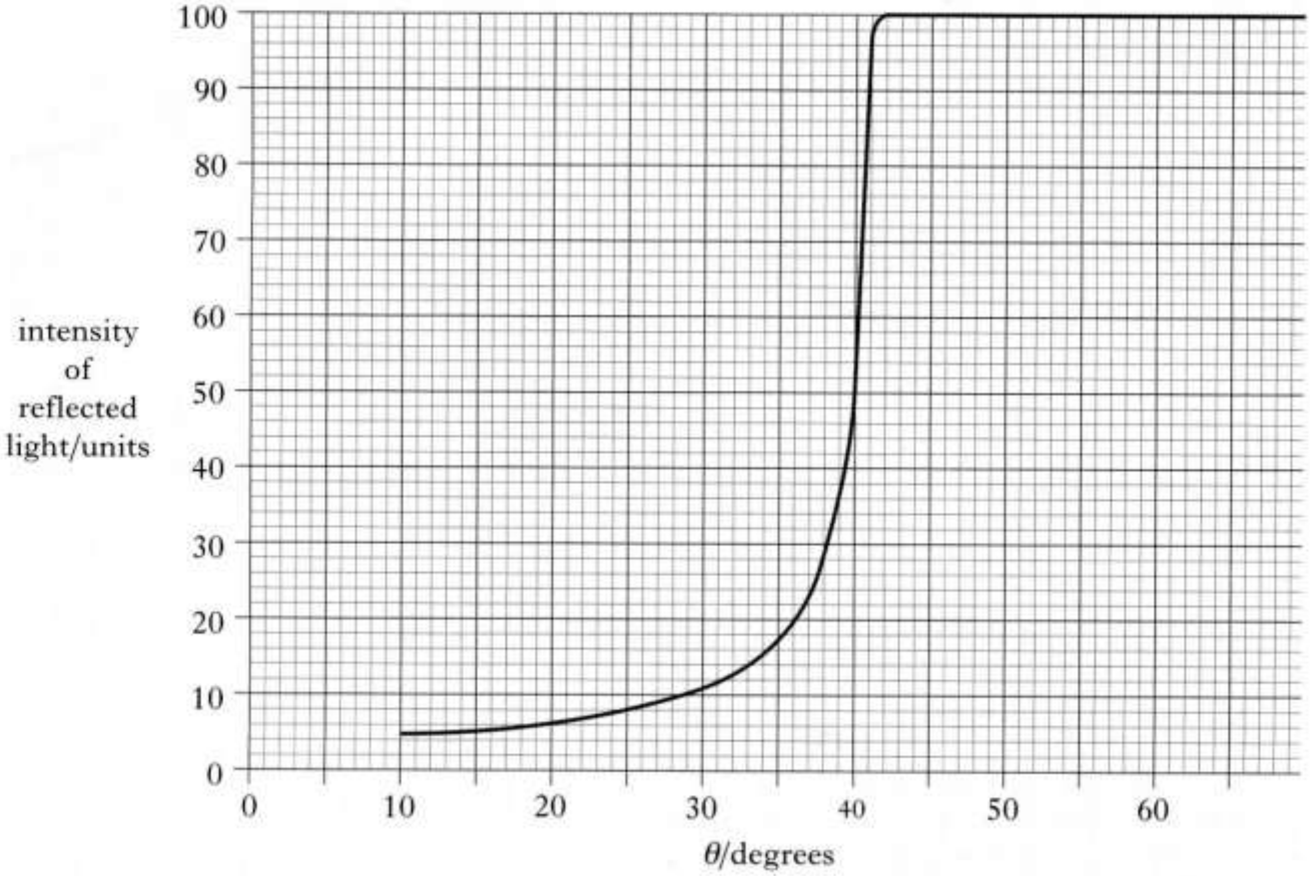
(*b*) Explain why, as angle θ is changed, it is important to keep the light meter at a constant distance from point X for each measurement of intensity. **1**

Return to Refraction of Light Contents

Mark:

27. (continued)

(c) The graph below is obtained from the student's results.



(i) What is the value of the critical angle in the glass for this light?

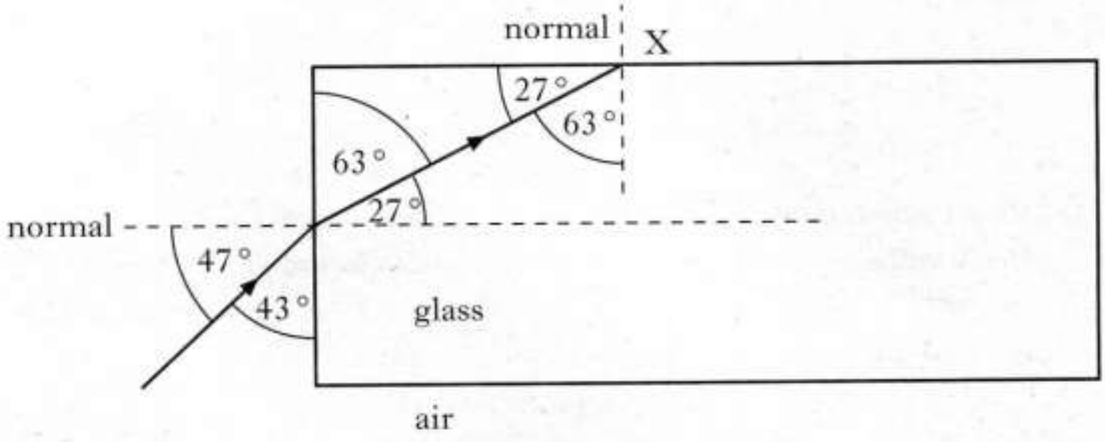
(ii) Calculate the refractive index of the glass for this light.

(iii) As the angle θ is increased, what happens to the intensity of ray T? **4**

Return to Refraction of Light Contents

2001

27. (*b*) A ray of monochromatic light passes from air into a block of glass as shown.



(i) Using information from the diagram, show that the refractive index of the glass for this light is 1·61.

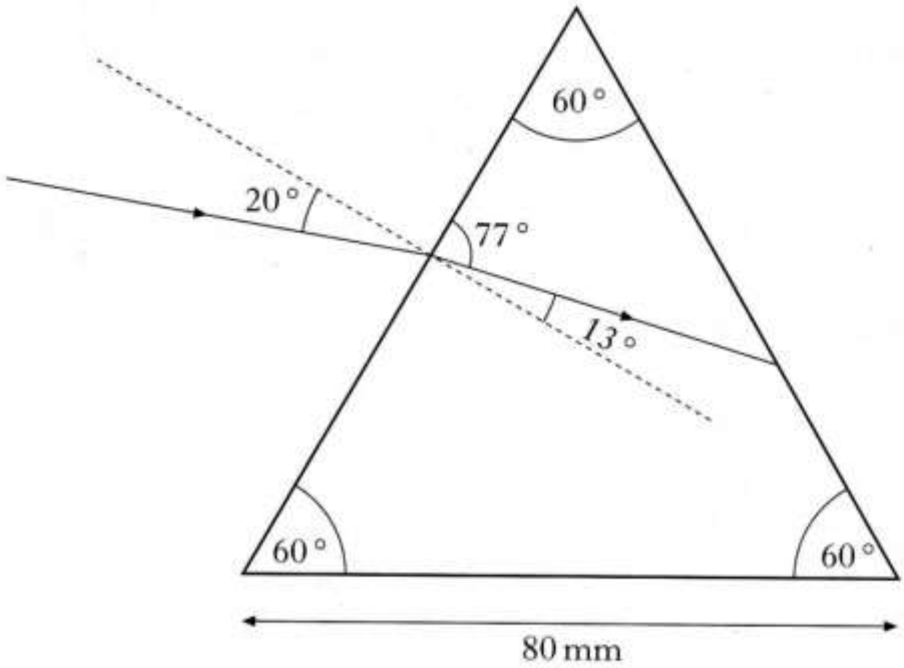
(ii) Show by calculation whether the ray is totally internally reflected at point X. **4**

Return to Refraction of Light Contents

2002

Marks

27. A ray of red light is directed at a glass prism of side 80 mm as shown in the diagram below.



(*a*) Using information from this diagram, show that the refractive index of the glass for this red light is 1·52. **1**

(*b*) What is meant by the term *critical angle*? **1**

(*c*) Calculate the critical angle for the red light in the prism. **2**

(*d*) Sketch a diagram showing the path of the ray of red light until after it leaves the prism. Mark on your diagram the values of all relevant angles. **3**

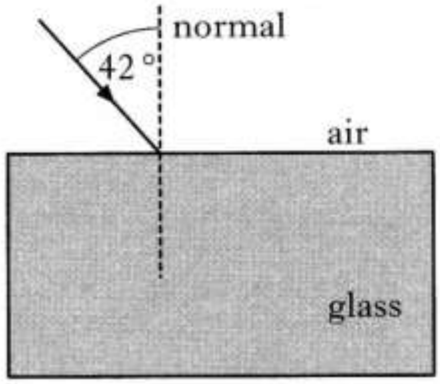
Return to Refraction of Light Contents

27.

2003

(*b*) A laser produces light of frequency $4 \cdot 74 \times 10^{14}$ Hz in air.

A ray of light from this laser is directed into a block of glass as shown below.



The refractive index of the glass for this light is 1·60.

(i) What is the value of the frequency of the light in the block of glass?

