Higher Physics

Particles & Waves Unit

Book 2 of 2

St Andrew's Academy

Name: ___________________________________

This booklet has homework exercises, notes and space for completing worked examples on the Particles & Waves Unit and covers the following key areas:

8. Refraction – Snell's Law
9. Total Internal Reflection & Critical Angle
10. Interference
11. Diffraction Grating
12. Photoelectric effect
13. Intensity of Radiation
14. Energy Level Diagrams

DATA SHEET

COMMON PHYSICAL QUANTITIES

Quantity	*Symbol*	*Value*	*Quantity*	*Symbol*	*Value*
Speed of light in vacuum	c	3.00×10^{8} m s^{-1}	Planck's constant	h	6.63×10^{-34} J s
Magnitude of the charge on an electron	e	1.60×10^{-19} C	Mass of electron	m_e	9.11×10^{-31} kg
Universal Constant of Gravitation	G	6.67×10^{-11} m^{3} kg^{-1} s^{-2}	Mass of neutron	m_n	1.675×10^{-27} kg
Gravitational acceleration on Earth	g	9·8 m s^{-2}	Mass of proton	m_p	1.673×10^{-27} kg
Hubble's constant	H_0	2.3×10^{-18} 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*	*Element*	*Wavelength*/nm	*Colour*
Hydrogen	656	Red	Cadmium	644	Red
	486	Blue-green		509	Green
	434	Blue-violet		480	Blue
	410	Violet	Lasers		
	397	Ultraviolet	*Element*	*Wavelength*/nm	*Colour*
	389	Ultraviolet	Carbon dioxide	9550 } 10590 }	Infrared
Sodium	589	Yellow	Helium-neon	633	Red

PROPERTIES OF SELECTED MATERIALS

Substance	*Density*/kg m^{-3}	*Melting Point*/K	*Boiling Point*/K
Aluminium	2.70×10^{3}	933	2623
Copper	8.96×10^{3}	1357	2853
Ice	9.20×10^{2}	273	. . . .
Sea Water	1.02×10^{3}	264	377
Water	1.00×10^{3}	273	373
Air	1·29	. . . .	. . . .
Hydrogen	9.0×10^{-2}	14	20

The gas densities refer to a temperature of 273 K and a pressure of 1.01×10^{5} Pa.

Relationships required for Physics Higher

$d = \bar{v}t$

$s = \bar{v}t$

$v = u + at$

$s = ut + \frac{1}{2}at^2$

$v^2 = u^2 + 2as$

$s = \frac{1}{2}(u + v)t$

$W = mg$

$F = ma$

$E_W = Fd$

$E_p = mgh$

$E_k = \frac{1}{2}mv^2$

$P = \frac{E}{t}$

$p = mv$

$Ft = mv - mu$

$F = G\frac{m_1 m_2}{r^2}$

$t' = \frac{t}{\sqrt{1 - \left(\frac{v}{c}\right)^2}}$

$l' = l\sqrt{1 - \left(\frac{v}{c}\right)^2}$

$f_o = f_s\left(\frac{v}{v \pm v_s}\right)$

$z = \frac{\lambda_{observed} - \lambda_{rest}}{\lambda_{rest}}$

$z = \frac{v}{c}$

$v = H_0 d$

$W = QV$

$E = mc^2$

$E = hf$

$E_k = hf - hf_0$

$E_2 - E_1 = hf$

$T = \frac{1}{f}$

$v = f\lambda$

$d\sin\theta = m\lambda$

$n = \frac{\sin\theta_1}{\sin\theta_2}$

$\frac{\sin\theta_1}{\sin\theta_2} = \frac{\lambda_1}{\lambda_2} = \frac{v_1}{v_2}$

$\sin\theta_c = \frac{1}{n}$

$I = \frac{k}{d^2}$

$I = \frac{P}{A}$

$V_{peak} = \sqrt{2}V_{rms}$

$I_{peak} = \sqrt{2}I_{rms}$

$Q = It$

$V = IR$

$P = IV = I^2R = \frac{V^2}{R}$

$R_T = R_1 + R_2 + ...$

$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + ...$

$E = V + Ir$

$V_1 = \left(\frac{R_1}{R_1 + R_2}\right)V_s$

$\frac{V_1}{V_2} = \frac{R_1}{R_2}$

$C = \frac{Q}{V}$

$E = \frac{1}{2}QV = \frac{1}{2}CV^2 = \frac{1}{2}\frac{Q^2}{C}$

path difference $= m\lambda$ or $\left(m + \frac{1}{2}\right)\lambda$ where $m = 0, 1, 2...$

random uncertainty $= \frac{\text{max. value} - \text{min. value}}{\text{number of values}}$

Additional Relationships

Circle

circumference $= 2\pi r$

area $= \pi r^2$

Sphere

area $= 4\pi r^2$

volume $= \frac{4}{3}\pi r^3$

Trigonometry

$\sin\theta = \frac{\text{opposite}}{\text{hypotenuse}}$

$\cos\theta = \frac{\text{adjacent}}{\text{hypotenuse}}$

$\tan\theta = \frac{\text{opposite}}{\text{adjacent}}$

$\sin^2\theta + \cos^2\theta = 1$

Electron Arrangements of Elements

Key

Atomic number
Symbol
Electron arrangement
Name

Transition Elements

Group 1 (1)	Group 2 (2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	Group 3 (13)	Group 4 (14)	Group 5 (15)	Group 6 (16)	Group 7 (17)	Group 0 (18)
1 **H** 1 Hydrogen																	2 **He** 2 Helium
3 **Li** 2,1 Lithium	4 **Be** 2,2 Beryllium											5 **B** 2,3 Boron	6 **C** 2,4 Carbon	7 **N** 2,5 Nitrogen	8 **O** 2,6 Oxygen	9 **F** 2,7 Fluorine	10 **Ne** 2,8 Neon
11 **Na** 2,8,1 Sodium	12 **Mg** 2,8,2 Magnesium											13 **Al** 2,8,3 Aluminium	14 **Si** 2,8,4 Silicon	15 **P** 2,8,5 Phosphorus	16 **S** 2,8,6 Sulfur	17 **Cl** 2,8,7 Chlorine	18 **Ar** 2,8,8 Argon
19 **K** 2,8,8,1 Potassium	20 **Ca** 2,8,8,2 Calcium	21 **Sc** 2,8,9,2 Scandium	22 **Ti** 2,8,10,2 Titanium	23 **V** 2,8,11,2 Vanadium	24 **Cr** 2,8,13,1 Chromium	25 **Mn** 2,8,13,2 Manganese	26 **Fe** 2,8,14,2 Iron	27 **Co** 2,8,15,2 Cobalt	28 **Ni** 2,8,16,2 Nickel	29 **Cu** 2,8,18,1 Copper	30 **Zn** 2,8,18,2 Zinc	31 **Ga** 2,8,18,3 Gallium	32 **Ge** 2,8,18,4 Germanium	33 **As** 2,8,18,5 Arsenic	34 **Se** 2,8,18,6 Selenium	35 **Br** 2,8,18,7 Bromine	36 **Kr** 2,8,18,8 Krypton
37 **Rb** 2,8,18,8,1 Rubidium	38 **Sr** 2,8,18,8,2 Strontium	39 **Y** 2,8,18,9,2 Yttrium	40 **Zr** 2,8,18,10,2 Zirconium	41 **Nb** 2,8,18,12,1 Niobium	42 **Mo** 2,8,18,13,1 Molybdenum	43 **Tc** 2,8,18,13,2 Technetium	44 **Ru** 2,8,18,15,1 Ruthenium	45 **Rh** 2,8,18,16,1 Rhodium	46 **Pd** 2,8,18,18,0 Palladium	47 **Ag** 2,8,18,18,1 Silver	48 **Cd** 2,8,18,18,2 Cadmium	49 **In** 2,8,18,18,3 Indium	50 **Sn** 2,8,18,18,4 Tin	51 **Sb** 2,8,18,18,5 Antimony	52 **Te** 2,8,18,18,6 Tellurium	53 **I** 2,8,18,18,7 Iodine	54 **Xe** 2,8,18,18,8 Xenon
55 **Cs** 2,8,18,18,8,1 Caesium	56 **Ba** 2,8,18,18,8,2 Barium	57 **La** 2,8,18,18,9,2 Lanthanum	72 **Hf** 2,8,18,32,10,2 Hafnium	73 **Ta** 2,8,18,32,11,2 Tantalum	74 **W** 2,8,18,32,12,2 Tungsten	75 **Re** 2,8,18,32,13,2 Rhenium	76 **Os** 2,8,18,32,14,2 Osmium	77 **Ir** 2,8,18,32,15,2 Iridium	78 **Pt** 2,8,18,32,17,1 Platinum	79 **Au** 2,8,18,32,18,1 Gold	80 **Hg** 2,8,18,32,18,2 Mercury	81 **Tl** 2,8,18,32,18,3 Thallium	82 **Pb** 2,8,18,32,18,4 Lead	83 **Bi** 2,8,18,32,18,5 Bismuth	84 **Po** 2,8,18,32,18,6 Polonium	85 **At** 2,8,18,32,18,7 Astatine	86 **Rn** 2,8,18,32,18,8 Radon
87 **Fr** 2,8,18,32,18,8,1 Francium	88 **Ra** 2,8,18,32,18,8,2 Radium	89 **Ac** 2,8,18,32,18,9,2 Actinium	104 **Rf** 2,8,18,32,32,10,2 Rutherfordium	105 **Db** 2,8,18,32,32,11,2 Dubnium	106 **Sg** 2,8,18,32,32,12,2 Seaborgium	107 **Bh** 2,8,18,32,32,13,2 Bohrium	108 **Hs** 2,8,18,32,32,14,2 Hassium	109 **Mt** 2,8,18,32,32,15,2 Meitnerium	110 **Ds** 2,8,18,32,32,17,1 Darmstadtium	111 **Rg** 2,8,18,32,32,18,1 Roentgenium	112 **Cn** 2,8,18,32,32,18,2 Copernicium						

Lanthanides	57 **La** 2,8,18,18,9,2 Lanthanum	58 **Ce** 2,8,18,20,8,2 Cerium	59 **Pr** 2,8,18,21,8,2 Praseodymium	60 **Nd** 2,8,18,22,8,2 Neodymium	61 **Pm** 2,8,18,23,8,2 Promethium	62 **Sm** 2,8,18,24,8,2 Samarium	63 **Eu** 2,8,18,25,8,2 Europium	64 **Gd** 2,8,18,25,9,2 Gadolinium	65 **Tb** 2,8,18,27,8,2 Terbium	66 **Dy** 2,8,18,28,8,2 Dysprosium	67 **Ho** 2,8,18,29,8,2 Holmium	68 **Er** 2,8,18,30,8,2 Erbium	69 **Tm** 2,8,18,31,8,2 Thulium	70 **Yb** 2,8,18,32,8,2 Ytterbium	71 **Lu** 2,8,18,32,9,2 Lutetium
Actinides	89 **Ac** 2,8,18,32,18,9,2 Actinium	90 **Th** 2,8,18,32,18,10,2 Thorium	91 **Pa** 2,8,18,32,20,9,2 Protactinium	92 **U** 2,8,18,32,21,9,2 Uranium	93 **Np** 2,8,18,32,22,9,2 Neptunium	94 **Pu** 2,8,18,32,24,8,2 Plutonium	95 **Am** 2,8,18,32,25,8,2 Americium	96 **Cm** 2,8,18,32,25,9,2 Curium	97 **Bk** 2,8,18,32,27,8,2 Berkelium	98 **Cf** 2,8,18,32,28,8,2 Californium	99 **Es** 2,8,18,32,29,8,2 Einsteinium	100 **Fm** 2,8,18,32,30,8,2 Fermium	101 **Md** 2,8,18,32,31,8,2 Mendelevium	102 **No** 2,8,18,32,32,8,2 Nobelium	103 **Lr** 2,8,18,32,32,9,2 Lawrencium

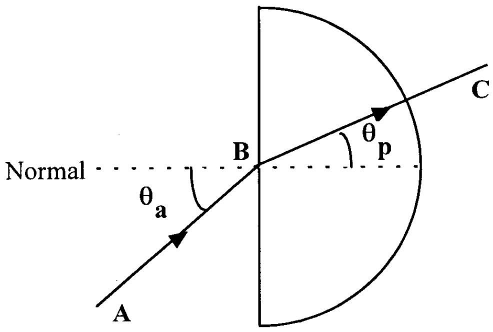
8. Refraction – Snell's Law

Learning Outcomes:

- Absolute refractive index of a material is the ratio of the sine of angle of incidence in vacuum (air) to the sine of angle of refraction in the material.
- Refractive index of air treated as the same as that of a vacuum.
- Situations where light travels from a more dense to a less dense substance.
- Refractive index can be found from the ration of speed of light in vacuum (air) to the speed in the material and the ratio of the wavelengths.
- Variation of refractive index with frequency.

