Cumbernauld Academy
Higher Physics
Particles and Waves
Homework

DATA SHEET

COMMON PHYSICAL QUANTITIES

Quantity	*Symbol*	*Value*	*Quantity*	*Symbol*	*Value*
Speed of light in vacuum	c	$3 \cdot 00 \times 10^{8}\ \mathrm{m\,s^{-1}}$	Planck's constant	h	$6 \cdot 63 \times 10^{-34}\ \mathrm{J\,s}$
Magnitude of the charge on an electron	e	$1 \cdot 60 \times 10^{-19}\ \mathrm{C}$	Mass of electron	m_e	$9 \cdot 11 \times 10^{-31}\ \mathrm{kg}$
Universal Constant of Gravitation	G	$6 \cdot 67 \times 10^{-11}\ \mathrm{m^3\,kg^{-1}\,s^{-2}}$	Mass of neutron	m_n	$1 \cdot 675 \times 10^{-27}\ \mathrm{kg}$
Gravitational acceleration on Earth	g	$9 \cdot 8\ \mathrm{m\,s^{-2}}$	Mass of proton	m_p	$1 \cdot 673 \times 10^{-27}\ \mathrm{kg}$
Hubble's constant	H_0	$2 \cdot 3 \times 10^{-18}\ \mathrm{s^{-1}}$			

REFRACTIVE INDICES

The refractive indices refer to sodium light of wavelength 589 nm and to substances at a temperature of 273 K.

Substance	*Refractive index*	*Substance*	*Refractive index*
Diamond	2·42	Water	1·33
Crown glass	1·50	Air	1·00

SPECTRAL LINES

Element	*Wavelength/nm*	*Colour*
Hydrogen	656	Red
	486	Blue-green
	434	Blue-violet
	410	Violet
	397	Ultraviolet
	389	Ultraviolet
Sodium	589	Yellow

Element	*Wavelength/nm*	*Colour*
Cadmium	644	Red
	509	Green
	480	Blue

Lasers

Element	*Wavelength/nm*	*Colour*
Carbon dioxide	9550, 10 590	Infrared
Helium-neon	633	Red

PROPERTIES OF SELECTED MATERIALS

Substance	*Density/kg m^{-3}*	*Melting point/K*	*Boiling point/K*
Aluminium	$2 \cdot 70 \times 10^{3}$	933	2623
Copper	$8 \cdot 96 \times 10^{3}$	1357	2853
Ice	$9 \cdot 20 \times 10^{2}$	273	....
Sea Water	$1 \cdot 02 \times 10^{3}$	264	377
Water	$1 \cdot 00 \times 10^{3}$	273	373
Air	1·29	....	....
Hydrogen	$9 \cdot 0 \times 10^{-2}$	14	20

The gas densities refer to a temperature of 273 K and a pressure of $1 \cdot 01 \times 10^{5}$ Pa.

Homework 1 – The Standard Model and Forces on Charges Particles

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

A quarks

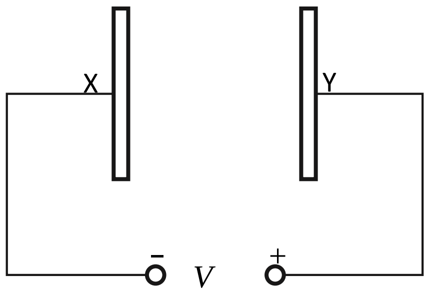
B electrons

C gluons

D neutrinos

E bosons.

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



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

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

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

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

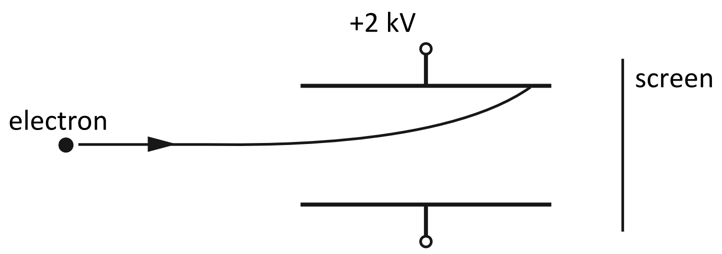
C $\sqrt{\dfrac{2V}{em}}$

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

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

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

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



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

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

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

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

Which of these statements is/are correct?

A I only

B II only

C III only

D I and II only

E I and III only

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

The charge on a down quark is $-\frac{1}{3}$.

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

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

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

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

I The force mediating particles are bosons.

II Gluons are the mediating particles of the strong force.

III Photons are the mediating particles of the electromagnetic force.

Which of these statements is/are correct?