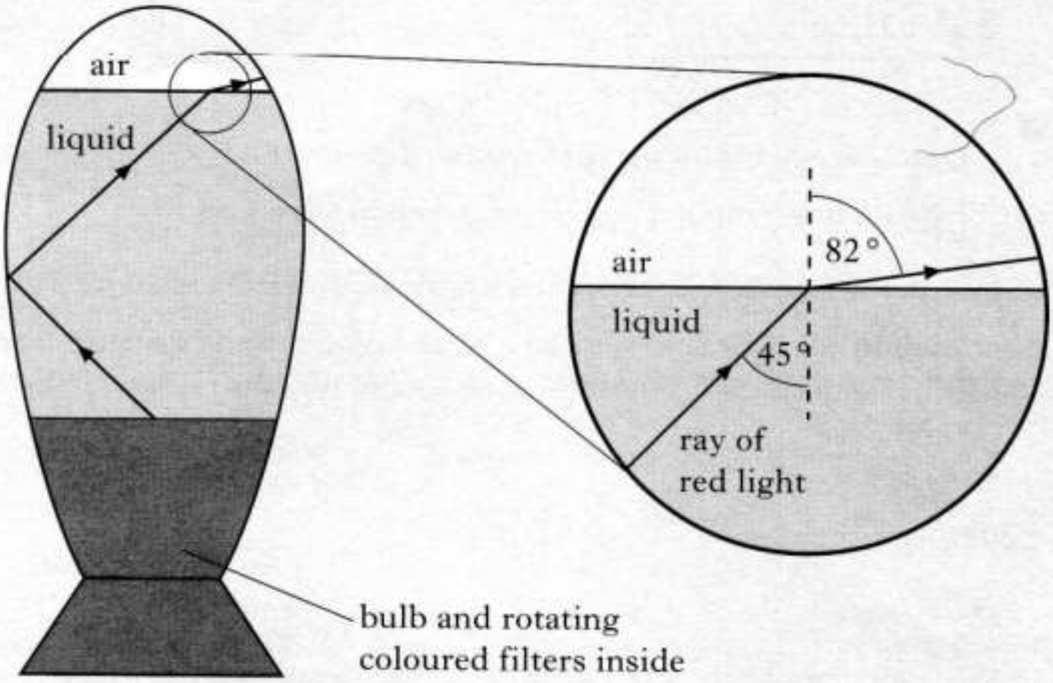
(ii) Calculate the wavelength of the light in the glass. **4**

Return to Refraction of Light Contents

2004

27. A decorative lamp has a transparent liquid in the space above a bulb. Light from the bulb passes through rotating coloured filters giving red or blue light in the liquid.

(*a*) A ray of red light is incident on the liquid surface as shown.



(i) Calculate the refractive index of the liquid for the red light.

(ii) A ray of blue light is incident on the liquid surface at the same angle as the ray of red light.

The refractive index of the liquid for blue light is greater than that for red light. Is the angle of refraction greater than, equal to or less than 82 ° for the blue light?

You must explain your answer. **3**

(*b*) A similar lamp contains a liquid which has a refractive index of 1·44 for red light. A ray of red light in the liquid is incident on the surface at an angle of 45 ° as before.

Sketch a diagram to show the path of this ray after it is incident on the liquid surface.

Mark on your diagram the values of all appropriate angles.

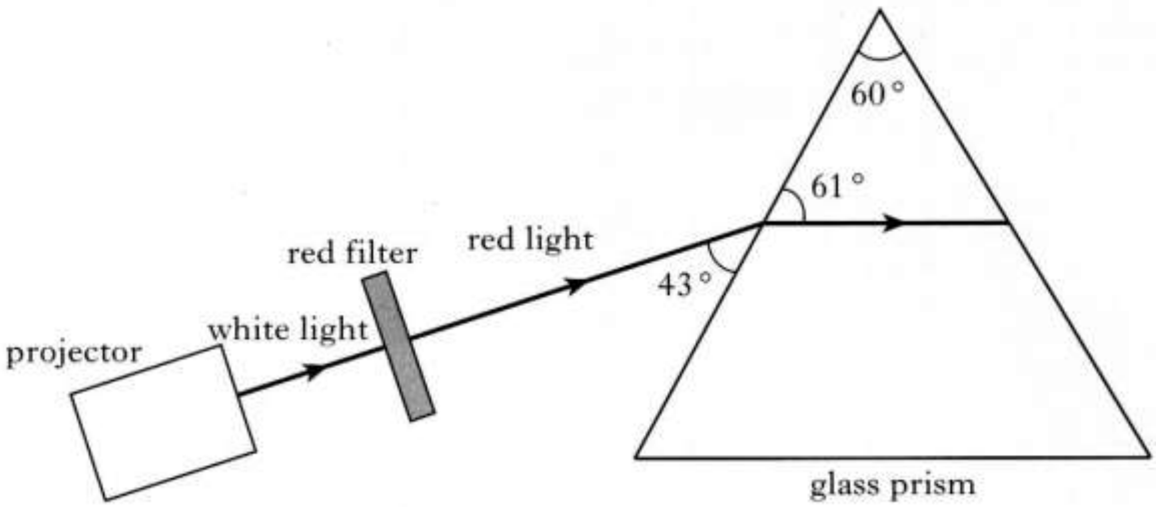
All relevant calculations must be shown. **3**

Return to Refraction of Light Contents

2005

28. A physics student investigates what happens when monochromatic light passes through a glass prism or a grating.

(*a*) The apparatus for the first experiment is shown below.



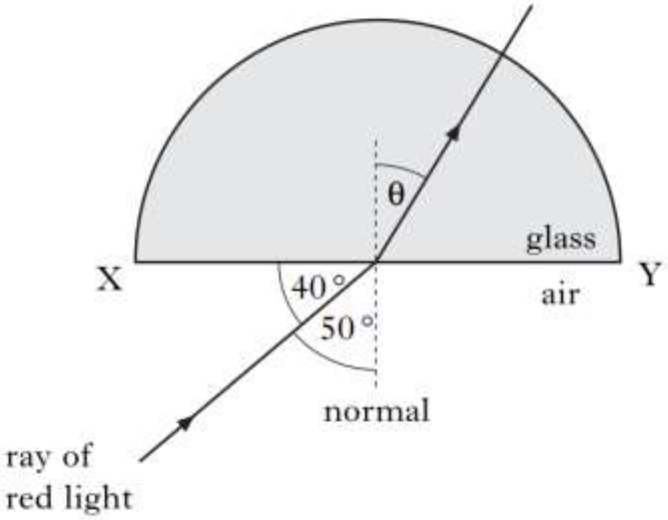
(i) Calculate the refractive index of the glass for the red light. **2**

(ii) Sketch a diagram which shows the ray of red light before, during and after passing through the prism. Mark on your diagram the values of all relevant angles. **2**

Return to Refraction of Light Contents

2007

29. A ray of red light is incident on a semicircular block of glass at the mid point of XY as shown.



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

(*a*) Calculate angle θ shown on the diagram. **2**

(*b*) The wavelength of the red light **in the glass** is 420 nm.

Calculate the wavelength of the light in air. **2**

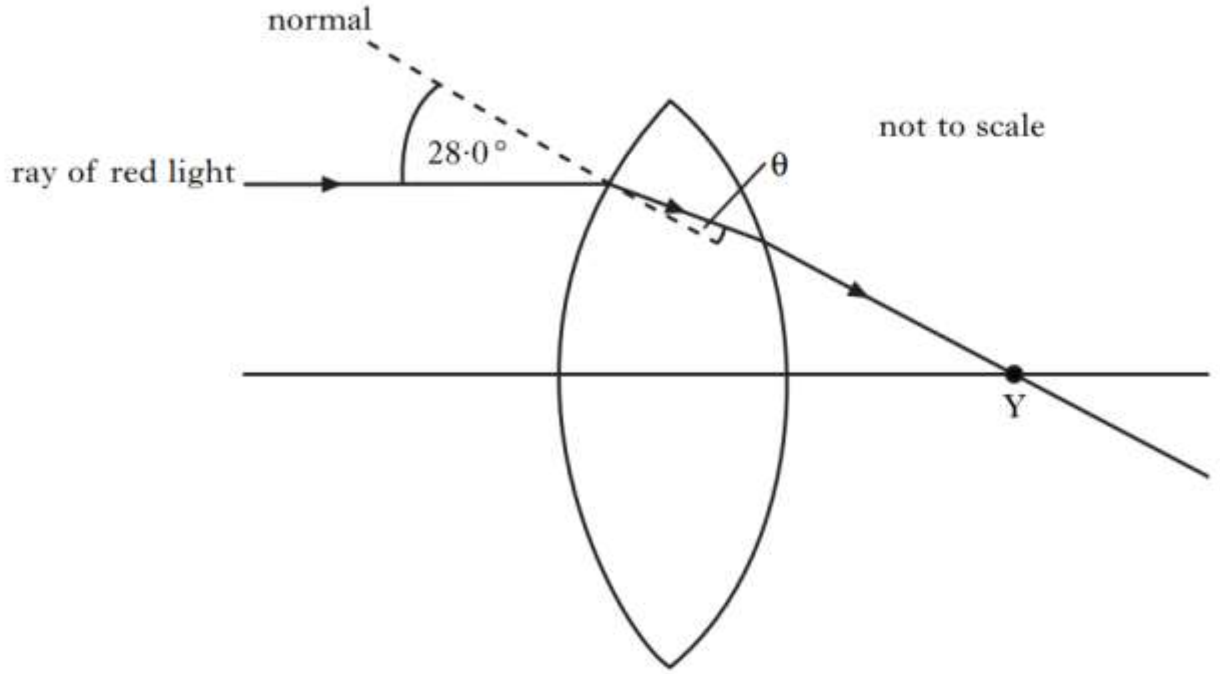
(*c*) The ray of red light is replaced by a ray of blue light incident at the same angle. The blue light enters the block at the same point.

Explain why the path taken by the blue light in the block is different to that taken by the red light. **1**

Return to Refraction of Light Contents

2008

27. (*a*) A ray of red light of frequency $4{\cdot}80 \times 10^{14}$ Hz is incident on a glass lens as shown.



The ray passes through point Y after leaving the lens.