Refraction and Refractive Index

Experiment – Refractive index of a perspex box



Method

- Place the block on white paper and trace around its outline. Draw in the normal at the midpoint *B*.
- With incident angle $\theta_a = 10°$, measure the angle θp, the refracted angle in the perspex.
- Repeat for the other values of incident angle.

Results

θ_1	θ_2	$\sin\theta_1 / \sin\theta_2$
10°		
20 °		
30 °		
40 °		
50 °		
60 °		

Now draw a graph of your results

- The ratio $\sin \theta_1 / \sin \theta_2$ is a constant when light passes obliquely from medium 1 to medium 2.
- The absolute refractive index, n, of a medium is the ratio $\sin \theta_1 / \sin \theta_2$ where θ_1 is in a vacuum (or air as an approximation) and θ_2 is in the medium.

i.e. $$n = \sin \theta_1 / \sin \theta_2$$

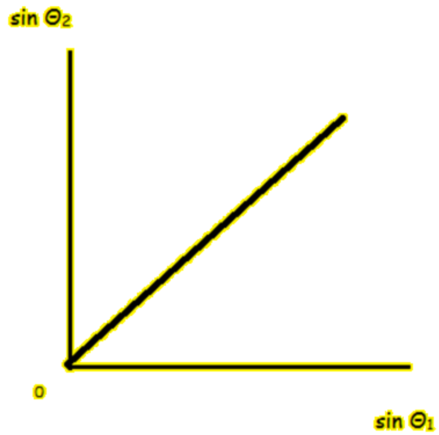
- Note that the refractive index of air is 1.
- Therefore, we can write:

- $$\frac{n_2}{n_1} = \frac{\sin \Theta_1}{\sin \Theta_2}$$

- The **refractive index** measures the effect a medium has on light. The greater the refractive index, the greater the change in speed and direction.
- The absolute refractive index is **always** a value greater than (or equal to) 1.

Calculating the refractive index, n, using a graph

- The refractive index can also be calculated by plotting a graph of how $\sin \theta_1$ varies with $\sin \theta_2$
- The refractive index is equal to the gradient of this graph.



Refractive Index and Frequency

- Note that the different colours are refracted through different angles.
- i.e. The refractive index depends on the frequency (colour) of the incident light.
- The refractive index of the medium for blue light is greater than that for red.
- This is why when white light passes through a triangular prism it is broken up into the colours of the rainbow.

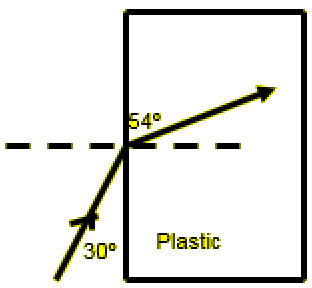
- Wavelength, λ, and velocity, v, change during refraction, but **frequency does not change**.
- i.e. The frequency of a wave is unaltered by a change in medium.
- When light passes from medium 1 to medium 2:

$$\frac{\sin \theta_1}{\sin \theta_2} = \frac{\lambda_1}{\lambda_2} = \frac{v_1}{v_2}$$

- Note: medium 1 will always be air at Higher level regardless of the direction of light

Example 1

Using information in the diagram, find the refractive index of the plastic:



Example 2

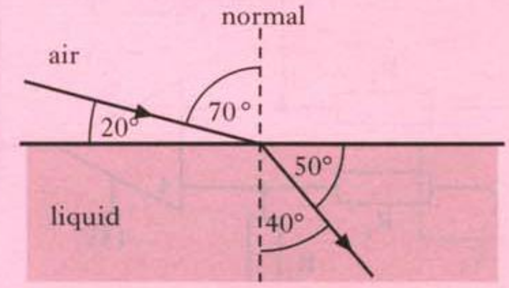
- Calculate the speed of light in glass of refractive index 1.50.

  (this is a common question, here the examiner assumes that you know the speed of light in air is $3x10^8$ ms^{-1})

Old Higher Past Paper Examples

2006 Qu: 15

15. The diagram represents a ray of light passing from air into liquid.



The refractive index of this liquid, relative to air, is

A $\frac{\sin 20°}{\sin 40°}$

B $\frac{\sin 40°}{\sin 70°}$

C $\frac{\sin 50°}{\sin 20°}$

D $\frac{\sin 70°}{\sin 40°}$

E $\frac{\sin 90°}{\sin 40°}$.

2006 Qu: 15

14. Microwaves of frequency $2 \cdot 0 \times 10^{10}$ Hz travel through air with a speed of $3 \cdot 0 \times 10^{8}$ m s^{-1}. On entering a bath of oil, the speed reduces to $1 \cdot 5 \times 10^{8}$ m s^{-1}.

The frequency of the microwaves in the oil is

A $1 \cdot 0 \times 10^{10}$ Hz

B $2 \cdot 0 \times 10^{10}$ Hz

C $4 \cdot 0 \times 10^{10}$ Hz

D $3 \cdot 0 \times 10^{18}$ Hz

E $6 \cdot 0 \times 10^{18}$ Hz.

2006 Qu: 16

16. Light travels from air into glass.

Which row in the table describes what happens to the speed, frequency and wavelength of the light?

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

2005 Qu: 16

16. A liquid and a solid have the same refractive index.

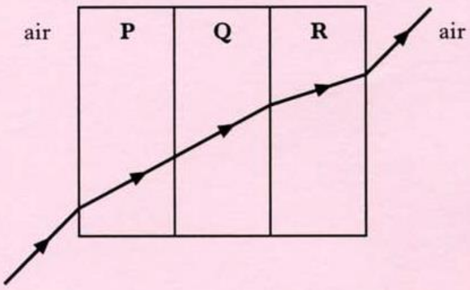
What happens to the speed and the wavelength of light passing from the liquid into the solid?

	Speed	*Wavelength*
A	stays the same	stays the same
B	decreases	decreases
C	decreases	increases
D	increases	increases
E	increases	decreases

2003 Qu: 16

16. An engineer creates an experimental window using sheets of transparent plastics **P**, **Q** and **R**.

A ray of light directed at the window follows the path shown.



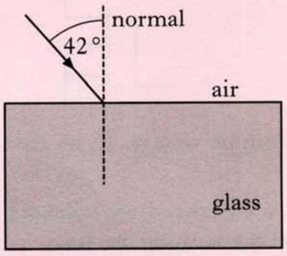
Which row in the table gives possible values for the refractive indices of the three plastics?

	P	***Q***	***R***
A	1·5	1·9	2·3
B	1·5	1·5	2·3
C	2·3	2·3	1·5
D	2·3	1·9	1·5
E	1·5	1·5	1·2

2003 Qu: 27

(*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.

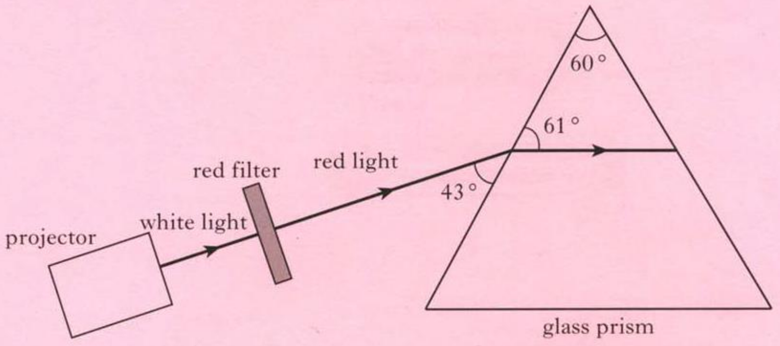
(i) What is the value of the frequency of the light in the block of glass?

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

2003 Qu: 27

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

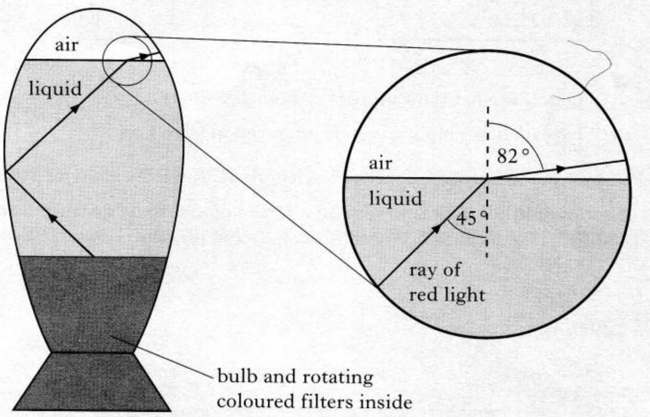
(*a*) The apparatus for the first experiment is shown below.



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

2004 Qu: 27

(*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?

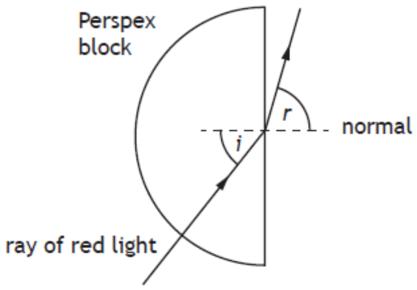
You must explain your answer. **3**

Revised / CfE Higher Past Paper Examples

CfE Specimen Qu: 12

A student is investigating the refractive index of a Perspex block for red light.

The student directs a ray of red light towards a semicircular Perspex block as shown.



The angle of incidence *i* is then varied and the angle of refraction *r* is measured using a protractor.

The following results are obtained.

i (°)	*r* (°)	*sin i*	*sin r*
10	16	0·17	0·28
15	25	0·26	0·42
20	32	0·34	0·53
25	37	0·42	0·60
30	53	0·50	0·80

(a) (i) Using square ruled paper, draw a graph to show how sin *r* varies with sin *i*. **3**

(ii) Use the graph to determine the refractive index of the Perspex for this light. **2**

(iii) Suggest **two** ways in which the experimental procedure could be improved to obtain a more accurate value for the refractive index. **2**

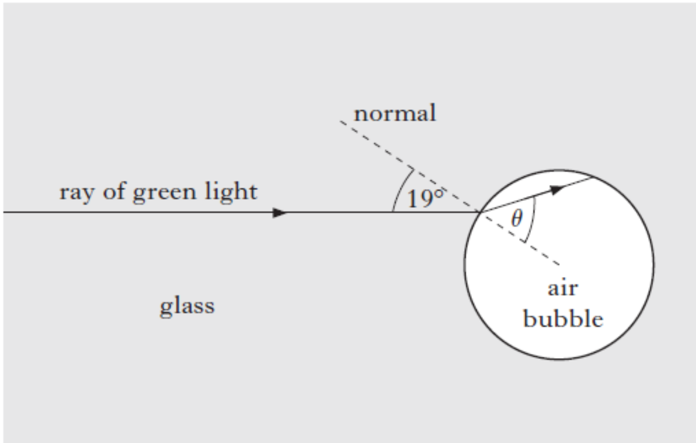
2013 Revised Qu: 29

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.