A I only

B II only

C I and II only

D II and III only

E I, II and III

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

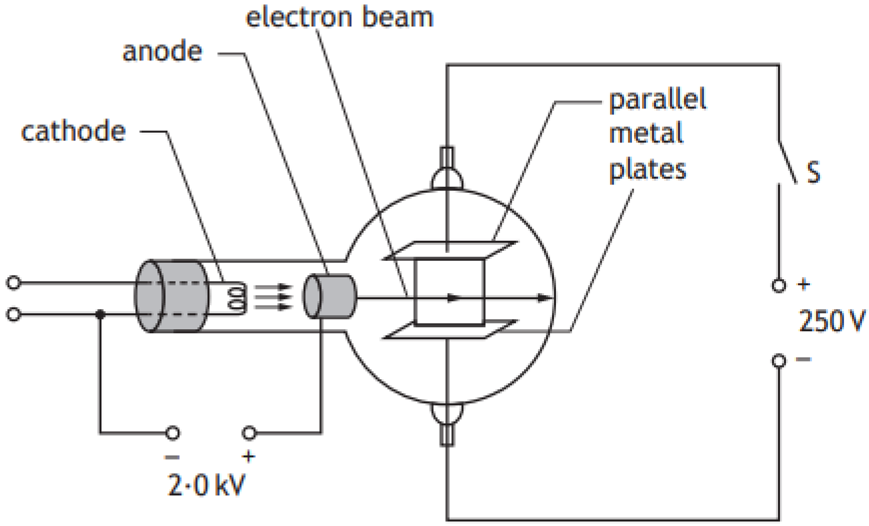
(b) In July 2012 scientists at CERN announced that they had found a particle that behaved in the way that they expected the Higgs boson to behave. Within a year this particle was confirmed to be a Higgs boson.

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. **(2)**

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**

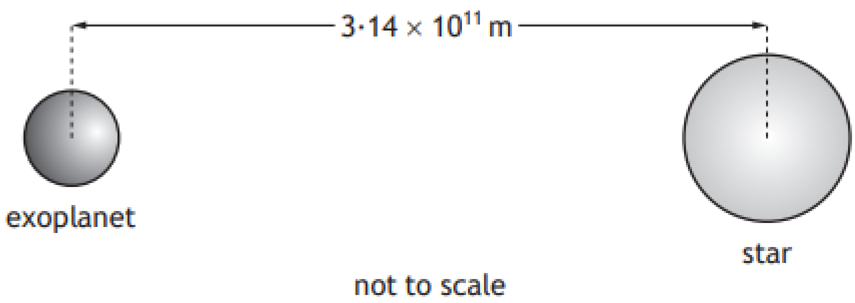
(b) The electrons then pass between the two parallel metal plates.

The electron beam current is 8·0 mA.

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

8. 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.



Compare the mass of the star with the mass of the exoplanet in terms of orders of magnitude. **2**

Homework 2 – Nuclear Reactions

1. The following statement describes a fusion reaction.

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

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

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

The energy released in the reaction is

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

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

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

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

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

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

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

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

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

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

3. The following statement represents a nuclear reaction.

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

Nucleus Z is

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

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

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

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

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

4. A nuclear fission reaction is represented by the following statement.

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

The nucleus represented by X is

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

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

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

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

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

5. A nucleus represented by ${}^{223}_{87}\mathrm{Fr}$ decays by beta emission.

The symbol representing the nucleus formed as a result of this decay is

A ${}^{224}_{87}\mathrm{Fr}$

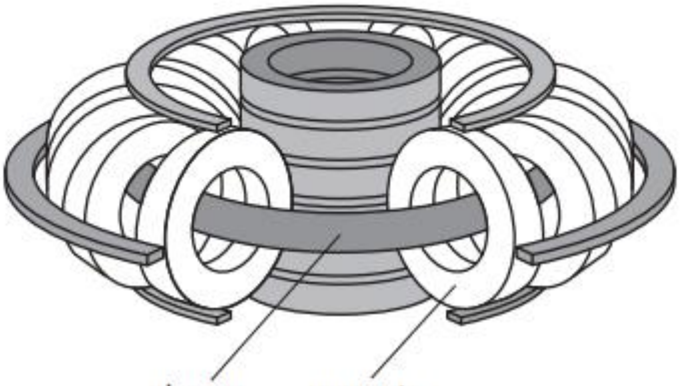
B ${}^{222}_{87}\mathrm{Fr}$

C ${}^{223}_{88}\mathrm{Ra}$

D ${}^{223}_{86}\mathrm{Rn}$

E ${}^{224}_{88}\mathrm{Ra}$.