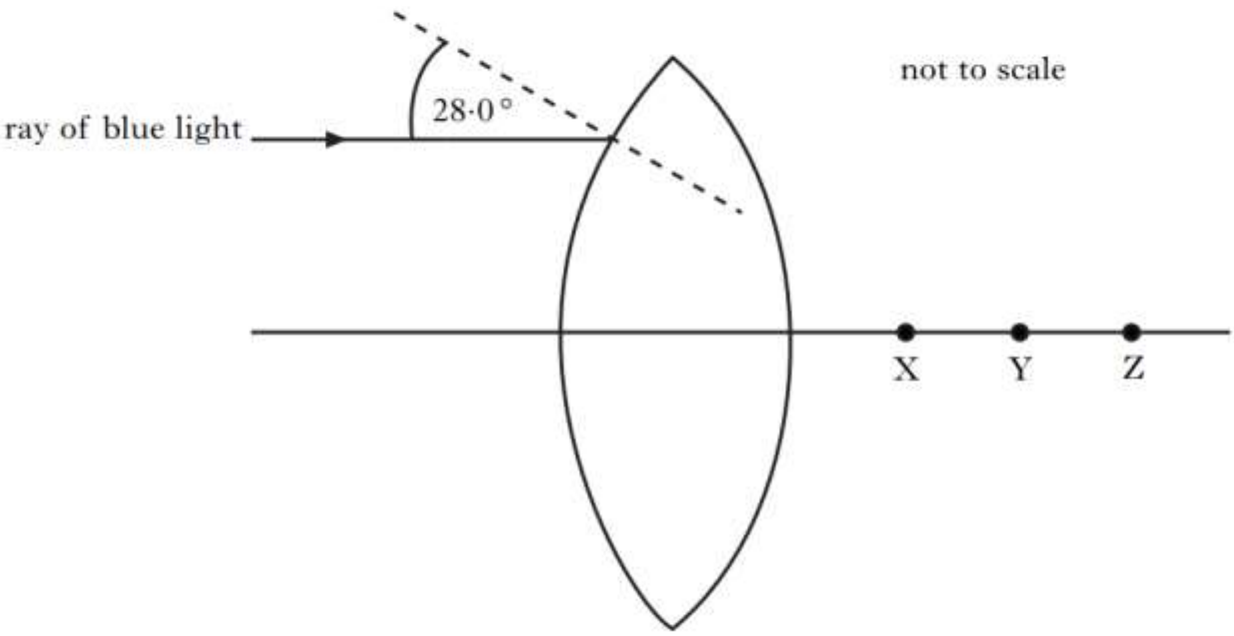
The refractive index of the glass is 1·61 for this red light.

(i) Calculate the value of the angle θ shown in the diagram. **2**

(ii) Calculate the wavelength of this light inside the lens. **3**

(*b*) The ray of red light is now replaced by a ray of blue light.

The ray is incident on the lens at the same point as in part (*a*).



Through which point, X, Y or Z, will this ray pass after leaving the lens?

You must justify your answer. **1**

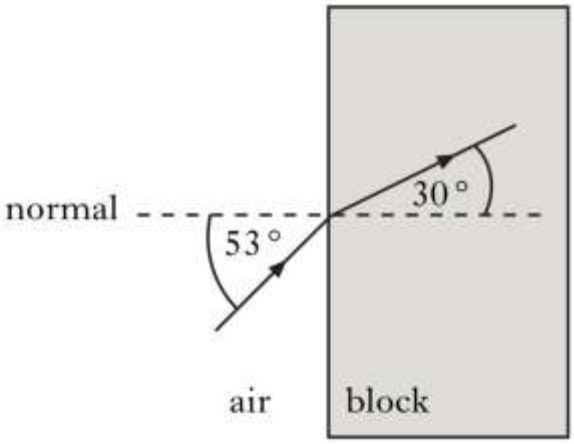
Return to Refraction of Light Contents

2009

28.

(*b*) Another source of light has a frequency of $4 \cdot 6 \times 10^{14}$ Hz in air.

A ray of this light is directed into a block of transparent material as shown.



Calculate the wavelength of the light in the block. **3**

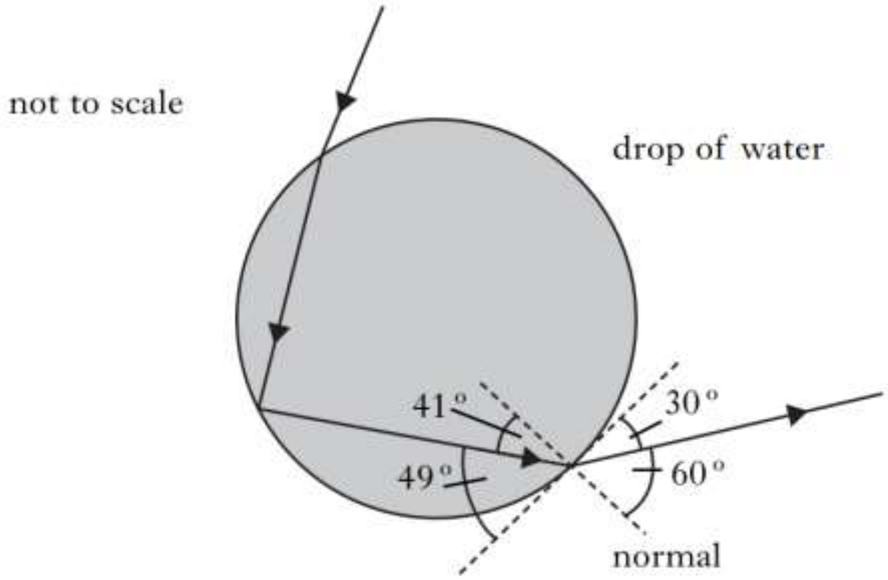
Return to Refraction of Light Contents

2010

28.

(*b*) The gardener observes a spectrum when sunlight illuminates the drops of water in the spray. This is because each drop of water is acting as a prism.

The diagram shows the path taken by light of wavelength 650 nm through a drop of water.



(i) What happens to the frequency of this light when it enters the drop of water? **1**

(ii) Using information from the diagram, calculate the refractive index of the water for this wavelength of light. **2**

(iii) Calculate the critical angle for this wavelength of light in the water. **2**

(iv) Light of shorter wavelength also passes through the drop of water.

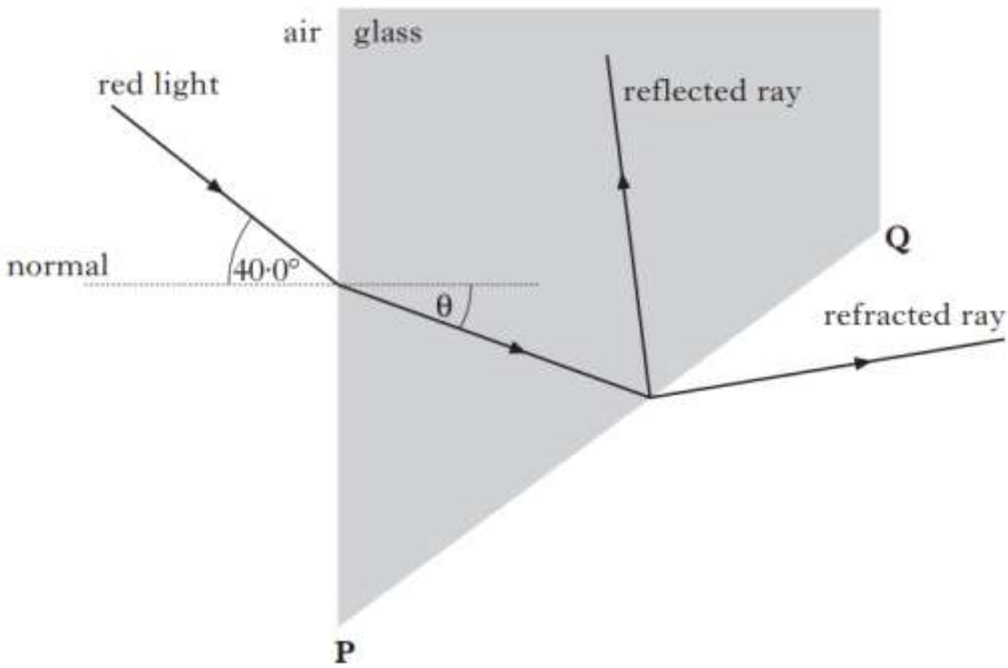
Will the critical angle for this light be less than, equal to, or greater than that for light of wavelength 650 nm?

Justify your answer. **2**

Return to Refraction of Light Contents

2011

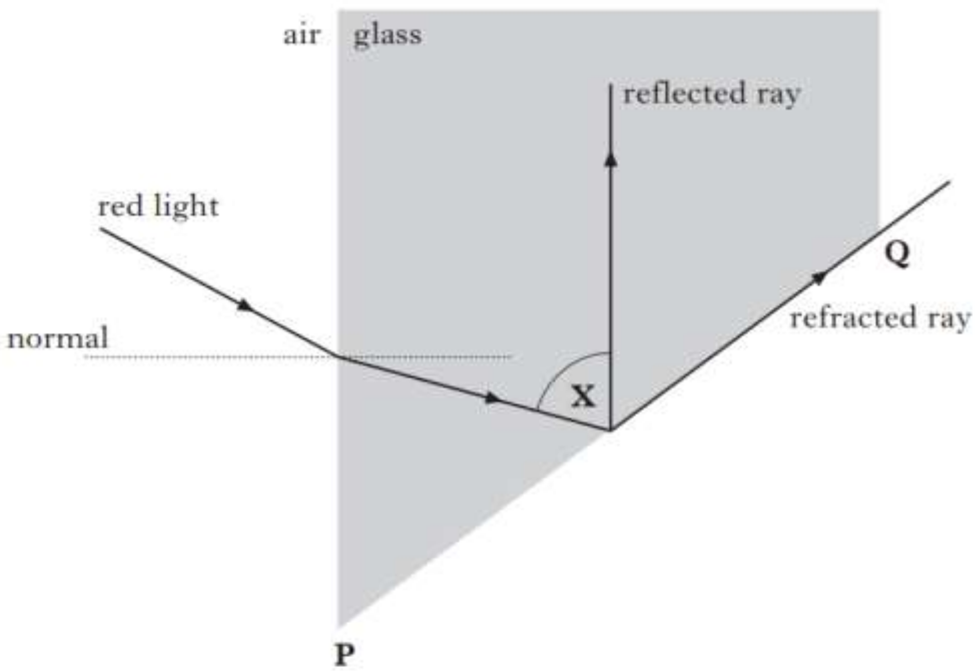
27. (*a*) A ray of red light is incident on a block of glass as shown.