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

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

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

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

Explain why a spectrum is produced.

9. Total Internal Reflection & Critical Angle

Learning Outcomes

- Critical angle and total internal reflection.

Total Internal Reflection & Critical Angle definitions by diagram

- Diagram 1 – light is refracted.
- Diagram 2 – Light is refracted at 90^0, the angle of incidence in this case is called the critical angle, **Θ_c**
- Diagram 3 – Any angle bigger than the critical angle will show Total Internal Reflection

Diagram 1

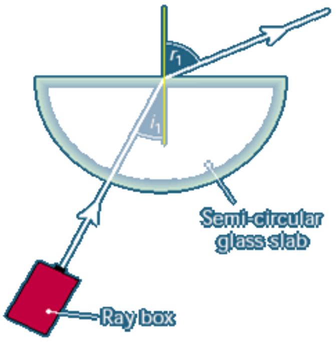


Diagram 2

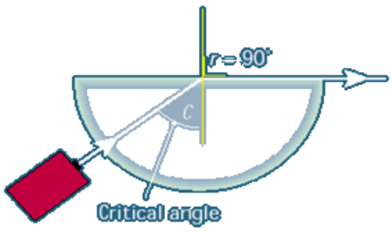
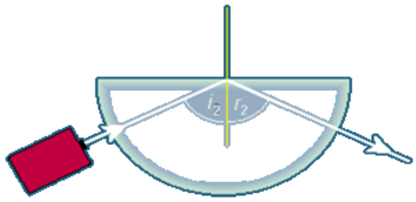
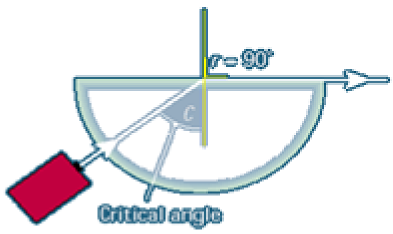


Diagram 3



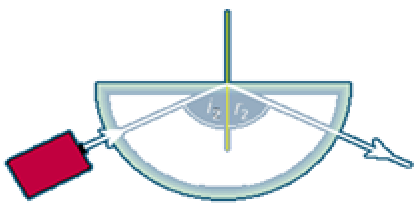
The Critical Angle

- The critical angle, Θ_c is the angle of incidence when the angle of refraction is 90^0.
- It is the smallest angle of incidence above which Total Internal Reflection occurs. It is often given the symbol, Θ_c



Total Internal Reflection

- Takes place when all of a light ray is completely reflected and none of it is refracted.
- This takes place at angles above the critical angle, Θ_c



Critical Angle and Refractive Index

$$n = \frac{1}{\sin \theta_c}$$

Example

Find the critical angle of a material with refractive index 1.4

Old Higher Past Paper Questions

2008 Qu: 16

16. The value of the absolute refractive index of diamond is 2·42.

The critical angle for diamond is

A 0·413°

B 24·4°

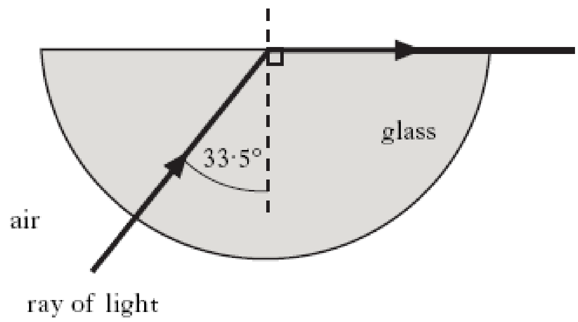
C 42·0°

D 65·6°

E 90·0°.

2009 Qu: 15

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



The refractive index of the glass for this light is

A 0·03

B 0·55

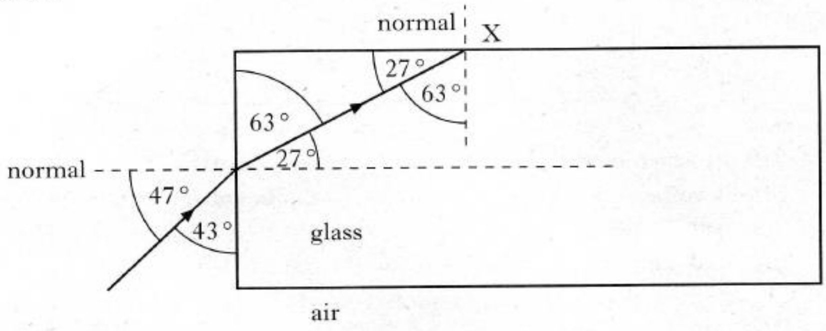
C 0·87

D 1·20

E 1·81.

2001 Qu: 27(b)

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

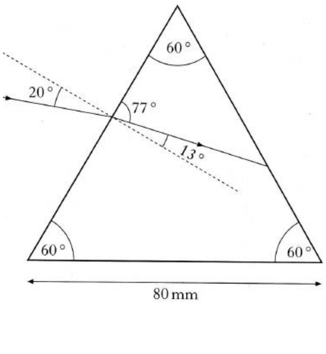


(i) Using information from the diagram, show that the refractive index of the glass for this light is 1·61.

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

2002 Qu: 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**

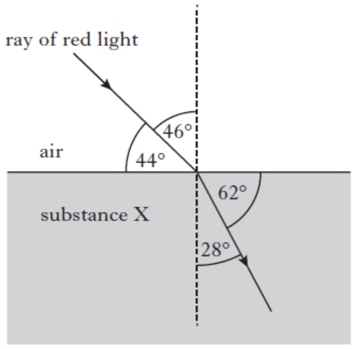
(*c*) Calculate the critical angle for the red light in the prism. **2**

(*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**

Revised / CfE Higher Past Paper Examples

Revised 2014 Qu: 15

13. The diagram shows the path of a ray of red light as it passes from air into substance X.



The critical angle for the light in substance X is

A 32°

B 41°

C 45°

D 52°

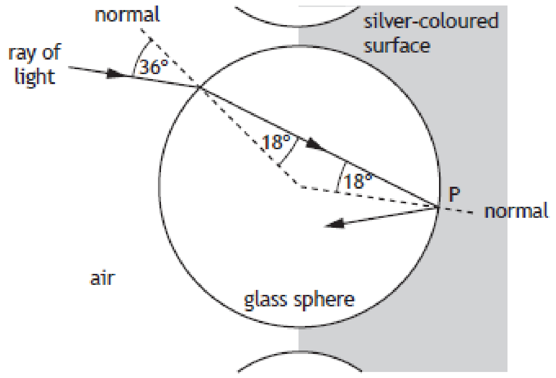
E 90°.

Cfe Higher 2016 Qu: 10

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.

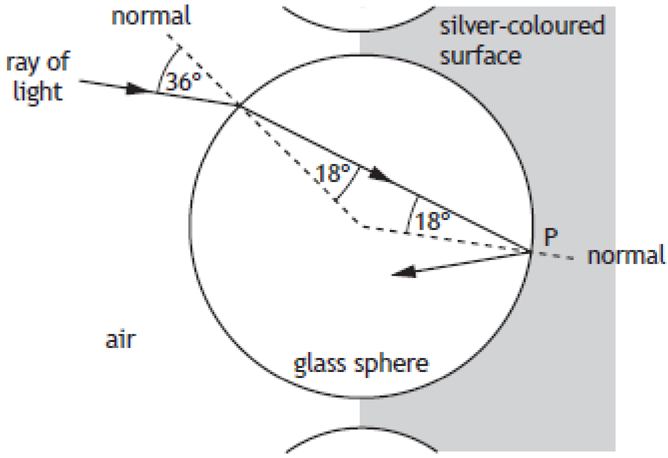


(a) Calculate the refractive index of the glass for this light. 3

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

(c) The light is reflected at point P.

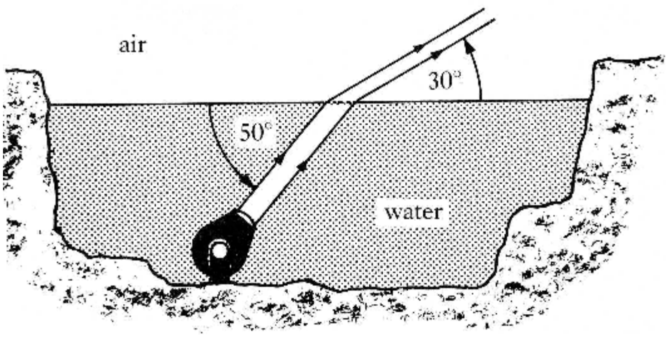
Complete the diagram below to show the path of the ray as it passes through the sphere and emerges into the air. 1



Snell's law, Total Internal Reflection and Critical Angle homework Due date:________

1.

The diagram below shows a parallel beam of monochromatic light emerging from an underwater spotlight in an ornamental pond.



The absolute refractive index of the water in this pond is

A 0·65

B 0·74

C 1·35

D 1·53

E 1·66.

2.

Light of frequency 6×10^{14} Hz passes from air into glass. The refractive index of the glass is 1·5 and the speed of light in air is 3×10^{8} m s^{-1}.

The wavelength of this light in the **glass** is

A $5{\cdot}0 \times 10^{-9}$ m

B $3{\cdot}3 \times 10^{-7}$ m

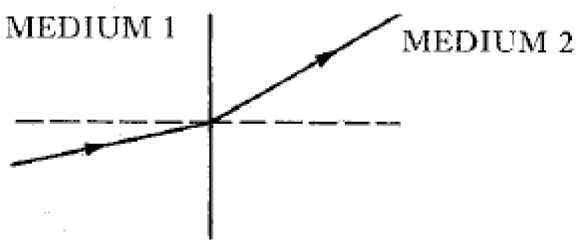
C $5{\cdot}0 \times 10^{-7}$ m

D $7{\cdot}5 \times 10^{-7}$ m

E $1{\cdot}8 \times 10^{23}$ m.

3.

A ray of light travels with speed v_1 through medium 1 and then passes into another medium 2, where it travels at speed v_2.



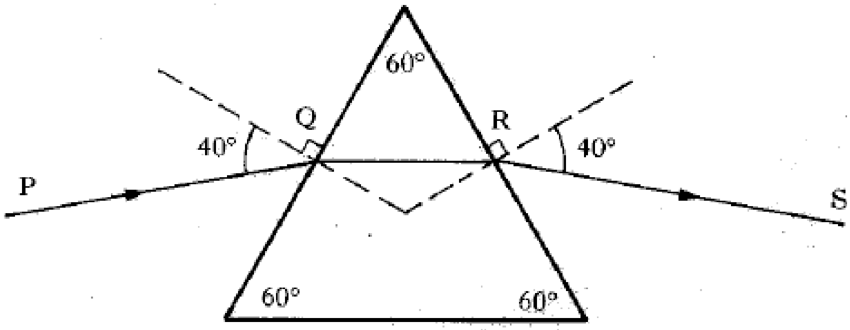
The refractive indices for medium 1 and medium 2 are n_1 and n_2 respectively.

Which row in the following table correctly compares the speeds and refractive indices for each medium?