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



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

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

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

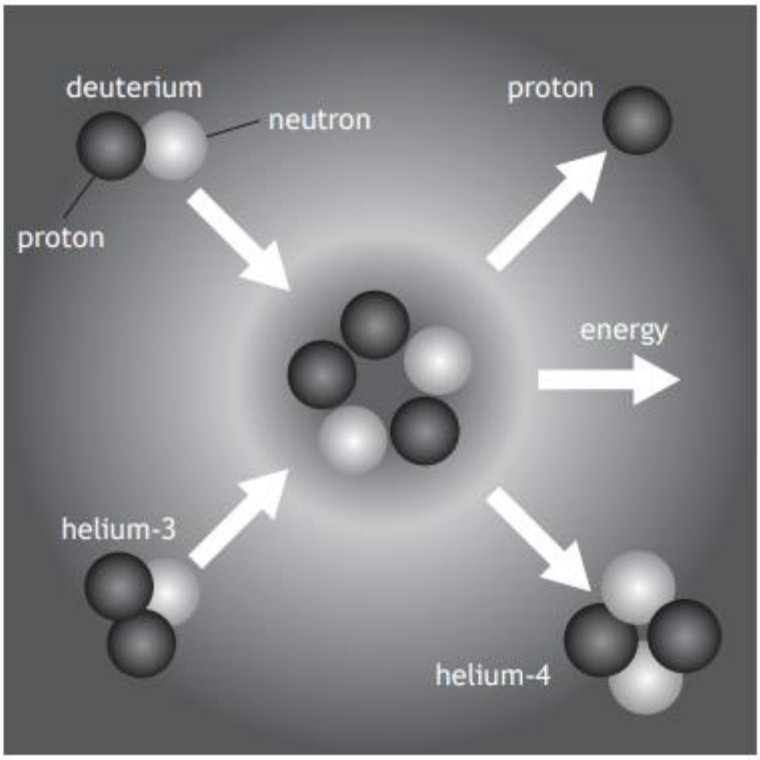
Particle	*Mass* (kg)
$^{2}_{1}H$	$3 \cdot 3436 \times 10^{-27}$
$^{3}_{1}H$	$5 \cdot 0083 \times 10^{-27}$
$^{4}_{2}He$	$6 \cdot 6465 \times 10^{-27}$
$^{1}_{0}n$	$1 \cdot 6749 \times 10^{-27}$

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

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

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

Reaction of helium-3 with deuterium



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

b) The following statement represents this fusion reaction.

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

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

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

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

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

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

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

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

Homework 3 – Wave Particle Duality

1. The table below shows the threshold frequency of radiation for photoelectric emission for some metals.

Metal	*Threshold frequency* (Hz)
sodium	$4{\cdot}4 \times 10^{14}$
potassium	$5{\cdot}4 \times 10^{14}$
zinc	$6{\cdot}9 \times 10^{14}$

Radiation of frequency $6{\cdot}3 \times 10^{14}$ Hz is incident on the surface of each of the metals.

Photoelectric emission occurs from

A sodium only

B zinc only

C potassium only

D sodium and potassium only

E zinc and potassium only.

2. Radiation of frequency $9{\cdot}00 \times 10^{15}$ Hz is incident on a clean metal surface.

The maximum kinetic energy of a photoelectron ejected from this surface is $5{\cdot}70 \times 10^{-18}$ J.

The work function of the metal is

A $2{\cdot}67 \times 10^{-19}$ J

B $5{\cdot}97 \times 10^{-18}$ J

C $1{\cdot}17 \times 10^{-17}$ J

D $2{\cdot}07 \times 10^{-2}$ J

E $9{\cdot}60 \times 10^{-1}$ J

3. Radiation is incident on a clean zinc plate causing photoelectrons to be emitted.

The source of radiation is replaced with one emitting radiation of a higher frequency.

The irradiance of the radiation incident on the plate remains unchanged.

Which row in the table shows the effect of this change on the maximum kinetic energy of a photoelectron and the number of photoelectrons emitted per second?

	Maximum kinetic energy of a photoelectron	*Number of photoelectrons emitted per second*
A	no change	no change
B	no change	increases
C	increases	no change
D	increases	decreases
E	decreases	increases

4. Ultraviolet radiation of frequency $7{\cdot}70 \times 10^{14}$ Hz is incident on the surface of a metal. Photoelectrons are emitted from the surface of the metal.

The maximum kinetic energy of an emitted photoelectron is $2{\cdot}67 \times 10^{-19}$ J.

The work function of the metal is

A $1{\cdot}07 \times 10^{-19}$ J

B $2{\cdot}44 \times 10^{-19}$ J

C $2{\cdot}67 \times 10^{-19}$ J

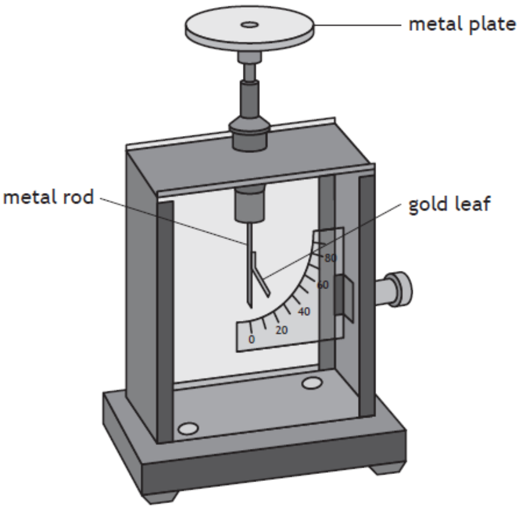
D $5{\cdot}11 \times 10^{-19}$ J

E $7{\cdot}78 \times 10^{-19}$ J.