The refractive index of the glass for this light is 1·66.

(i) Calculate the value of the angle θ shown in the diagram. **2**

(ii) The direction of the incident light ray is now changed so that the refracted ray emerges along face **PQ** as shown.



(A) Calculate the critical angle for the red light in this glass. **2**

(B) Determine the size of angle **X** shown in the diagram. **1**

Return to Refraction of Light Contents

2011

27. (continued)

(*b*) The ray of red light is now replaced with a ray of blue light.

This ray of blue light is directed towards the block along the same path as the ray of red light in part (*a*)(ii).

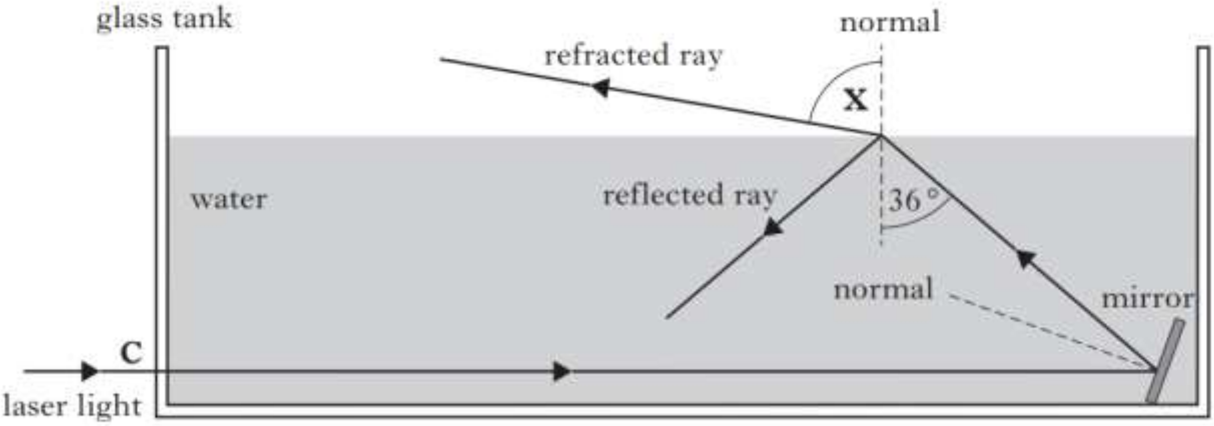
Is this ray of blue light refracted at face **PQ**?

Justify your answer. **2**

Return to Refraction of Light Contents

2012 RH

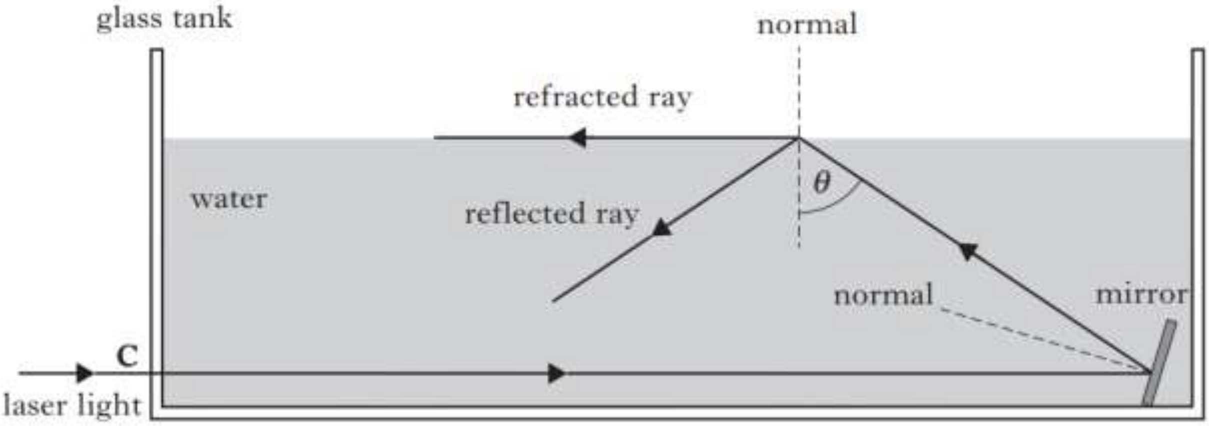
29. A technician investigates the path of laser light as it passes through a glass tank filled with water. The light enters the glass tank along the normal at **C** then reflects off a mirror submerged in the water.



The refractive index of water for this laser light is 1·33.

(*a*) Calculate angle **X**. **2**

(*b*) The mirror is now adjusted until the light follows the paths shown.



(i) State why the value of θ is equal to the critical angle for this laser light in water. **1**

(ii) Calculate angle θ. **2**

(*c*) The water is now replaced with a liquid which has a greater refractive index. The mirror is kept at the same angle as in part (*b*) and the incident ray again enters the tank along the normal at **C.**

Draw a sketch which shows the path of the light ray after it has reflected off the mirror.

Your sketch should only show what happens at the surface of the liquid. **1**

Return to Refraction of Light Contents

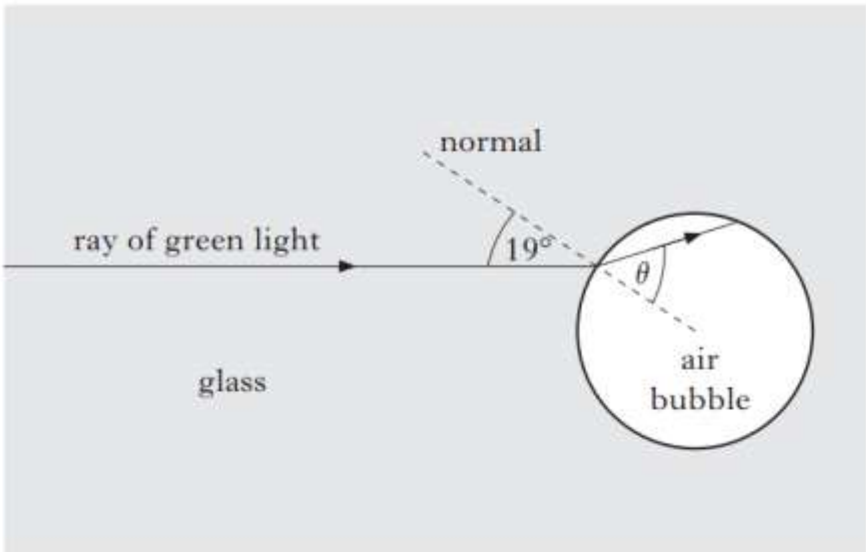
2013 RH

29. A student places a glass paperweight containing air bubbles on a sheet of white paper.

The student notices that when white light passes through the paperweight, a pattern of spectra is produced.

The student decides to study this effect in more detail by carrying out an experiment in the laboratory.

A ray of green light follows the path shown as it enters an air bubble inside glass.



not to scale

The refractive index of the glass for this light is 1·49.

(*a*) Calculate the angle of refraction, θ, inside the air bubble. **2**

(*b*) Calculate the maximum angle of incidence at which a ray of green light can enter the air bubble. **2**

(*c*) The student now replaces the ray of green light with a ray of white light.

Explain why a spectrum is produced. **1**

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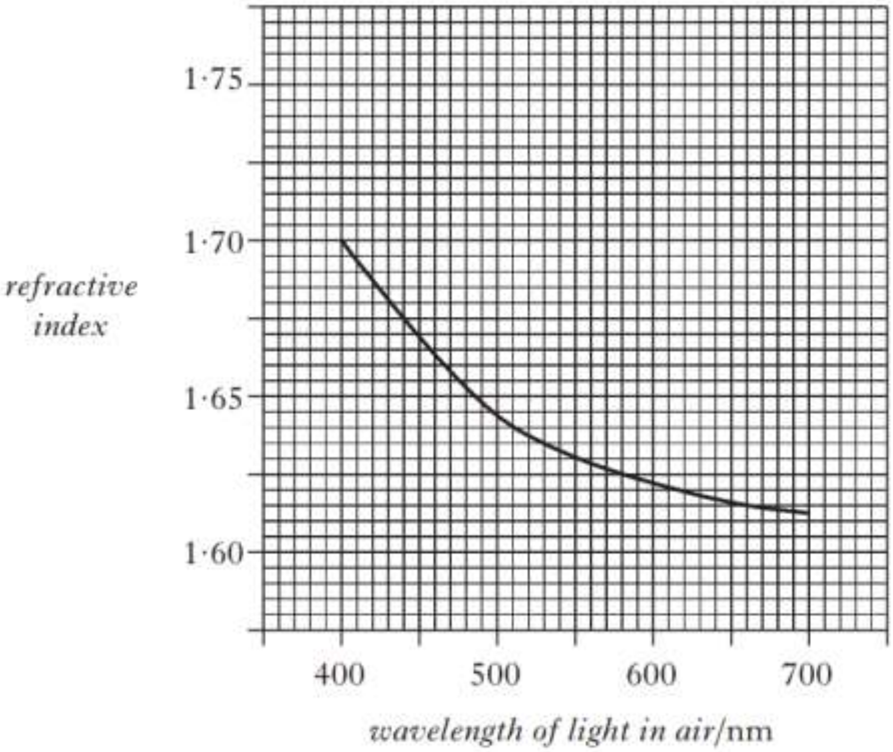
2014 RH

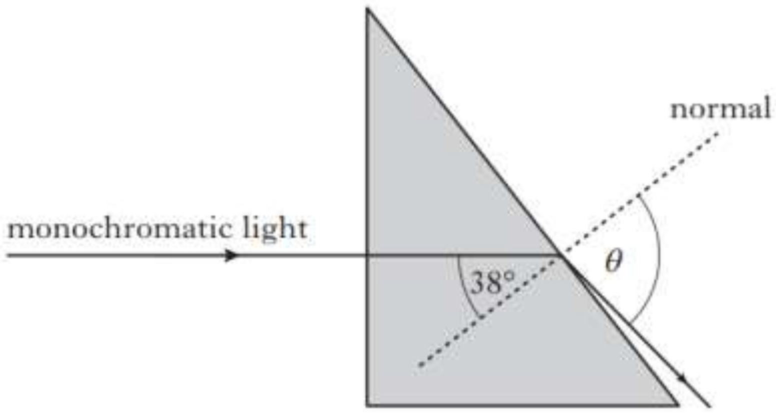
29. Monochromatic light is shone into a triangular prism of flint glass.