	Speed of light	*Refractive Index*
A	v_2 is less than v_1	n_2 is less than n_1
B	v_2 is the same as v_1	n_2 is less than n_1
C	v_2 is the same as v_1	n_2 is greater than n_1
D	v_2 is greater than v_1	n_2 is less than n_1
E	v_2 is greater than v_1	n_2 is greater than n_1

4.

(*a*) The diagram below shows the path of a monochromatic beam of light through a triangular plastic prism.



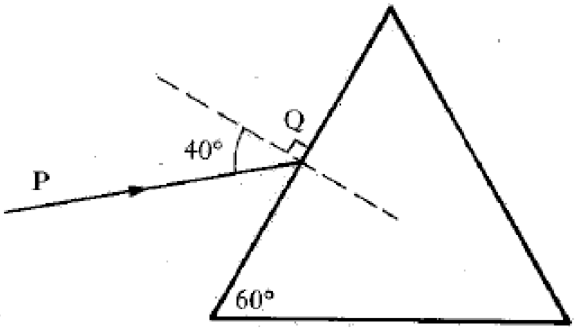
plastic prism

(i) Calculate the refractive index of the plastic.

(ii) Sketch a copy of the above diagram with ray PQRS clearly labelled. (Sizes of angles need not be shown.)

Add to your drawing the path which the ray PQ would take from Q if the prism were made of a plastic with a **slightly higher** refractive index.

(*b*) The original prism is now replaced with one of the same size and shape but made from glass of refractive index 1·80.



glass prism

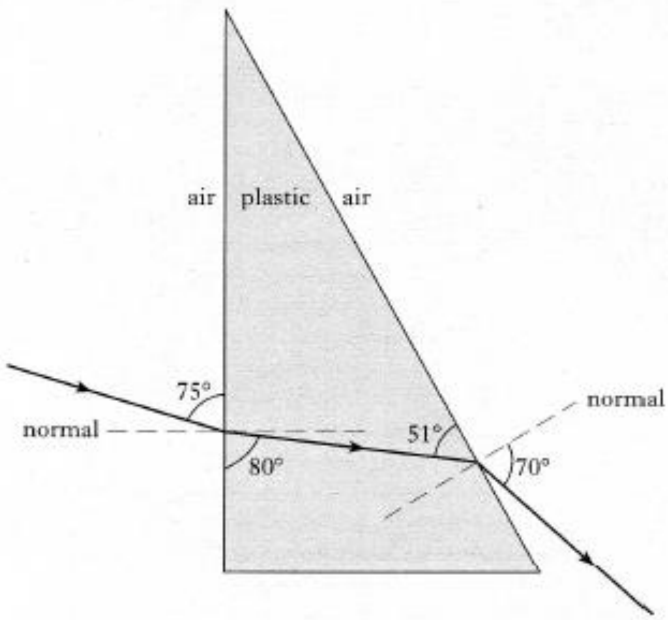
(i) Calculate the critical angle for this glass.

(ii) Draw an accurate diagram, showing the passage of the ray PQ through this prism until after it emerges into the air.

Mark on your diagram the values of all relevant angles.

5.

(*a*) The diagram below shows the refraction of a ray of red light as it passes through a plastic prism.

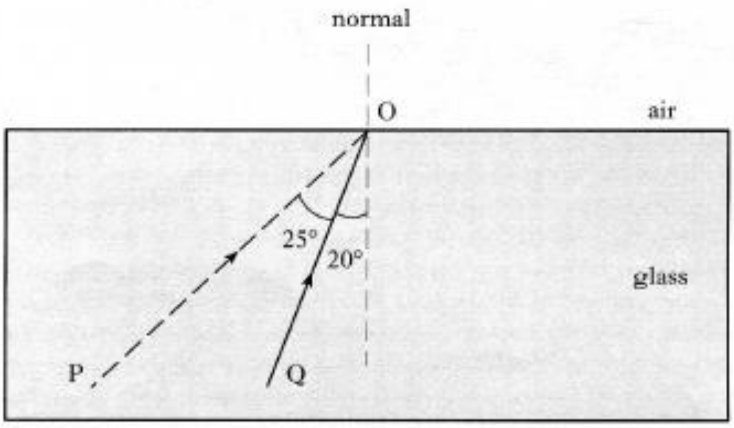


Calculate the refractive index of the plastic for this red light.

(*b*) The refractive index of a glass block is found to be 1·44 when red light is used.

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

(ii) The diagram shows the paths of two rays of this red light, PO and QO, in the glass block.



When rays PO and QO strike the glass-air boundary, **three** further rays of light are observed.

Copy and complete the diagram to show **all five** rays.

Clearly indicate which of the three rays came from P and which came from Q.

The values of all angles should be shown on the diagram.

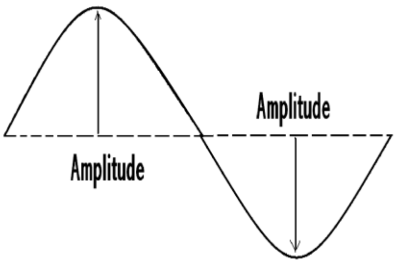
10. Interference

Learning Outcomes:

- Conditions for constructive and destructive interference.
- Constructive and destructive interference in terms of phase between two waves.
- Coherent waves have a constant phase relationship and have the same frequency, wavelength and velocity.
- Interference of waves using two coherent sources.

Waves Revision

- The energy of a wave depends on its amplitude (a).



Old Higher 2007

14. The energy of a wave depends on its

A amplitude

B period

C phase

D speed

E wavelength.

Wave Equation

- Wavelength, λ: the length of one wave (m).
- Frequency, f: the number of waves per second (Hz).
- Wave speed, v: the speed of a wave (ms^{-1})
- They are all related by the equation:

$$v = f \lambda$$

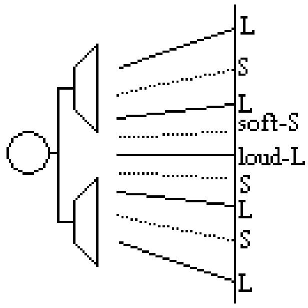
Interference and Path Difference

Coherent Sources

- If waves coming from two sources have the same frequency, wavelength and velocity and are in phase, then the two sources are coherent.
- They will also have the same amplitude.
- A coherent wave is a wave which has no phase difference / constant phase relationship.

Interference of sound

- In the experiment we set up two coherent sound sources.
- We can hear a series of soft and loud noises as we move parallel to the two sound sources.
- This can be explained by interference – the process by which two waves interact.



Interference

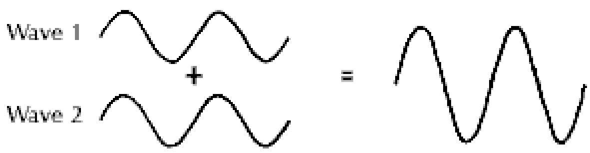
- When two sets of waves (any type – water, micro, sound) meet, they combine to produce a new pattern.
- The new pattern depends on the original wavelengths, amplitudes etc.
- Waves combine in one of two ways:

a. Constructive Interference (loud)
b. Destructive Interference (soft)

Interference is the test for a wave.

Constructive Interference

- Two sets of waves meet in phase.
- Two crests meet or two troughs meet to produce a larger crest or trough.
- This is where we heard **loud sounds** in the demo.



Constructive Interference

Maxima

- In an interference pattern formed by two coherent sources, maxima occur at points of **constructive interference**:

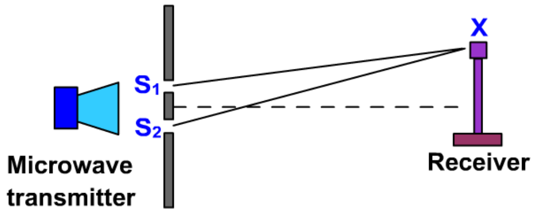
Path difference = mλ	for maxima

where m is an integer, λ is the wavelength i.e. path difference = λ, 2λ, 3λ, etc.

- Note - the space between each maxima is equal to one wavelength.

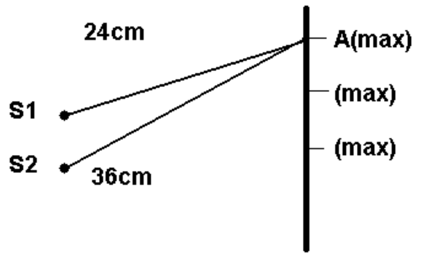
Example 1:

- Microwave radiation of wavelength 2.5 cm is passed through two slits (giving two coherent sources).
- A receiver is moved from directly between the two sources (central maximum) up to the third area of constructive interference.
- What is the path difference, $S_2X - S_1X$?



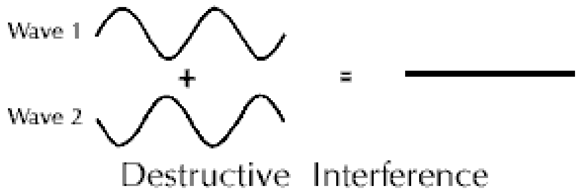
Example 2

Find the wavelength of the waves used in the diagram if the second off-centre maximum occurs at A:



Destructive interference

Two sets of waves meet out of phase.
One crest meets a trough and they cancel each other out.
This is where we heard soft sounds in the demo.

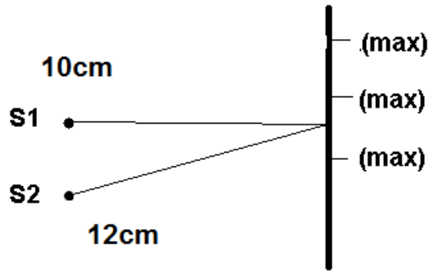


Minima

- Minima occur at points of **destructive interference**:
- Path difference = (m+½)λ for minima
- i.e. path difference = ½λ, 1½λ, 2½λ, etc.

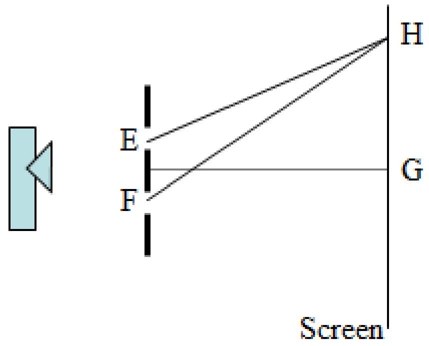
Example 1

- Find the wavelength of the waves used below for the **zero order minimum**:



Example 2

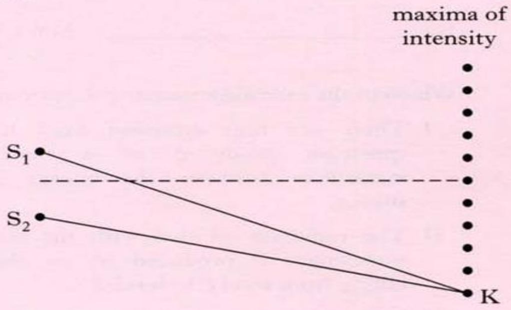
- In a microwave interference experiment, **H** is the first **order** minimum, that is there is one other minimum between **H** and **G**.
- Measurement of distances **EH** and **FH** gives: **EH** = 42.1 cm and **FH** = 46.6 cm.
- Calculate:
  (a) the wavelength; and
  (b) the frequency of the microwaves used.



Multi-choice Past Paper Examples:

Old Higher 2000 Qu: 14

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



The path difference $S_1K - S_2K$ is 154 mm. The wavelength of the waves is

A 15·4 mm

B 25·7 mm

C 28·0 mm

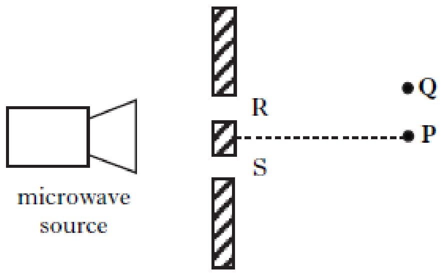
D 30·8 mm

E 34·2 mm.