5. 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**

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



gold-leaf electroscope

a) Ultraviolet light is shone onto the negatively charged metal plate. The gold-leaf electroscope does not discharge. This indicates that photoelectrons are not ejected from the surface of the metal.
Suggest one reason why photoelectrons are not ejected from the surface of the metal. **1**

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

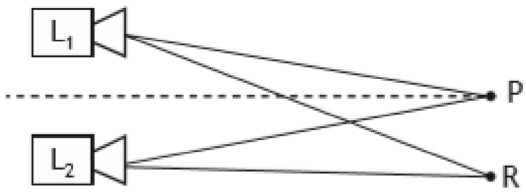
The work function for the metal plate is $6{\cdot}94 \times 10^{-19}$ J.

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

(ii) The irradiance of the ultraviolet light on the metal plate is reduced by increasing the distance between the gold-leaf electroscope and the ultraviolet light source.
State what effect, if any, this has on the maximum kinetic energy of the photoelectrons ejected from the surface of the metal.
Justify your answer. **2**

Homework 4 – Interference and Diffraction

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



At position P, which is the same distance from both loudspeakers, there is a maximum.
The next maximum is at position R, where $L_1R = 5{\cdot}6$ m and $L_2R = 5{\cdot}3$ m.
The speed of sound in air is 340 m s^{-1}.
The frequency of the sound emitted by the loudspeakers is

A $8{\cdot}8 \times 10^{-4}$ Hz

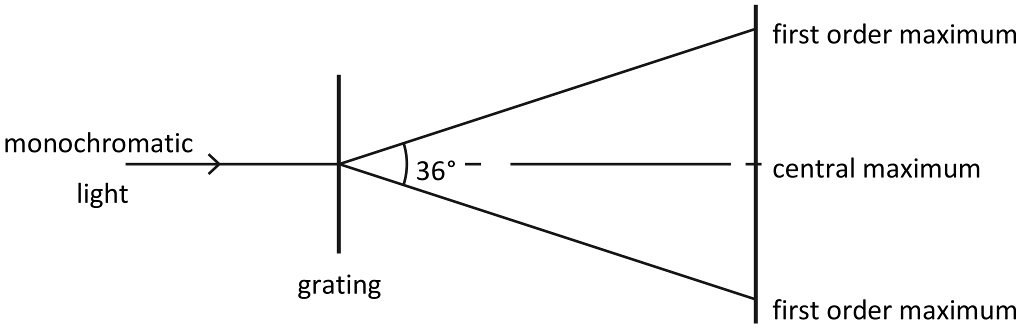
B $3{\cdot}1 \times 10^{1}$ Hz

C $1{\cdot}0 \times 10^{2}$ Hz

D $1{\cdot}1 \times 10^{3}$ Hz

E $3{\cdot}7 \times 10^{3}$ Hz.

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



The wavelength of the light is 633 nm.

The separation of the slits on the grating is

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

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

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

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

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

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

I Waves from coherent sources have the same velocity.

II Waves from coherent sources have the same wavelength.

III Waves from coherent sources have a constant phase relationship.

Which of these statements is/are correct?

A I only

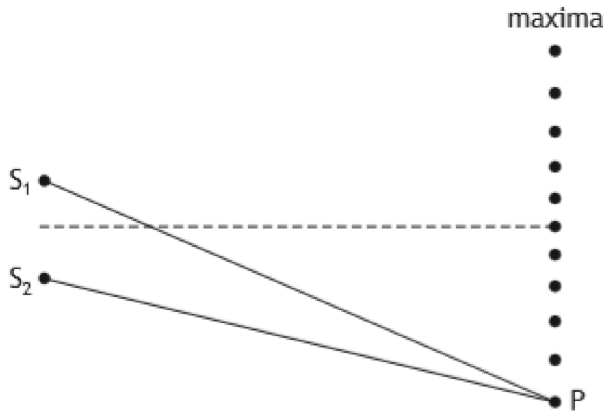
B II only

C I and II only

D I and III only

E I, II and III

4. Waves from two coherent sources, S1 and S2, produce an interference pattern. Maxima are detected at the positions shown below.



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

The wavelength of the waves is

A 15·4 mm

B 25·7 mm

C 28·0 mm

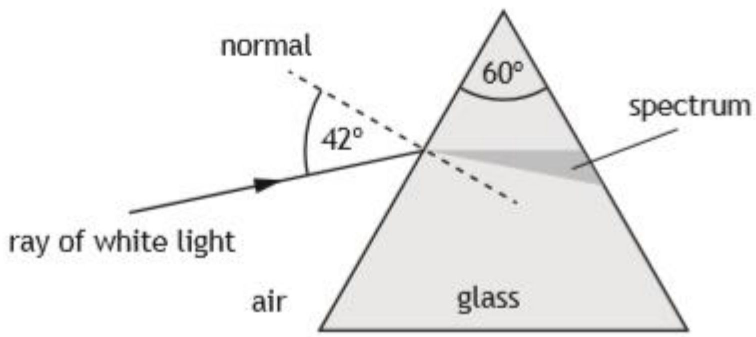
D 30·8 mm

E 34·2 mm.