The graph shows how the refractive index of flint glass varies with the wavelength of light in air.



(*a*) A ray of monochromatic light of wavelength 660 nm in air passes through the prism as shown.

not to scale



Calculate the angle of refraction θ. **2**

(*b*) The ray of light is now replaced with one of shorter wavelength.

Is the speed of this new ray in the prism less than, the same as or greater than the speed of the 660 nm ray in the prism?

Justify your answer. **2**

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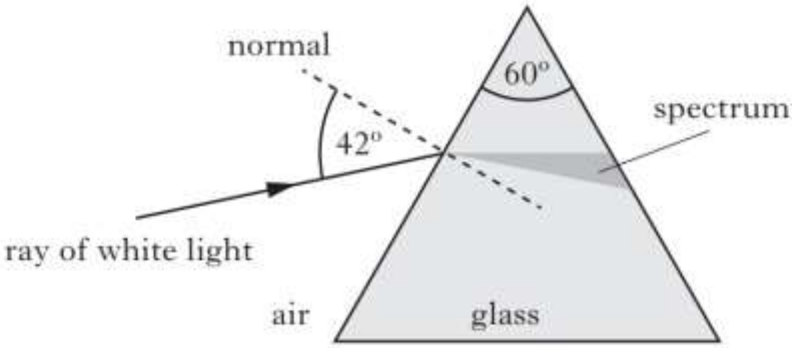
2015 RH

29. 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 the red light in the glass prism. **2**

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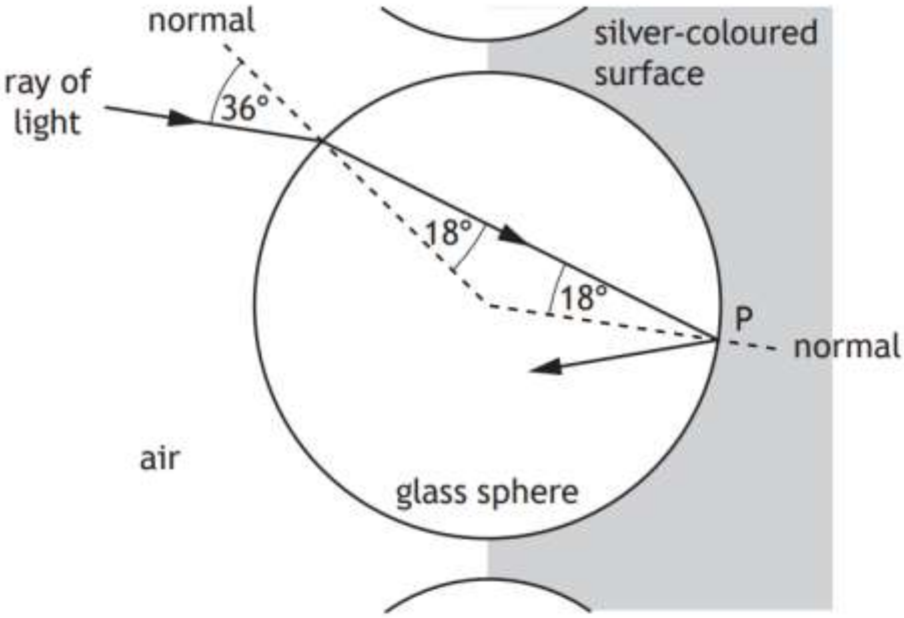
2016

10. 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**

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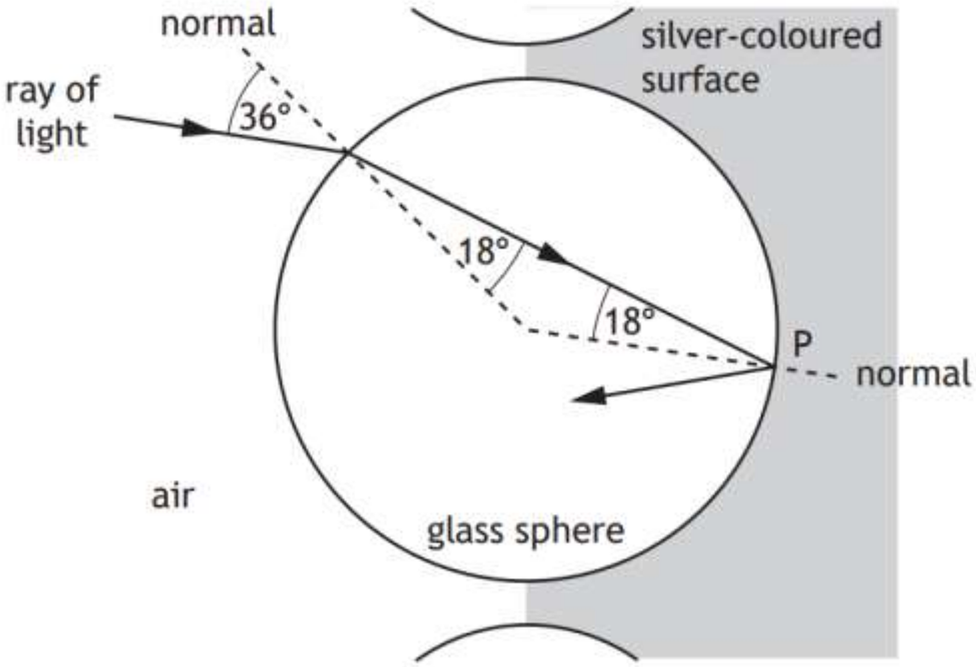
2016

(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**



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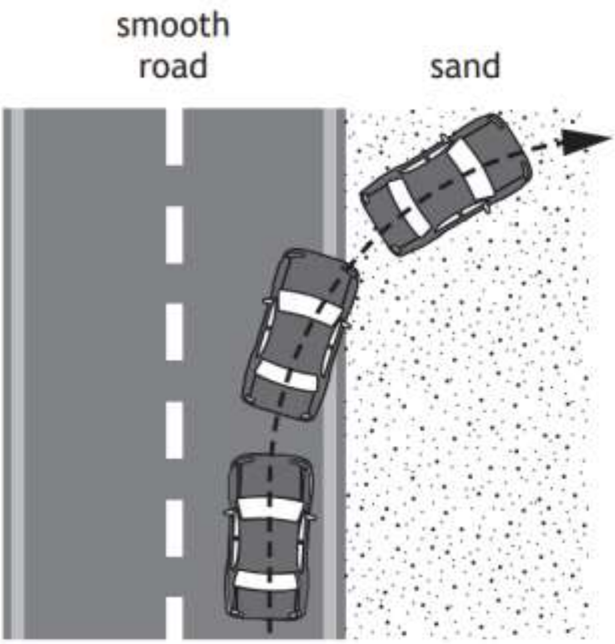
2017

11. The use of analogies from everyday life can help better understanding of physics concepts. A car moving from a smooth surface to a rough surface, eg from a road to sand, can be used as an analogy for the refraction of light.



Use your knowledge of physics to comment on this analogy. **3**

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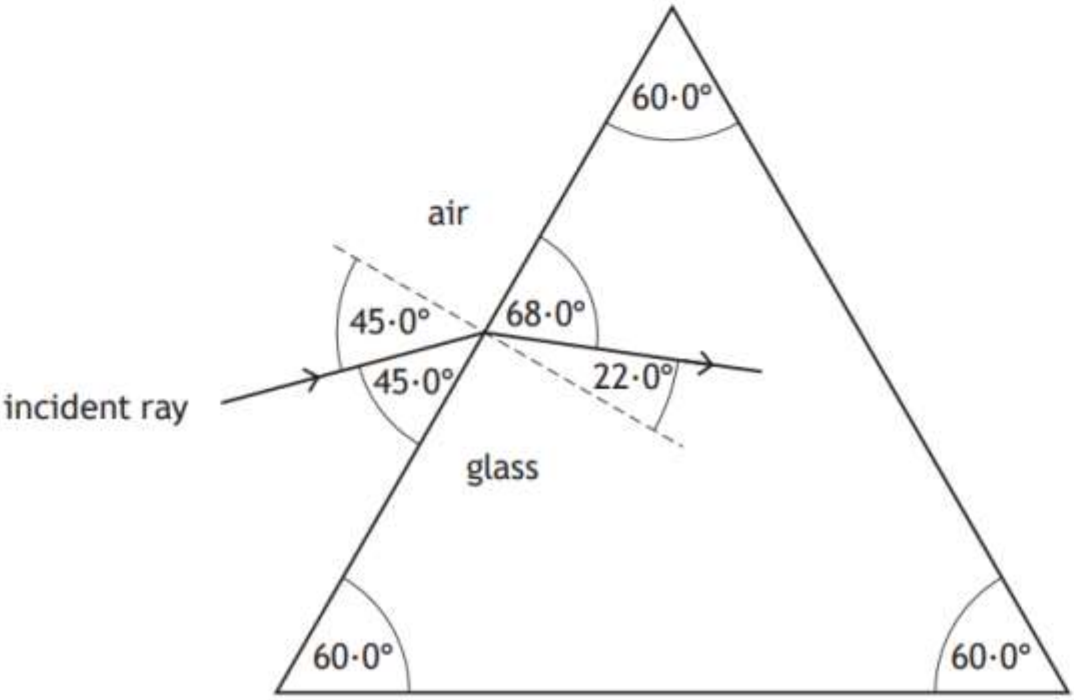
2018