Old Higher 2008 Qu: 14

14. A source of microwaves of wavelength λ is placed behind two slits, R and S.

A microwave detector records a maximum when it is placed at P.



The detector is moved and the **next** maximum is recorded at Q.

The path difference (SQ – RQ) is

A 0

B $\frac{\lambda}{2}$

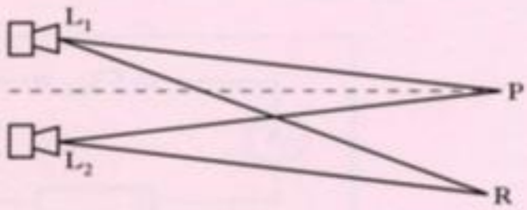
C λ

D $\frac{3\lambda}{2}$

E 2λ.

Old Higher 2004 Qu: 14

14. 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 intensity.

The next maximum intensity is at position R, where $L_1R = 5{\cdot}6$ m and $L_2R = 5{\cdot}3$ m.

The speed of sound is $340\,\text{m s}^{-1}$.

The frequency of the sound emitted by the loudspeakers is given by

A $\frac{5{\cdot}6 - 5{\cdot}3}{340}$ Hz

B $\frac{340}{5{\cdot}6 + 5{\cdot}3}$ Hz

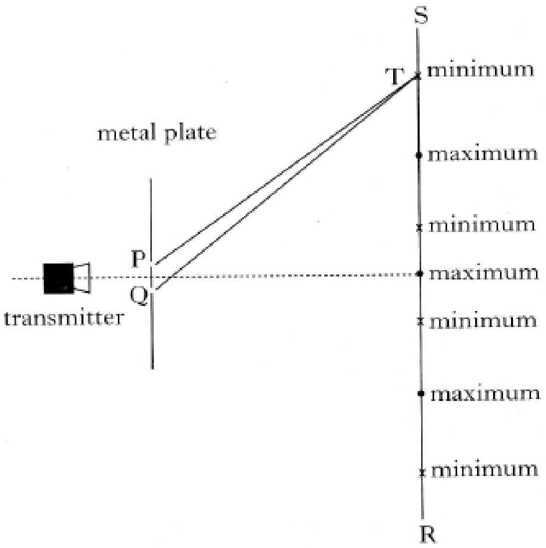
C $\frac{340}{5{\cdot}6 - 5{\cdot}3}$ Hz

D $340 \times (5{\cdot}6 - 5{\cdot}3)$ Hz

E $340 \times (5{\cdot}6 + 5{\cdot}3)$ Hz.

Old Higher 2004 Qu: 15

15. Microwave radiation is incident on a metal plate which has 2 slits, P and Q. A microwave receiver is moved from R to S, and detects a series of maxima and minima of intensity at the positions shown.



The microwave radiation has a wavelength of 4 cm.

The path difference between PT and QT is

A 2 cm

B 3 cm

C 4 cm

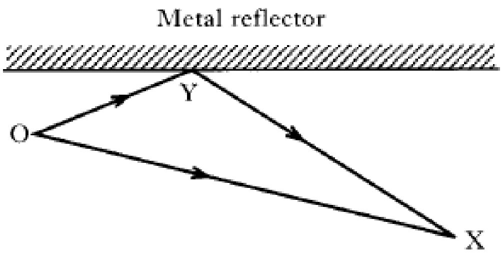
D 5 cm

E 6 cm.

Old Higher 2006 Qu: 14

14. A microwave source at point O produces waves of wavelength 28 mm.

A metal reflector is placed as shown.



An interference pattern is produced.
Constructive interference occurs at point X.
The distance OX is 400 mm.
The total path length OYX is

A 414 mm

B 421 mm

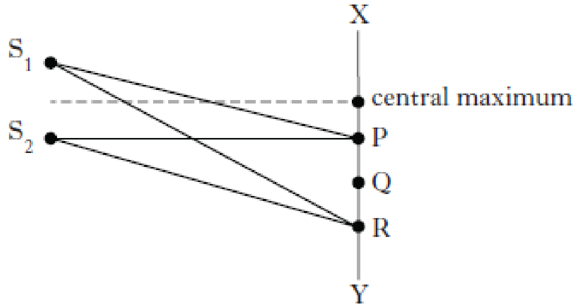
C 442 mm

D 456 mm

E 463 mm.

Old Higher 2006 Qu: 14

9. S_1 and S_2 are sources of coherent waves. An interference pattern is obtained between X and Y.



The first order maximum occurs at P, where $S_1P = 200$ mm and $S_2P = 180$ mm.

For the third order maximum, at R, the path difference $(S_1R - S_2R)$ is

A 20 mm

B 30 mm

C 40 mm

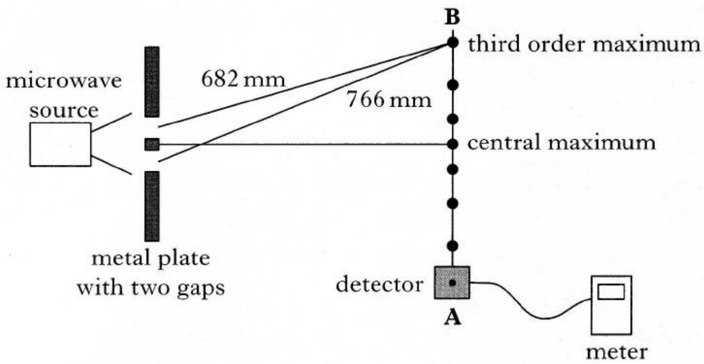
D 50 mm

E 60 mm.

Section 2 Past Paper Examples:

Old Higher 2003 Qu: 28(a)

(*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.

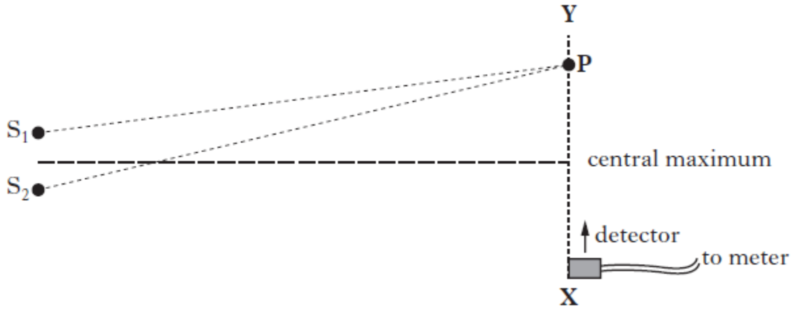
Explain, in terms of waves, how the pattern of maxima and minima is produced.

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

Old Higher 2013 Qu: 28(a)

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.

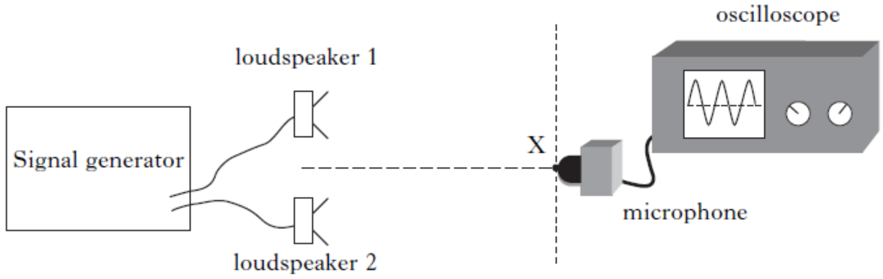
The distance from S_1 to P is 620 mm.

The wavelength of the waves is 28 mm.

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

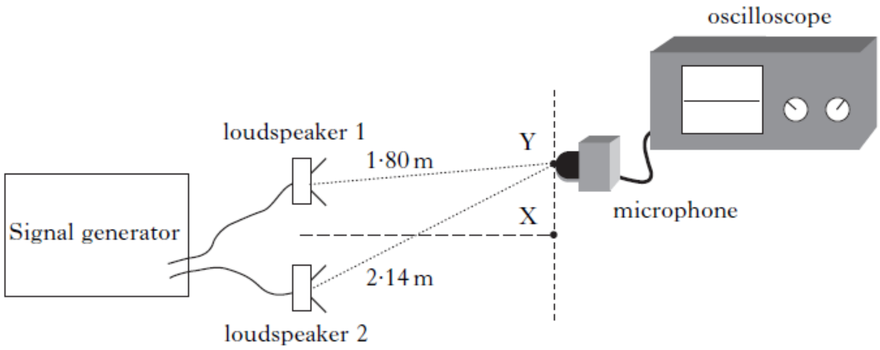
Old Higher 2010 Qu: 27

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?

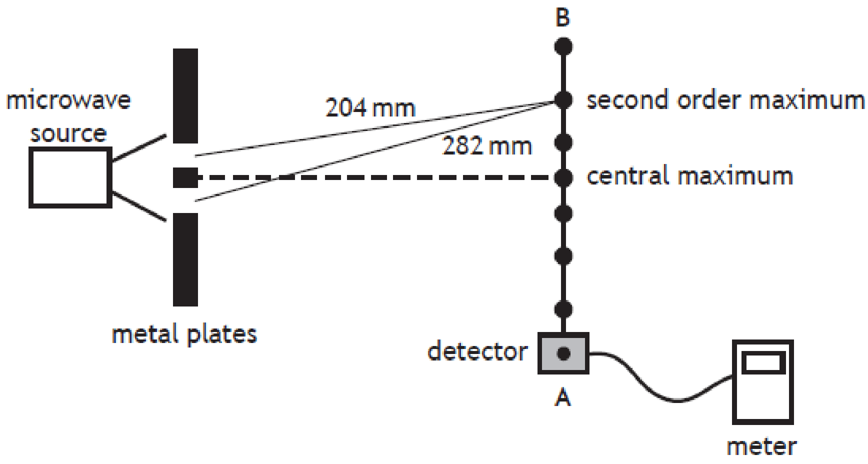
Explain your answer. **2**

(4)

CfE Higher 2016 Qu: 27

...

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

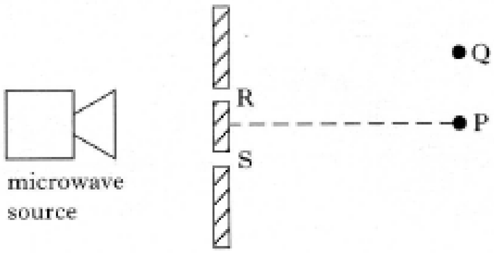
(b) Explain, in terms of waves, how a maximum is produced. 1

(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

Interference homework **Due date:______________**

1. A source of microwaves of wavelength λ is placed behind two slits, R and S. A microwave detector records the maximum response when it is placed at P, where RP = SP.



The microwave detector is moved and the **next** maximum is recorded at Q.

The path difference (SQ−RQ) must be

A 0

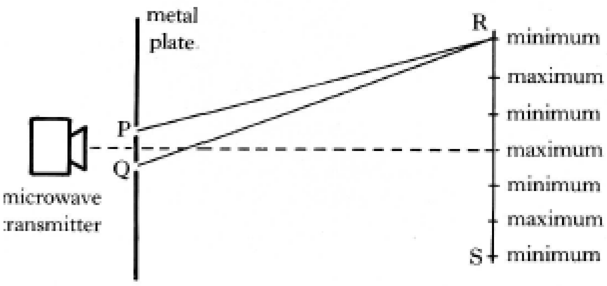
B $\frac{\lambda}{2}$

C λ

D (any odd number) $\times \frac{\lambda}{2}$

E (any whole number) $\times \lambda$.