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

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

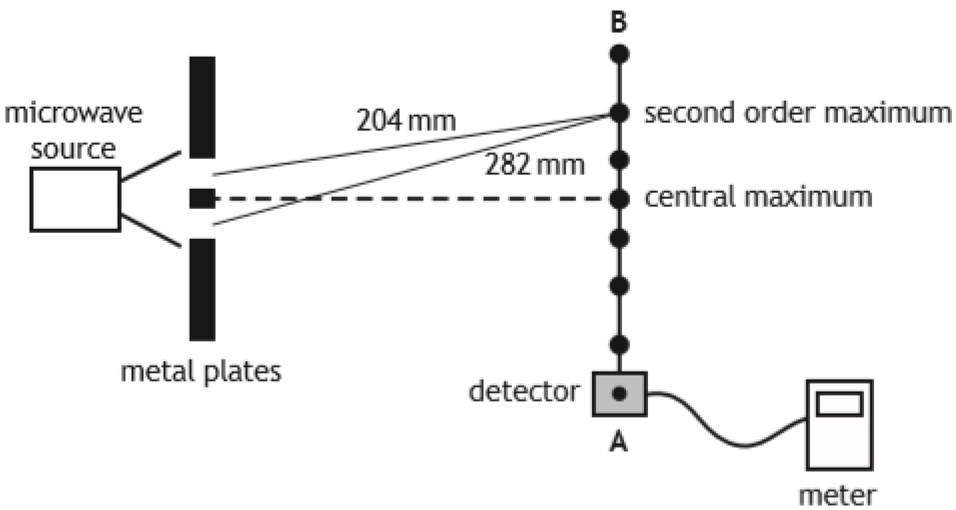
not to scale



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

(ii) The refractive index of the glass for red light is 1·54. Calculate the speed of red light in the glass prism. 3

6. 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.

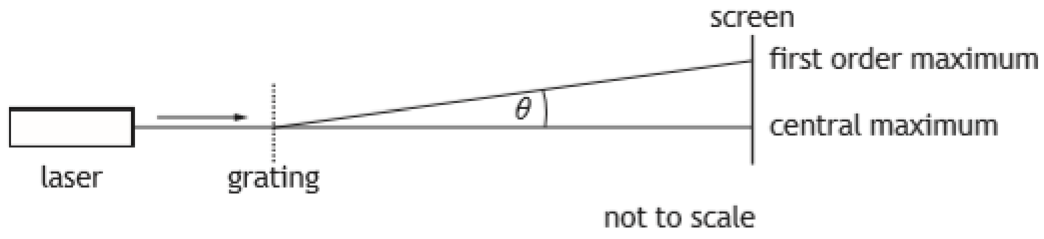
(a) The microwaves passing through the gaps are coherent.
State what is meant by the term *coherent*. **1**

(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.

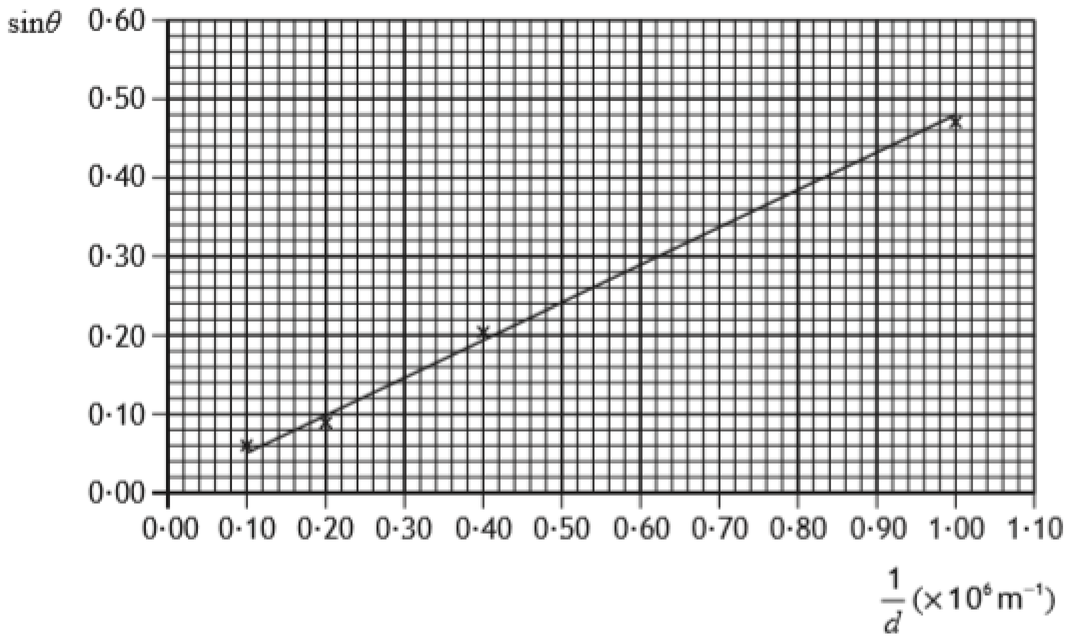
Calculate the wavelength of the microwaves. **3**