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



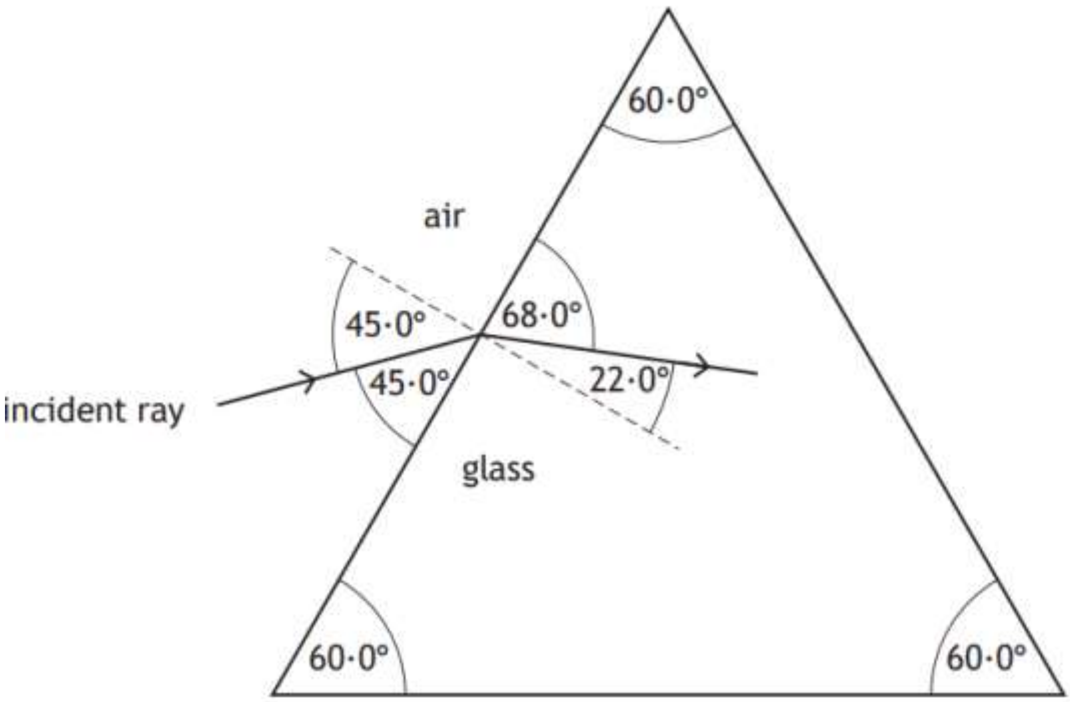
(a) Show that the refractive index of the glass for this ray of light is 1·89. **2**

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

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

(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**



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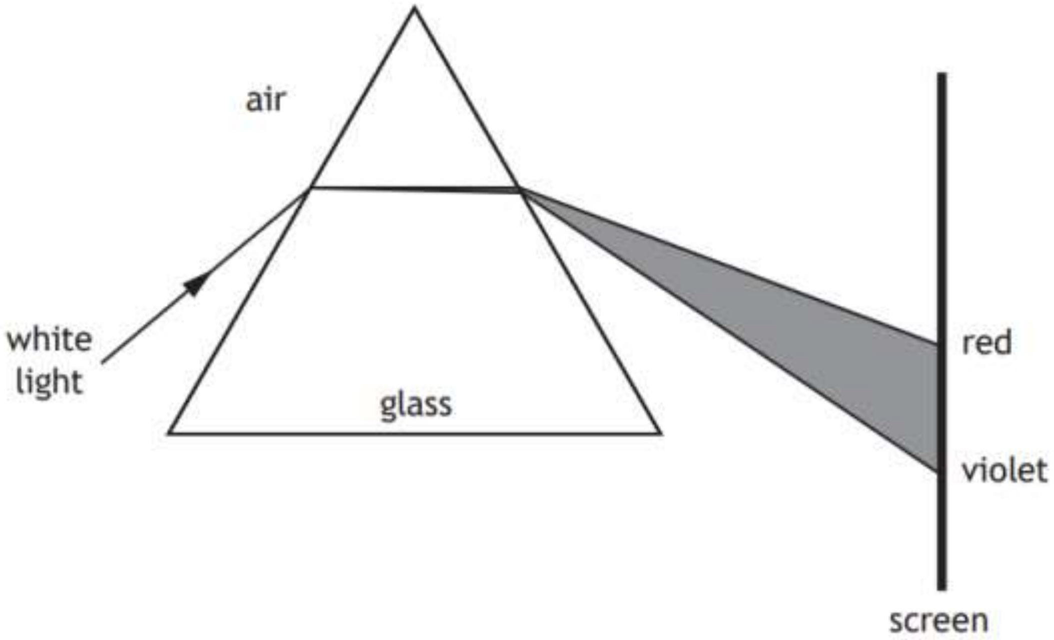
2018

9. (continued)

(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**

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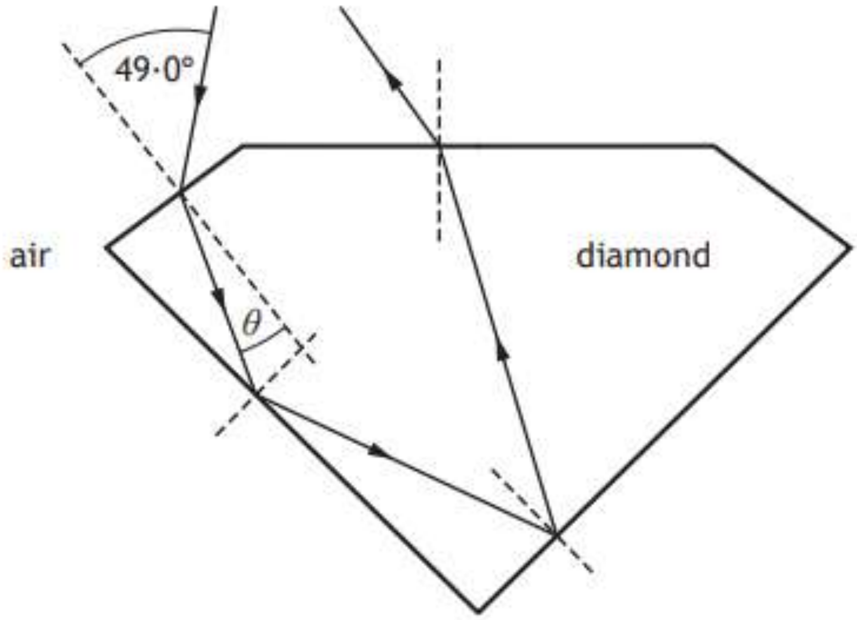
2019

11. Diamonds sparkle because light that enters the diamond is reflected back to an observer.



(a) A ray of monochromatic light is incident on a diamond at an angle of 49·0°.

The refractive index of diamond for this light is 2·42.

Calculate the angle of refraction θ. **3**

(b) Calculate the critical angle of the diamond for this light. **3**

(c) Moissanite is a transparent material with a greater refractive index than diamond. A sample of moissanite is made into the same shape as the diamond.

State whether the sample of moissanite sparkles more or less than the diamond.

You must justify your answer. **3**

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Spectra

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2000

28.

(*b*) A semiconductor chip is used to store information. The information can only be erased by exposing the chip to ultraviolet radiation for a period of time.

The following data is provided.

Frequency of ultraviolet radiation used	$= 9{\cdot}0 \times 10^{14}$ Hz
Minimum intensity of ultraviolet radiation required at the chip	$= 25$ W m^{-2}
Area of the chip exposed to radiation	$= 1{\cdot}8 \times 10^{-9}$ m^2
Time taken to erase the information	= 15 minutes
Energy of radiation needed to erase the information	$= 40{\cdot}5$ μJ

(i) Calculate the energy of a photon of the ultraviolet radiation used.

(ii) Calculate the number of photons of the ultraviolet radiation required to erase the information.

(iii) Sunlight of intensity 25 W m^{-2}, at the chip, can also be used to erase the information.

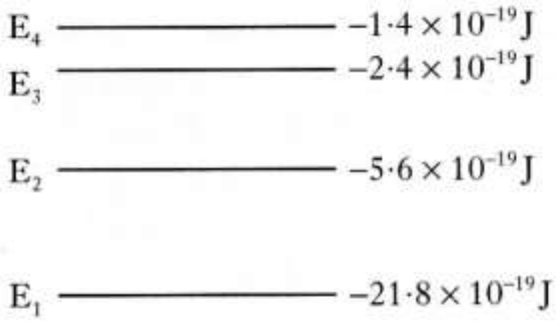
State whether the time taken to erase the information is greater than, equal to or less than 15 minutes.

You must justify your answer. **5**

2003

27. (*a*) Electrons which orbit the nucleus of an atom can be considered as occupying discrete energy levels.

The following diagram shows some of the energy levels for a particular atom.



(i) The transition between which two of these energy levels produces radiation with the longest wavelength? You must justify your answer.

(ii) Calculate the frequency of the photon produced when an electron falls from E_3 to E_2. **5**

Return to Spectra Contents

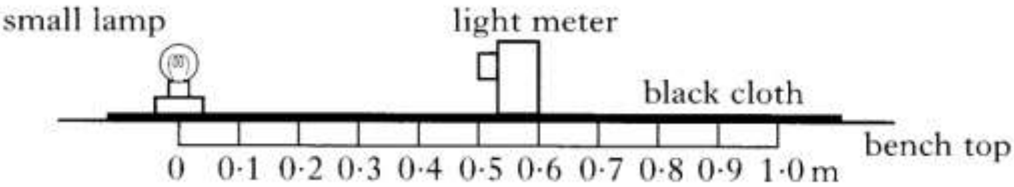
2006

28. A student carries out an experiment to investigate how irradiance on a surface varies with distance from a small lamp.

Irradiance is measured with a light meter.

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

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



The following results are obtained.

Distance from source/ m	0·20	0·30	0·40	0·50
Irradiance/ units	675	302	170	108

(*a*) What is meant by the term *irradiance*? **1**

(*b*) Use **all** the data to find the relationship between irradiance I and distance d from the source. **2**

(*c*) What is the purpose of the black cloth on top of the bench? **1**

(*d*) The small lamp is replaced by a laser.

Light from the laser is shone on to the light meter.