2. A microwave transmitter is directed at a metal plate which has two slits P and Q in it as shown. The microwave radiation emitted has a wavelength of 3 cm.



A microwave receiver is moved from R to S and, in doing so, detects maxima and minima of intensity at the positions shown.

What is the path difference between PR and QR?

A 1·5 cm

B 3·0 cm

C 4·5 cm

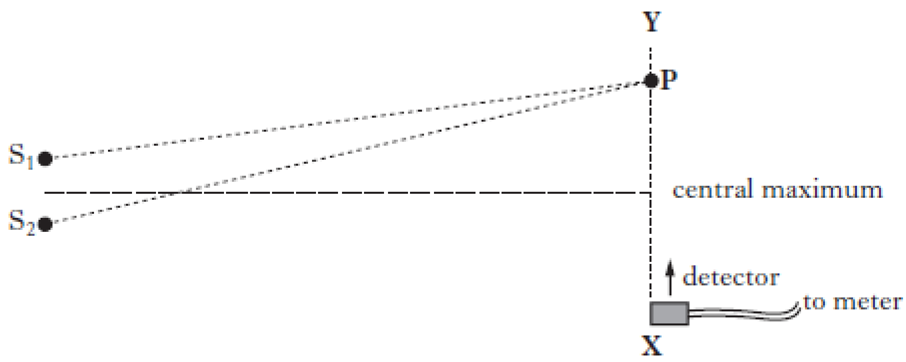
D 6·0 cm

E 9·0 cm

3.

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.

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

The distance from S_1 to P is 620 mm.

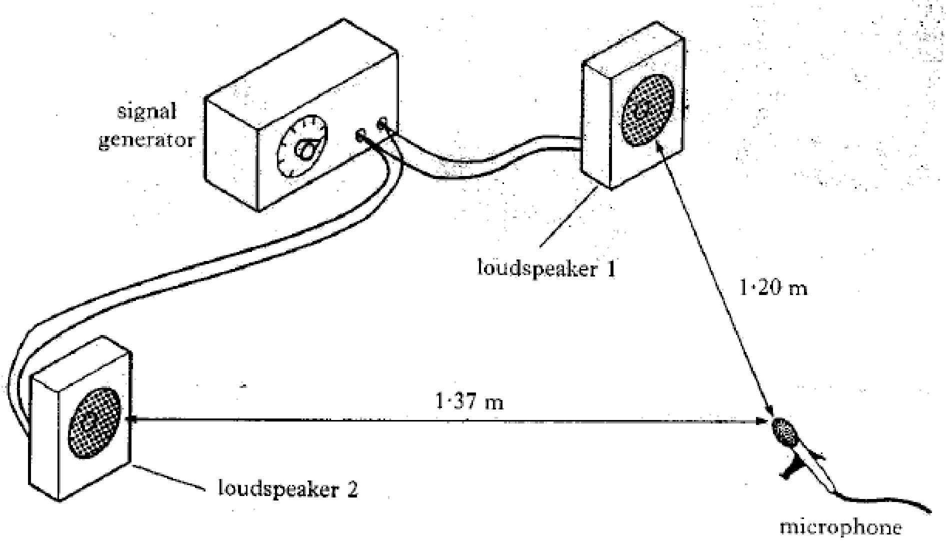
The wavelength of the waves is 28 mm.

Calculate the distance from S_2 to P.

4.

Loudspeakers 1 and 2 are both connected to the same signal generator which is set to produce a 1 kHz signal.

Loudspeaker **1** is switched on but loudspeaker 2 is switched off.

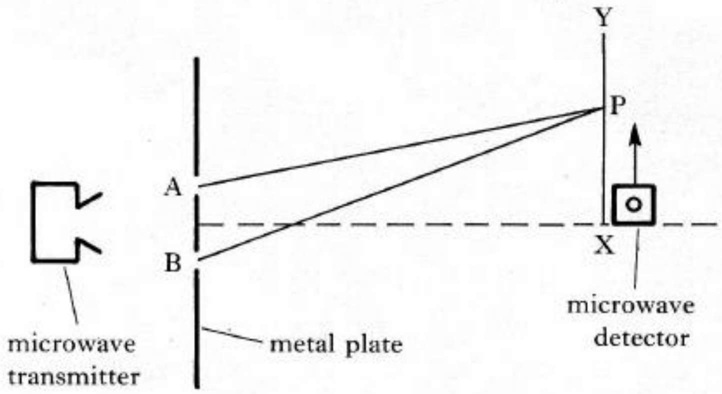


State **and** explain what happens to the amplitude of the signal picked up by the microphone when loudspeaker 2 is switched on.

Your explanation should include a calculation using the value of the speed of sound in air as 340 m s^{-1}.

5.

Microwaves are passed through two slits, A and B, in a metal plate as shown in the diagram below.



A microwave detector is moved along a straight line from X to Y. The **first minimum** of microwave intensity is detected at point P. The distance AP is 41 cm and BP is 43 cm.

Find the wavelength of the microwaves.

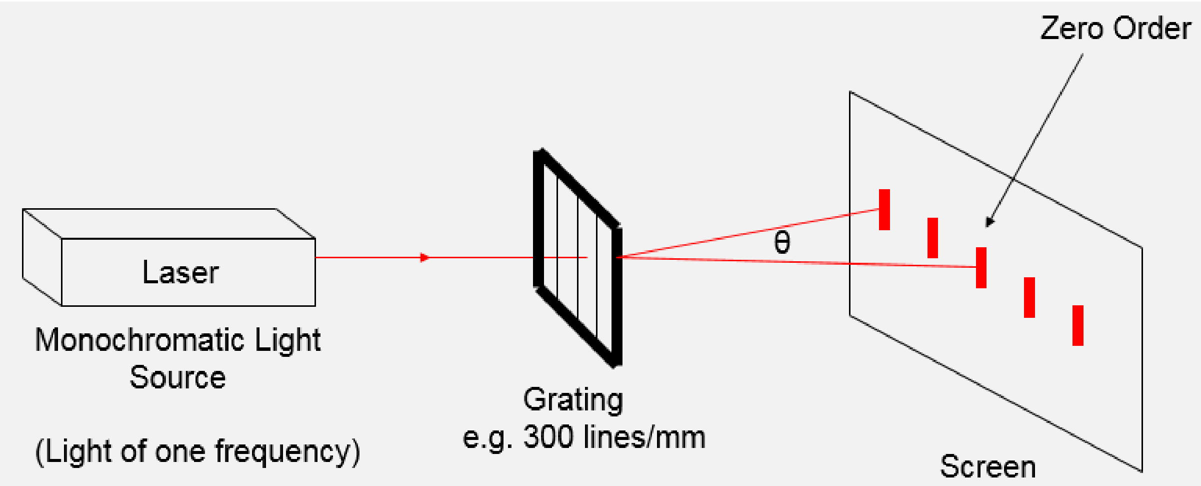
11. Diffraction grating

Learning Outcomes:

- The relationship between the wavelength, distance between the sources, distance from the sources and the spacing between maxima or minima.
- The relationship between grating spacing, wavelength and angle to the maxima.

The Grating and Monochromatic Light

- A grating consists of many equally spaced slits positioned extremely close together (e.g. 300 lines per mm).
- Light is diffracted through each slit and interference takes place in a similar fashion to the double slit.



The Grating Equation

- For a grating:

$$m\lambda = d \sin \theta$$

m = order of the maximum
λ = wavelength of light
d = separation of slits
θ = angle from zero order to nth maximum
λ and d must be in same units!!!

Calculating separation of slits, d

- d is the distance between the slits on the grating.
- It is usually very small, e.g. **10^{-6} m**.
- You can find d if you are given N, the number of slits (or lines) per metre on the grating.

$$d = \frac{1}{N}$$

Example:

- If N = 500 lines per mm, calculate d:

How to increase the separation of the maxima (increase θ**)**

If the grating equation is rearranged to $\sin\theta = n\lambda / d$, then it can be seen that to increase θ (the separation of the maxima) you can:

1. Increase the wavelength (move from blue towards red light).
2. Decrease the slit separation (have more lines per mm).
3. Move the screen further away.

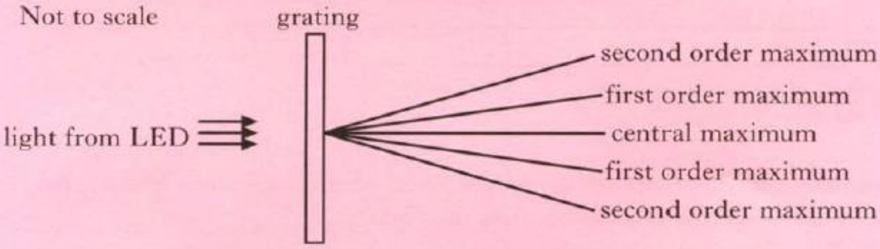
Example

- A diffraction grating with 300 lines per mm is used to produce an interference pattern. The 2nd order maximum is obtained at a diffracted angle of 19º.
- Calculate the wavelength of the light.

Old Higher 2006 Qu: 27(b)

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

Not to scale

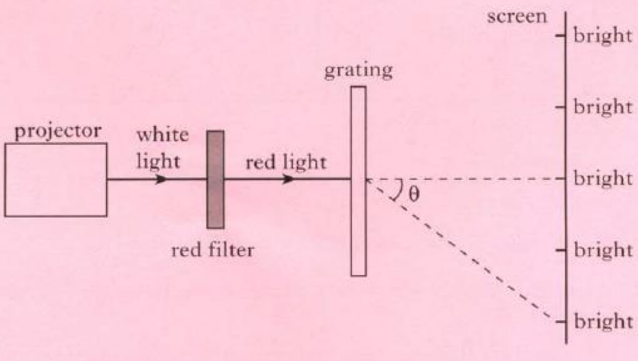


Light from this LED has a wavelength of $6{\cdot}35 \times 10^{-7}$ m. The spacing between lines in the grating is $5{\cdot}0 \times 10^{-6}$ m.

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

Old Higher 2005 Qu: 28(b)

(*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**

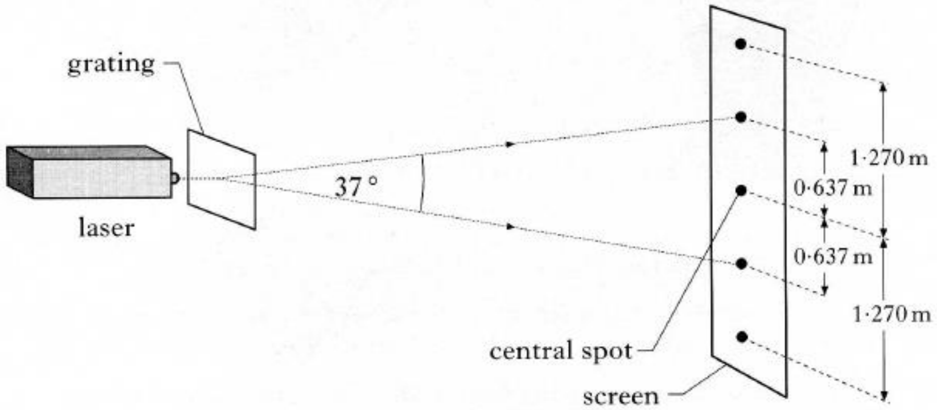
(ii) Calculate the angle θ of the second order maximum. **2**

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

Old Higher 2004 Qu: 28(b)

(*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.