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



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

The separation of the slits d is different for each grating.
The angle between the central maximum and the first order maximum θ, produced by each grating, is measured.
The results are used to produce a graph of $\sin\theta$ against $\frac{1}{d}$.

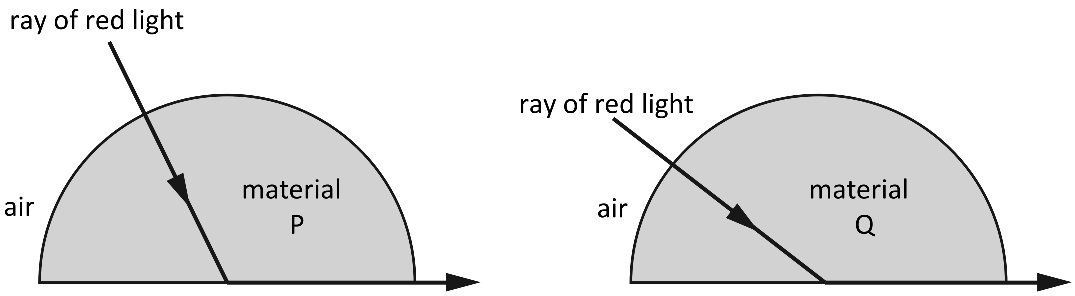


(i) Determine the wavelength of the light from the laser used in this experiment. **3**

(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**

Homework 5 – Refraction

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



A student makes the following statements.

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

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

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

Which of these statements is/are correct?

A I only

B II only

C III only

D I and II only

E I, II and III

2.

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

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

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

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

3. Light travels from **glass** into **air**.

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

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

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

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

A 0·125 W m^{-2}

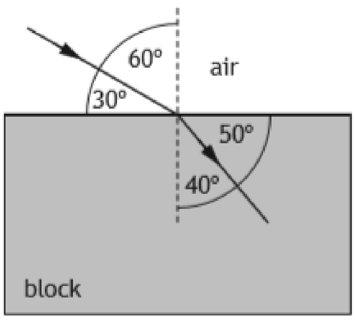
B 0·50 W m^{-2}

C 2·0 W m^{-2}

D 8·0 W m^{-2}

E 128 W m^{-2}.

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



The speed of this light in the block is

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

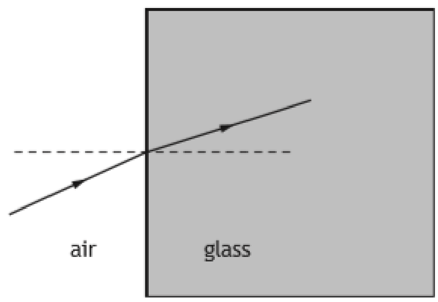
B $1{\cdot}96 \times 10^8$ m s^{-1}

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

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

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

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



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

The refractive index of the glass for this light is $1 \cdot 50$.

The frequency of this light in the glass is

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

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

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

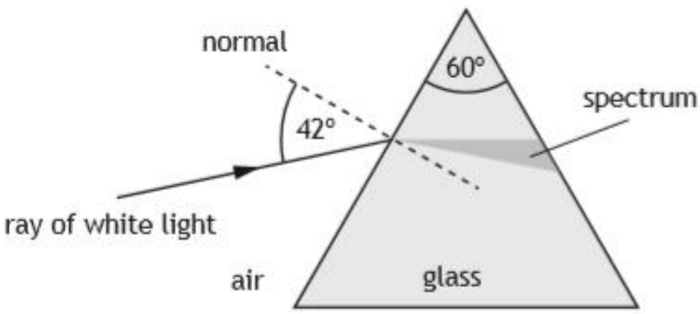
D $4 \cdot 76 \times 10^{14}$ Hz

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

6. 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



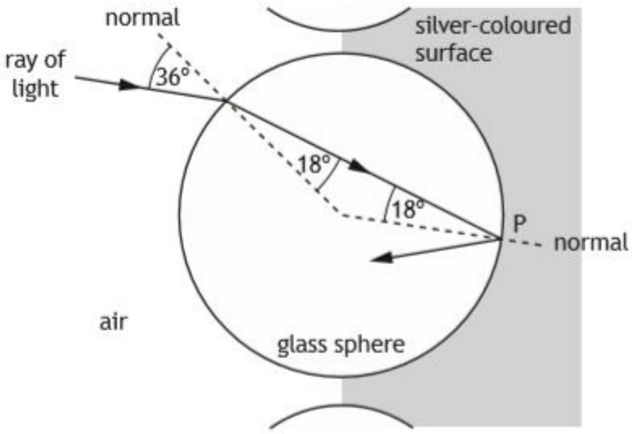
(i) Explain why a spectrum is produced in the glass prism. 1

(ii) The refractive index of the glass for red light is 1·54. 3

Calculate the speed of red light in the glass prism.