A reading is taken from the light meter when the distance between it and the laser is 0·50 m.

The distance is now increased to 1·00 m.

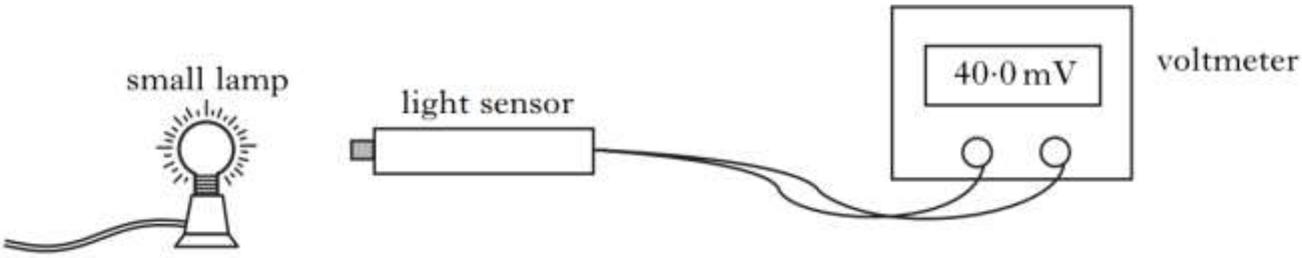
State how the new reading on the light meter compares with the one taken at 0·50 m.

Justify your answer. **2**

2008

28. The diagram shows a light sensor connected to a voltmeter.

A small lamp is placed in front of the sensor.



The reading on the voltmeter is 20 mV for each 1·0 mW of power incident on the sensor.

(*a*) The reading on the voltmeter is 40·0 mV.

The area of the light sensor is $8{\cdot}0 \times 10^{-5}\,\text{m}^2$.

Calculate the irradiance of light on the sensor. **3**

(*b*) The small lamp is replaced by a different source of light.

Using this new source, a student investigates how irradiance varies with distance.

The results are shown.

Distance/m	0·5	0·7	0·9
Irradiance/W m^{-2}	1·1	0·8	0·6

Can this new source be considered to be a point source of light?

Use **all** the data to justify your answer. **2**

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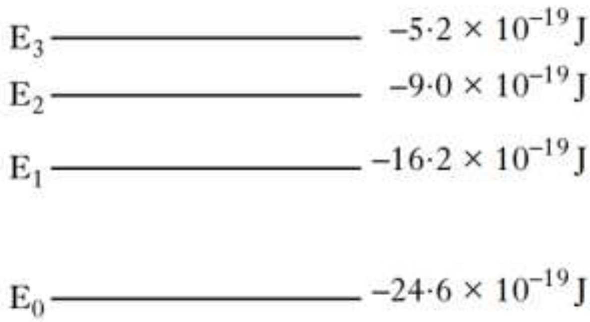
2009

28. (*a*) Electrons which orbit the nucleus of an atom can be considered as occupying discrete energy levels.

The following diagram shows some of the energy levels for a particular atom.



(i) Radiation is produced when electrons make transitions from a higher to a lower energy level.

Which transition, between these energy levels, produces radiation with the shortest wavelength?

Justify your answer. **2**

(ii) An electron is excited from energy level E_2 to E_3 by absorbing light energy.

What frequency of light is used to excite this electron? **2**

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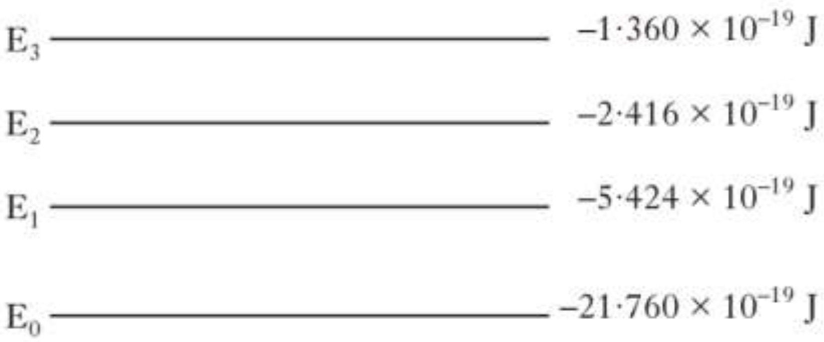
2011

30.

(*b*) The Sun emits a continuous spectrum of visible light. When this light passes through hydrogen atoms in the Sun's outer atmosphere, certain wavelengths are absorbed.

The diagram shows some of the energy levels for the hydrogen atom.



(i) One of the wavelengths absorbed by the hydrogen atoms results in an electron transition from energy level E_1 to E_3.

Calculate this wavelength. **3**

(ii) The absorption of this wavelength produces a faint dark line in the continuous spectrum from the Sun.

In which colour of the spectrum is this dark line observed? **1**

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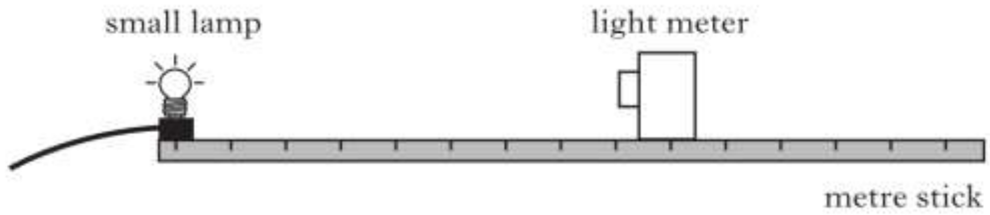
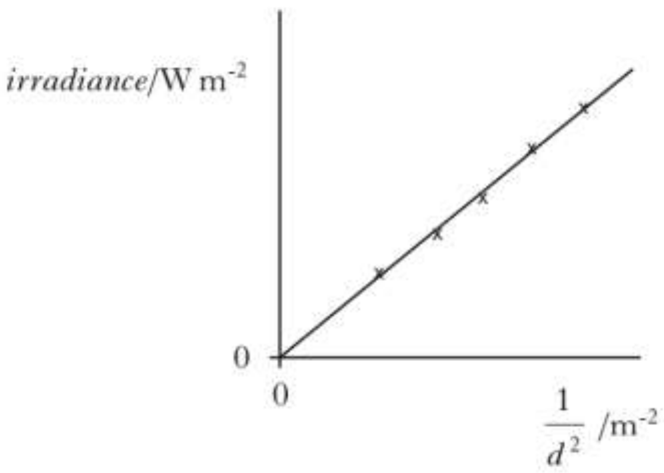
2012 RH

30. A student investigates how irradiance I varies with distance d from a small lamp.

The following apparatus is set up in a darkened laboratory.



The results are used to produce the following graph.



(*a*) Explain why this graph confirms the relationship $I = \frac{k}{d^2}$ **1**

(*b*) The irradiance of light from the lamp at a distance of 1·6 m is 4·0 W m^{-2}.

Calculate the irradiance of the light at a distance of 0·40 m from the lamp. **2**

(*c*) The experiment is repeated with the laboratory lights switched on.

Copy the graph shown and, on the same axes, draw another line to show the results of the second experiment. **1**

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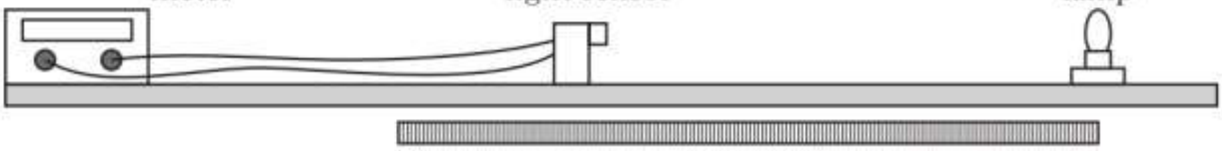
2013 TH

30. (*a*) A technician uses the following apparatus to investigate the relationship between the irradiance of the light from a lamp and the distance from it.

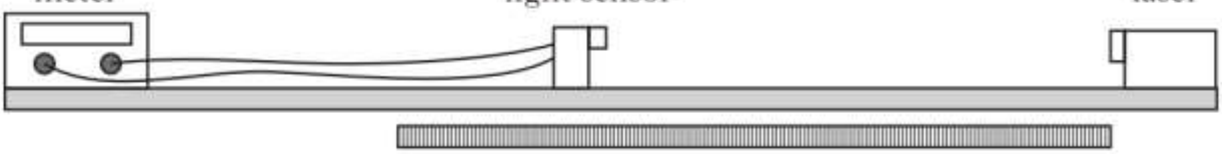


The results of the experiment are shown.

Distance between light sensor and lamp/m	*Irradiance*/units
0·10	242
0·15	106
0·20	60
0·25	39

Use **all** the results to determine whether or not the lamp behaves like a point source of light in this experiment. **2**

(*b*) The experiment is now repeated using a $1{\cdot}00 \times 10^{-4}$ W laser which produces light of wavelength 633 nm.



(i) Explain why the results obtained with the laser differ from those obtained using the lamp. **1**

(ii) Calculate the number of photons emitted by the laser each second. **3**

(iii) Light from the laser is described as *coherent*.