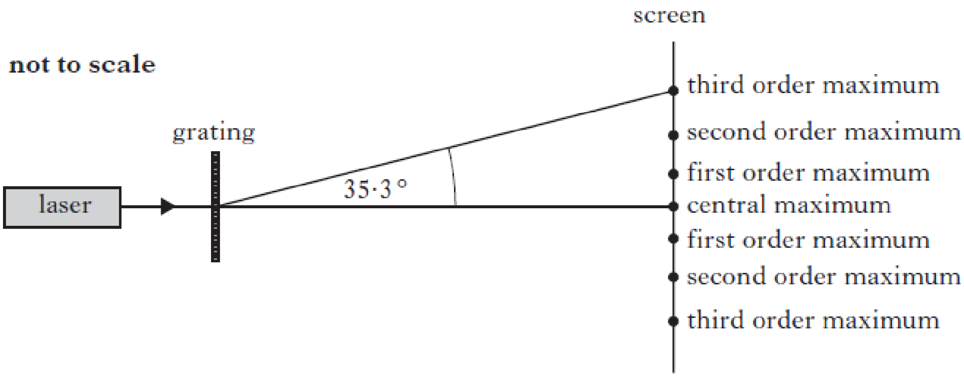
How does the wavelength of the light from this laser compare with that from the original laser?

You must justify your answer. **2**

Revised Higher 2012 Qu: 28(b)

(*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.



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**

(5)

Diffraction grating homework **Due date:______________**

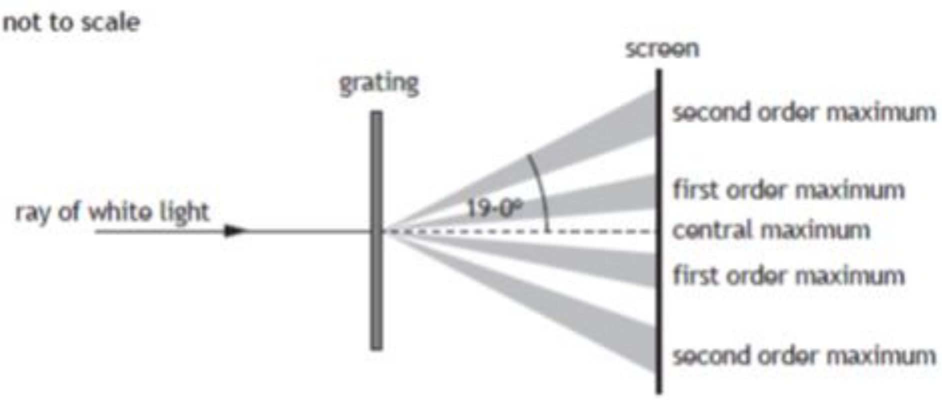
1.

Monochromatic light of wavelength λ passes through a grating and produces a pattern of bright maxima on a screen. The separation of lines on the grating is d and the grating is at a distance L from the screen. Which of the following pairs of changes will **always** produce an **increase** in the spacing of the maxima on the screen?

A	increase L	increase d
B	increase λ	increase d
C	decrease L	decrease λ
D	increase L	decrease λ
E	increase λ	decrease d

2.

In the experiment, a ray of white light is incident on a grating.



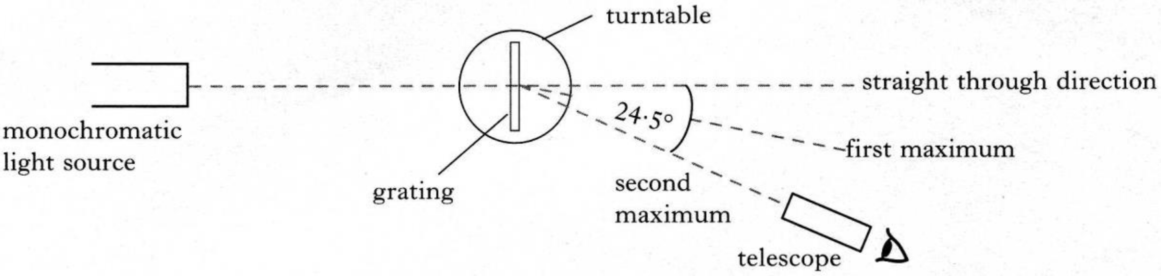
The angle between the central maximum and the second order maximum for red light is 19·0°.
The frequency of this red light is $4{\cdot}57 \times 10^{14}$ Hz.

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

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

3.

A grating with 300 lines/mm is used with a spectrometer and a source of monochromatic light to view an interference pattern as shown below.

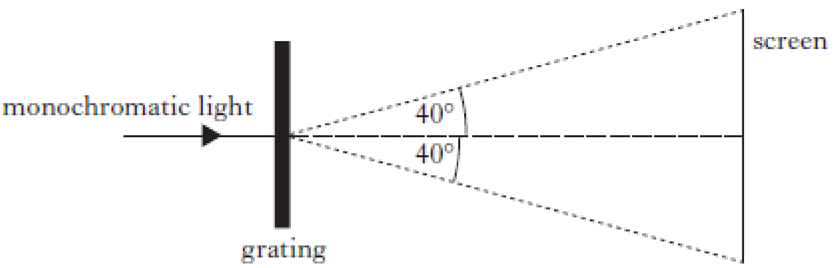


The second maximum of interference is observed when the telescope is at an angle of 24·5°.

Calculate the wavelength of the light.

4.

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.

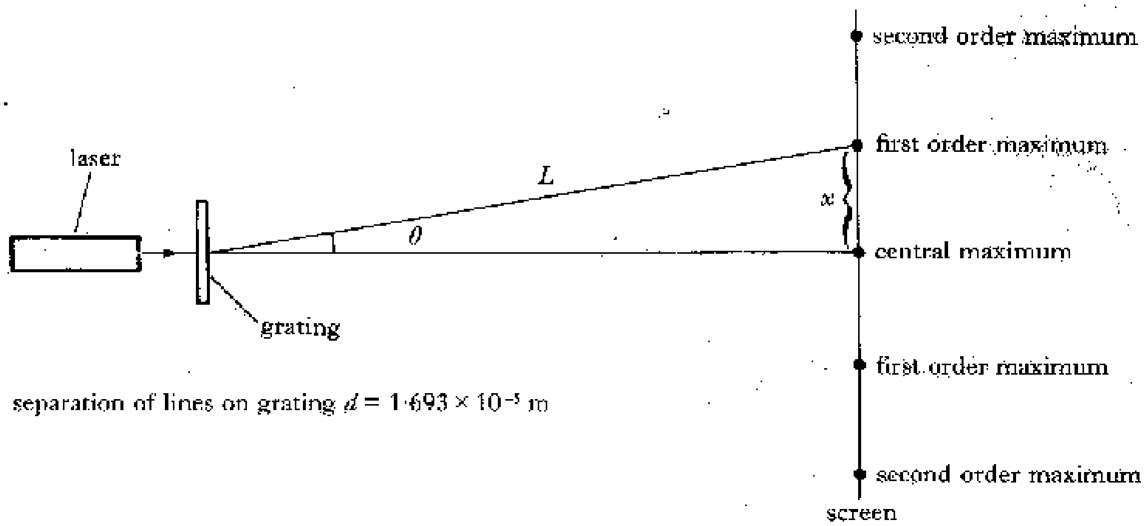


The wavelength of the light is 420 nm and the separation of the slits on the grating is $3{\cdot}27 \times 10^{-6}$ m.

Determine the total number of maxima visible on the screen.

5.

The apparatus shown below is set up to determine the wavelength of light from a laser:



separation of lines on grating $d = 1{\cdot}693 \times 10^{-5}$ m

The wavelength of the light is calculated using the equations

$$\lambda = d \sin\theta \quad \text{and} \quad \sin\theta = \frac{x}{L}$$

where angle θ and distances x and L are as shown in the diagram.

(*a*) Seven students measure the distance L with a tape measure.

Their results are as follows.

2·402 m   2·399 m   2·412 m   2·408 m

2·388 m   2·383 m   2·415 m

Calculate the mean value for L **and** the approximate random error in the mean.

(*b*) The best estimate of the distance x is (91 ± 1) mm.

Show by calculation whether L or x has the larger percentage error.

(*c*) Calculate the wavelength, in nanometres, of the laser light.

You must give your answer in the form

final value ± error.

(*d*) Suggest an improvement which could be made so that a more accurate estimate of the wavelength could be made.

You must use only the same equipment and make the same number of measurements.

12. Photoelectric effect

Learning Outcomes:

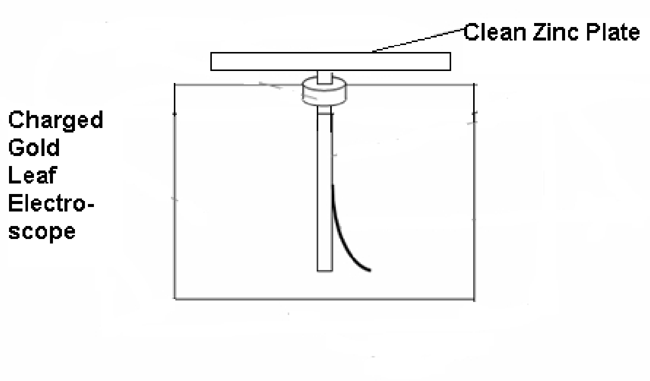
- Photoelectric effect as evidence for the particulate nature of light
- Photons of sufficient energy can eject electrons from the surface of materials
- The threshold frequency is the minimum frequency of a photon required for photoemission
- The work function of the material is the minimum energy required to cause photoemission
- Determination of the maximum kinetic energy of photoelectrons

What is the photoelectric effect?

- Sometimes, when electromagnetic radiation above a certain frequency strikes a surface, electrons are emitted.
- This can be used to detect radiation and is the basis on which solar cells and light dependent resistors operate.

Gold leaf electroscope

- The photoelectric effect can be demonstrated using a gold leaf electroscope:



Results

1. Only negatively charged electroscopes (metal) discharge.
2. Even dim UV light is enough to discharge, this is because it has a high frequency
3. White light does not work as it has a lower frequency

Frequency

- We can see that photoelectric emission depends on frequency.
- The minimum frequency required for photoelectric emission to occur is called the **threshold frequency, f_0.**
- Below this frequency, no emission occurs

Irradiance

- Increasing irradiance at $f < f_0$ will still have no effect.
- Increasing irradiance at $f > f_0$ will cause more photoelectric emission. They are directly proportional.
- A bigger irradiance results in a bigger photoelectric current produced.

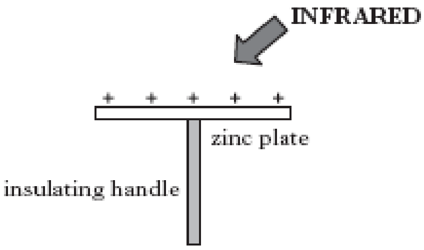
Old Higher 2012 Qu: 15

15. Clean zinc plates are mounted on insulating handles and then charged.

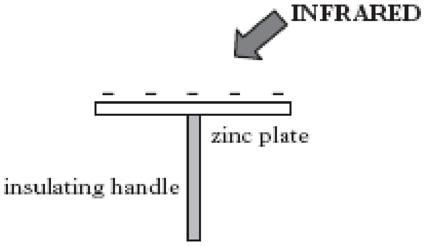
Different types of electromagnetic radiation are now incident on the plates as shown.

Which of the zinc plates is most likely to discharge due to photoelectric emission?