7. Retroflective materials reflect light to enhance the visibility of clothing.

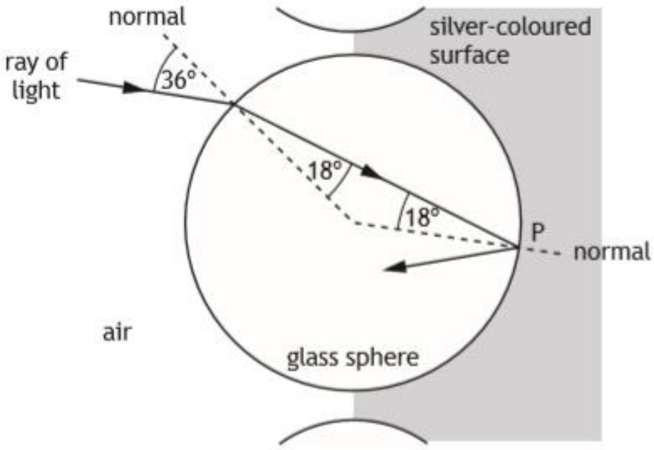
One type of retroflective material is made from small glass spheres partially embedded in a silver-coloured surface that reflects light. A ray of monochromatic light follows the path shown as it enters one of the glass spheres.



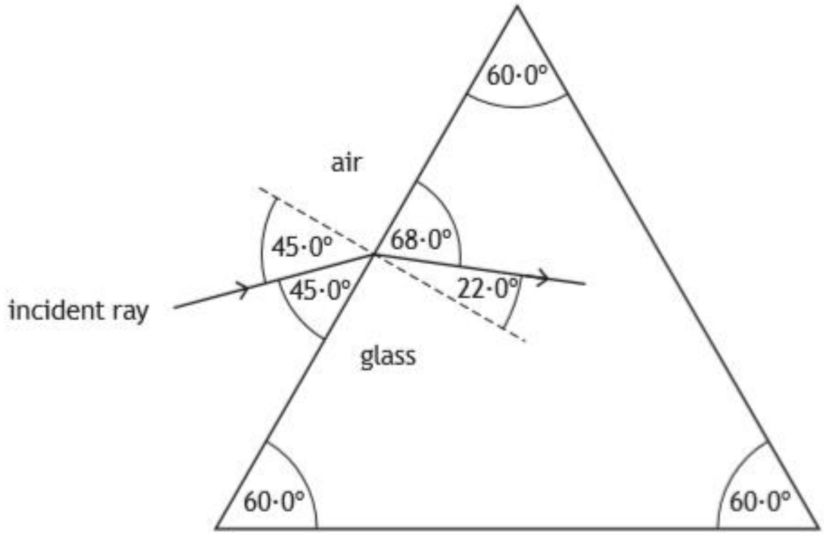
(a) Calculate the refractive index of the glass for this light. 3

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

(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



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



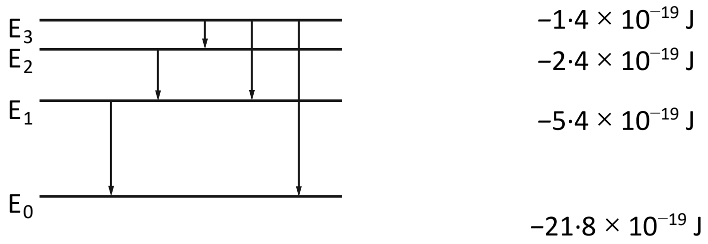
(a) Show that the refractive index of the glass for this ray of light is 1·89. 2

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

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

Homework 6 – Spectra

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



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

A E_1 to E_0

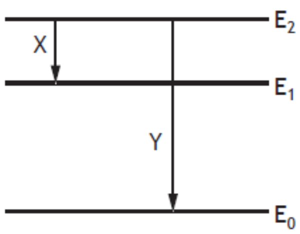
B E_2 to E_1

C E_3 to E_2

D E_3 to E_1

E E_3 to E_0.

2. Part of the energy level diagram for an atom is shown



X and Y represent two possible electron transitions.

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

I Transition Y produces photons of higher frequency than transition X

II Transition X produces photons of longer wavelength than transition Y

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

Which of the statements is/are correct?