Describe, in terms of photons, two differences between the light from the laser and the light from the lamp used in part (*a*). **1**

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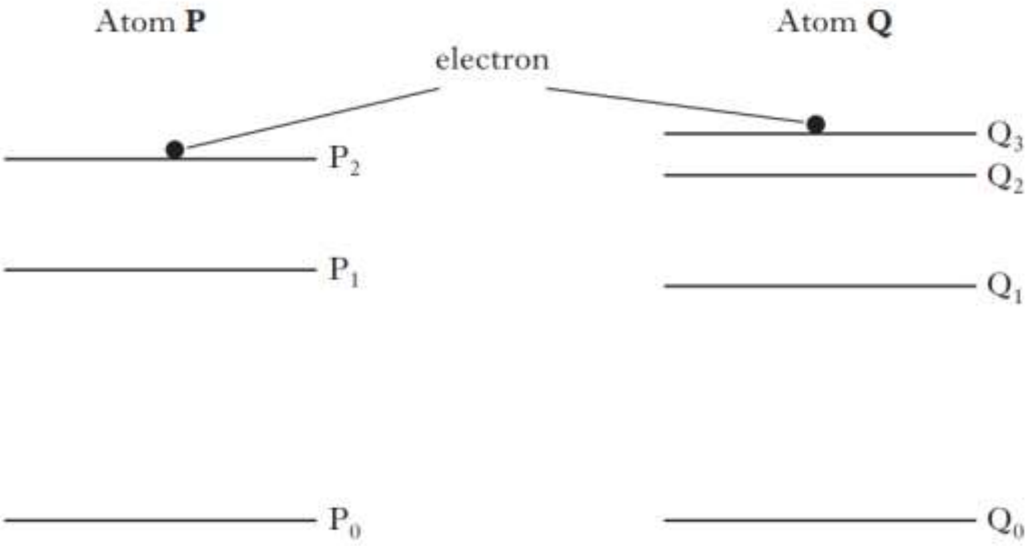
2014 TH

31. The following diagrams represent some of the energy levels for two different atoms **P** and **Q**. The diagrams are drawn to the same scale.



Electrons are continuously excited to levels P_2 and Q_3.

When electrons make transitions to lower energy levels, photons of light are emitted.

This light is observed as various lines in the emission spectrum of each atom.

(*a*) For atom **Q**, determine the number of lines in the emission spectrum for the energy levels shown. **1**

(*b*) Considering both atoms, identify the transition that produces radiation of the lowest frequency. **1**

(*c*) The table shows information about the energy levels in atom **P**.

Energy Level	*Energy*/J
P_2	$-2{\cdot}4 \times 10^{-19}$
P_1	$-5{\cdot}4 \times 10^{-19}$
P_0	$-21{\cdot}8 \times 10^{-19}$

Calculate the shortest wavelength of radiation emitted from atom **P**. **3**

(*d*) (i) The emission line due to the transition from P_2 to P_1 is the **same colour** as the emission line due to the transition from Q_2 to Q_1.

Explain this observation. **1**

(ii) The emission line due to the transition from P_2 to P_1 is **brighter** than the emission line due to the transition from Q_2 to Q_1.

Explain this observation. **1**

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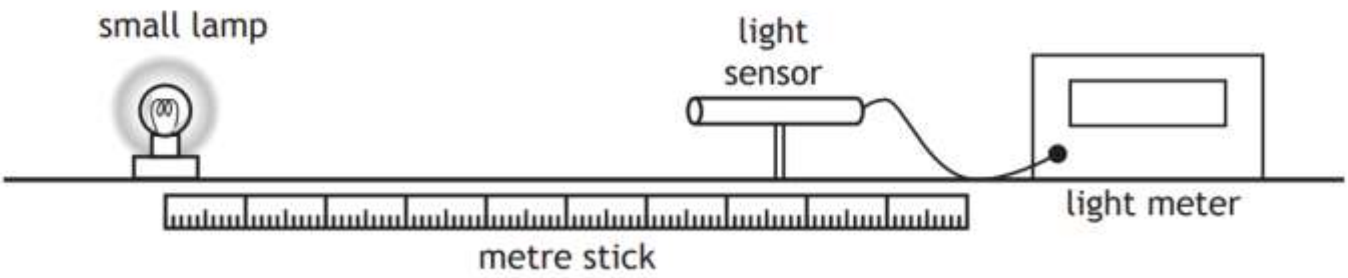
2015

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**

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2017

6. The visible spectrum of light emitted by a star is observed to contain a number of dark lines. The dark lines occur because certain wavelengths of light are absorbed when light passes through atoms in the star's outer atmosphere.

The diagram shows some of the energy levels for a hydrogen atom.

(a) For the energy levels shown in the diagram, identify the electron transition that would lead to the absorption of a photon with the highest frequency. **1**

(b) An electron makes the transition from energy level E_1 to E_3.

Determine the frequency of the photon absorbed. **3**

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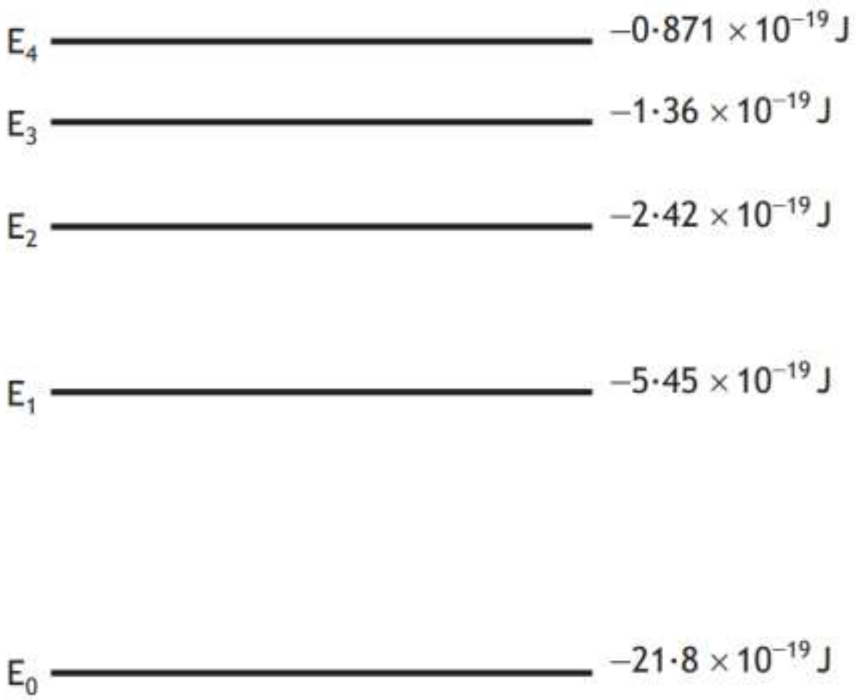
2018

10. In a laboratory experiment, light from a hydrogen discharge lamp is used to produce a line emission spectrum. The line spectrum for hydrogen has four lines in the visible region as shown.

(a) The production of the line spectrum can be explained using the Bohr model of the atom.

State **two** features of the *Bohr model* of the atom. **2**

(b) Some of the energy levels of the hydrogen atom are shown.



One of the spectral lines is due to electron transitions from E_3 to E_1.

Determine the frequency of the photon emitted when an electron makes this transition. **3**

(c) In the laboratory, a line in the hydrogen spectrum is observed at a wavelength of 656 nm.

When the spectrum of light from a distant galaxy is viewed, this hydrogen line is now observed at a wavelength of 661 nm.

Determine the recessional velocity of the distant galaxy. **5**

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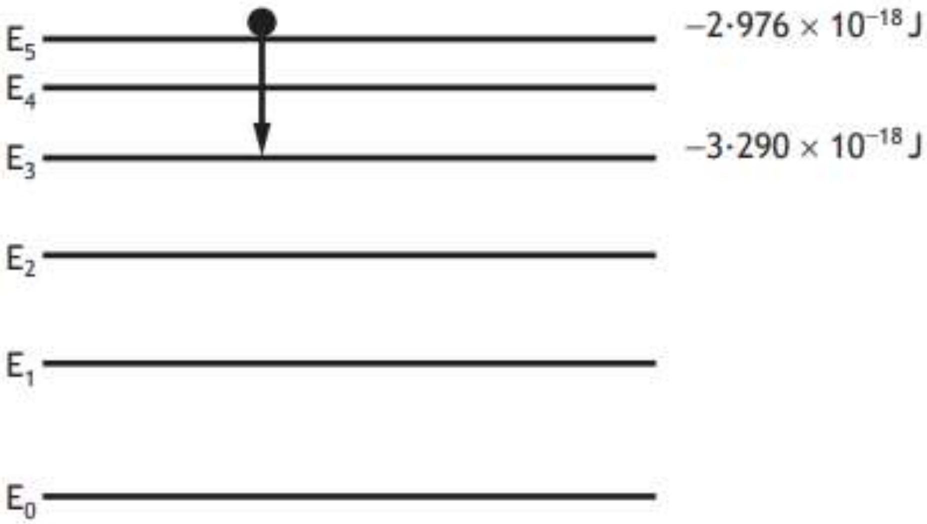
9. A laser emits light when electrons are stimulated to fall from a high energy level to a lower energy level.

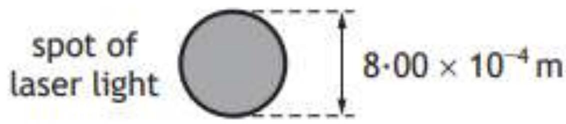
The diagram shows some of the energy levels involved.

In one particular laser, a photon is produced by the electron transition from E_5 to E_3 as shown.



(a) (i) Determine the wavelength of the photon emitted. **4**

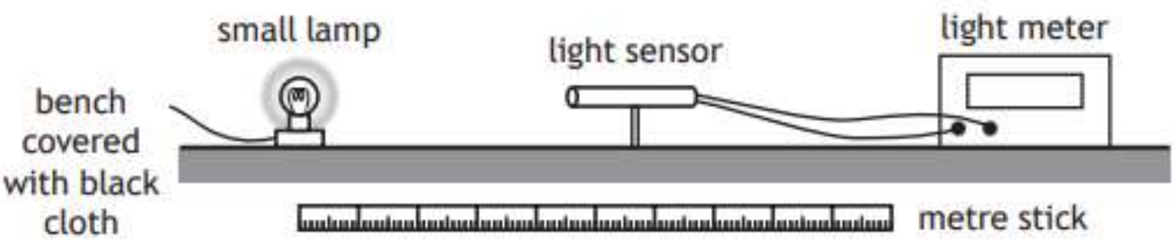
(ii) The laser beam is shone onto a screen. The beam produces a spot of diameter $8{\cdot}00 \times 10^{-4}$ m.



The irradiance of the spot of light on the screen is 9950 W m^{-2}.

Determine the power of the laser beam. **4**

(b) A student investigates how irradiance I varies with distance d from a point source of light, using the apparatus shown.



Describe how this apparatus could be used to verify the inverse square law for a point source of light. **3**

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