A I only

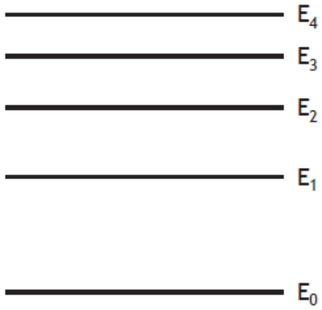
B I and II only

C I and III only

D II and III only

E I, II and III

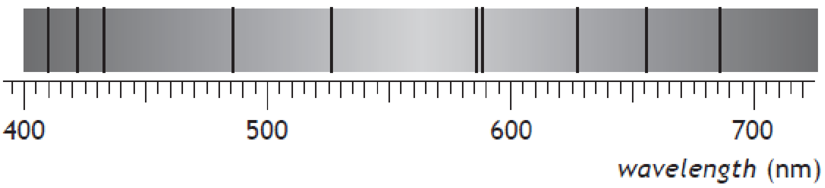
3. When light passes through the outer layers of the Sun certain frequencies of light are absorbed by hydrogen atoms, producing dark lines in the spectrum.
The diagram represents some of the energy levels for a hydrogen atom.



The number of absorption lines in the spectrum caused by the transition of electrons between these energy levels is

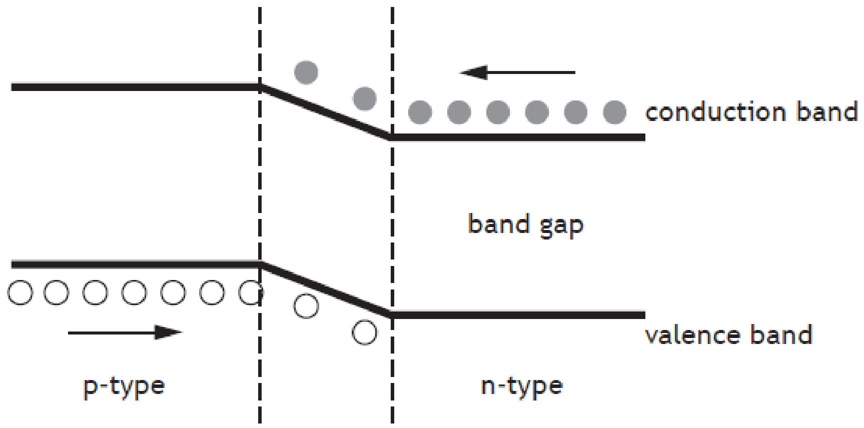
A 4
B 6
C 9
D 10
E 20.

4. Light from the Sun is used to produce a visible spectrum.
A student views this spectrum and observes a number of dark lines as shown.



Explain how these dark lines in the spectrum of sunlight are produced. 2

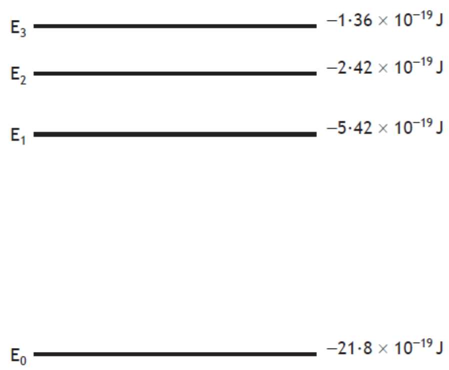
5. Some cars use LEDs in place of filament lamps.
An LED is made from semiconductor material that has been doped with impurities to create a p-n junction.
The diagram represents the band structure of an LED.



The energy gap between the valence band and conduction band is known as the band gap.
The band gap for the LED is $3{\cdot}03 \times 10^{-19}$ J

(A) Calculate the wavelength of the light emitted by the LED. 4
(B) Determine the colour of the light emitted by the LED. 1

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.



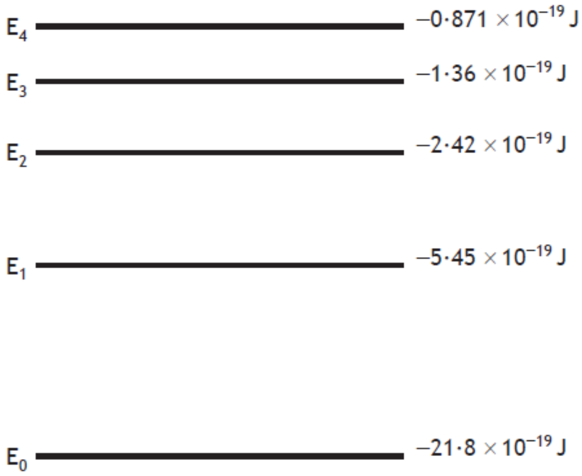
(a) For the energy levels shown in the diagram, identify the electron transition that would lead to the absorption of a photon with the highest frequency. 1

(b) An electron makes the transition from energy level E_1 to E_3. Determine the frequency of the photon absorbed. 3

7. 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