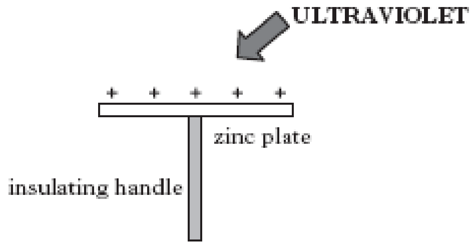
A



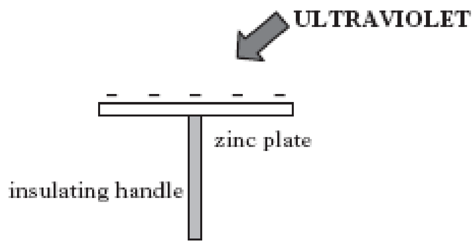
B



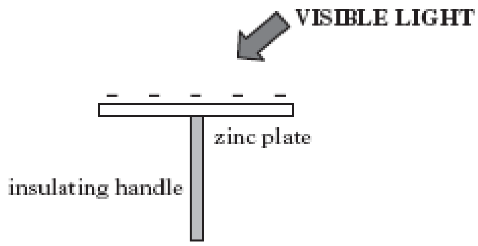
C



D



E



7. 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

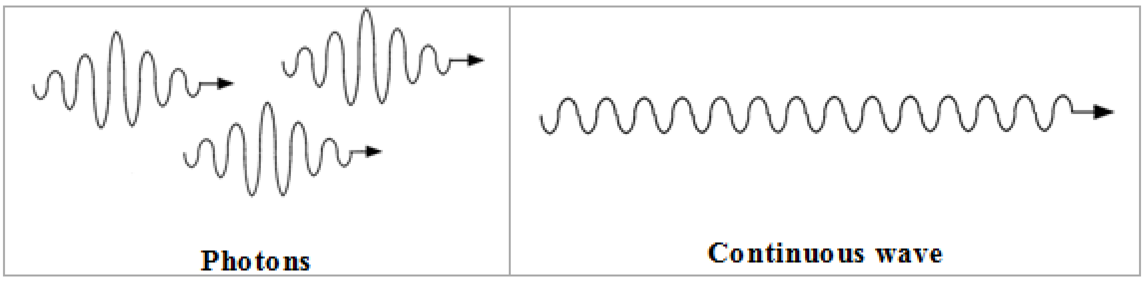
Quantum Theory Does light travel as waves or photons?

- Modern physics now takes the view that light can act both like a wave and like a particle without contradiction. It depends on how we test it.
- If we look for evidence that it is a wave, we can find it. But also, if we look for evidence that it is a particle we can find that too.
- The universe seems to be made up of things that are both particle-like and wave-like. This is known as wave–particle duality.

- To eject an electron from a metal requires a precise amount of energy. A weak UV source has sufficient energy to do this for a clean zinc surface, but no matter how high the intensity of the white light is, no electrons are ejected.
- This is true even though, over a period of time, the 'total' energy of the white light is greater than that of the UV.

- In 1904 Einstein applied an earlier idea of Planck to the phenomenon and proposed that light was not a continuous wave, but existed as a stream of 'packets' or '**quanta'**.

- These quanta are called **photons** and are particles of light (and other electromagnetic radiation), although unlike other particles they have no mass.



Revised Higher 2012

28. One of the most important debates in scientific history asked the question:

"Is light a wave or a particle?"

Use your knowledge of physics to comment on our understanding of this issue. **(3)**

Energy of Photons

- A photon has energy given by:

$$E = h\,f$$

- E = energy (J)
- f = frequency (Hz)
- h = Planck's constant (6.63×10^{-34}Js) – given in data sheet

V = f λ

- Often only the wavelength of light is given. As we know that light travels at 3×10^{8} ms^{-1} (known as **c**) we can use the equation v = f λ and our energy equation is then re-arranged:

$$E = h\,\frac{c}{\lambda}$$

Work function

- When a photon is absorbed its energy is used to release an electron.
- The **minimum energy needed by an electron to produce photoelectric emission** (escape from a metal) is called the **work function**, which is dependent on frequency:

$$\text{Work function} = h\,f_0$$

- Every metal has a different value for work function.

Any extra energy is kinetic energy, E_k

- Such an electron would escape but have no kinetic energy.
- If the energy of the incoming electron, E = hf (where $f>f_0$), is greater than the work function, then the extra energy will appear as **kinetic energy**:
- $E_k = E - E_0$

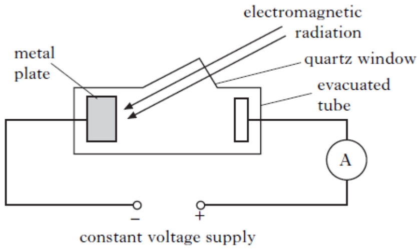
$$E_k = hf - hf_0$$

Example 1

- The work function for Gold is 7.84×10^{-19} J
- A piece of Gold is illuminated with frequency of 1.5×10^{15} Hz
- Will photoelectrons be emitted from the Gold foil?

Example 2 (Old Higher 2007 Qu: 30)

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.

(*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.

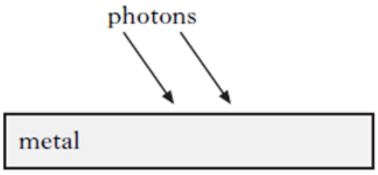
Section 2 Past Paper Questions

Old Higher 2008 Qu: 29

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.

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



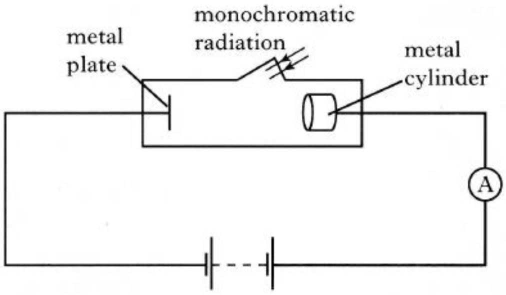
This releases photoelectrons from the surface of the metal.

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

Calculate the work function of the metal.

Old Higher 2005 Qu: 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.

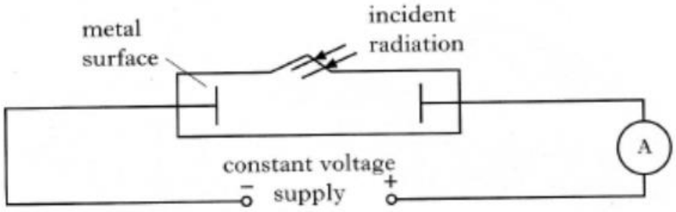
(*b*) The metal of the plate has a work function of $3{\cdot}11 \times 10^{-19}$ J. The wavelength of the radiation is 400 nm.

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

Old Higher 2000 Qu: 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?

(*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**

Photoelectric effect homework **Due date:______________**

1.

To demonstrate the photoelectric effect, radiation is directed onto the surface of a clean charged zinc plate.

Which of the following sets of conditions is required to produce the emission of photoelectrons from the zinc plate?

	Charge on zinc plate	*Frequency of radiation*
A	positive	above a certain value
B	negative	above a certain value
C	positive	any value
D	negative	any value
E	negative	below a certain value

2.

Photons of energy $7{\cdot}0 \times 10^{-19}$ J are incident on a clean metal surface. The work function for the metal is $9{\cdot}0 \times 10^{-19}$ J.

Which one of the following is correct?

A No electrons are emitted from the metal.

B Electrons with a maximum kinetic energy of $2{\cdot}0 \times 10^{-19}$ J are emitted from the metal.

C Electrons with a maximum kinetic energy of $7{\cdot}0 \times 10^{-19}$ J are emitted from the metal.

D Electrons with a maximum kinetic energy of $9{\cdot}0 \times 10^{-19}$ J are emitted from the metal.

E Electrons with a maximum kinetic energy of $16{\cdot}0 \times 10^{-19}$ J are emitted from the metal.

3.

A student makes a note of the following statements after a lesson about photoelectric emission.

I Photoelectric emission from a metal occurs only if the frequency of the incident radiation is greater than the threshold frequency.

II The threshold frequency depends on the metal from which photoemission takes place.

III If the frequency of the incident radiation is less than the threshold frequency, increasing its intensity will cause photoemission.

Which of the above statements is/are correct?

A I only

B II only

C I and II only

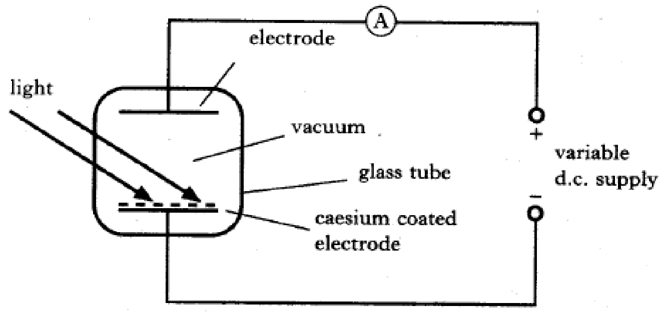
D II and III only

E I, II and III

4.

(*a*) It is quoted in a text book that
"the work function of caesium is $3{\cdot}04 \times 10^{-19}$J".
Explain what is meant by the above statement.

(*b*) In an experiment to investigate the photoelectric effect, a glass vacuum tube is arranged as shown below.



The tube has two electrodes, one of which is coated with caesium.
Light of frequency $6{\cdot}1 \times 10^{14}$Hz is shone on to the caesium coated electrode.

(i) Calculate the maximum kinetic energy of a photoelectron leaving the caesium coated electrode.

(ii) An electron leaves the caesium coated electrode with this maximum kinetic energy. Calculate its kinetic energy as it reaches the upper electrode when the p.d. across the electrodes is 0·8 V.

(*c*) The polarity of the supply voltage is now reversed.
Calculate the minimum voltage which should be supplied across the electrodes to stop photoelectrons from reaching the upper electrode.

13. Intensity of Radiation

Learning Outcomes

- Irradiance and the inverse square law.
- Irradiance is power per unit area.
- The relationship between irradiance and distance from a point light source.
- Line and continuous emission spectra, absorption spectra and energy level transitions.

Irradiance (known as Intensity in older past papers)

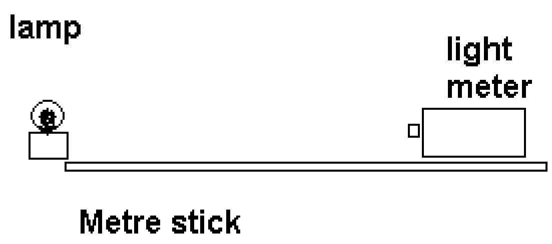
- When radiation falls on a surface, the irradiance, I, is defined as the power per unit area:

$$I = \frac{P}{A}$$

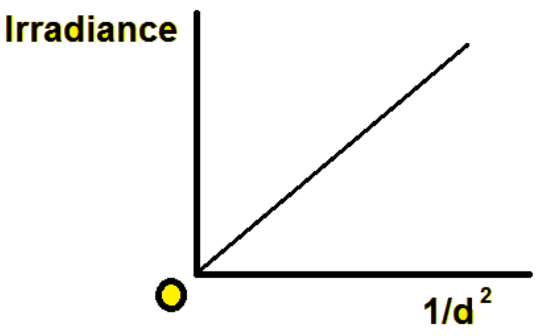
- I – intensity (Wm^{-2}) [or lux]
- P – power (W)
- A – area (m^2)

Experimentally proving the inverse square law

- A light meter can measure the intensity of light from a bulb in a darkened room at various distances over a metre.



- Measure irradiance levels at different distances and plot a graph of your results (I and $1/d^2$). The graph confirms the inverse square law.



Irradiance and distance

- As you move further away from a point source, the intensity of radiation decreases.
- The relationship between intensity (I) and distance (d) can be shown to follow an **inverse square law:**
- **$I \propto \frac{1}{d^2}$ in rel. sh. as $I = \frac{k}{d^2}$**

  Therefore: **$I_1 d_1^2 = I_2 d_2^2$**

- ***This is only the case for a <u>point source</u> of light – one that radiates light in all directions i.e. a lamp not a laser (or a torch)**

<u>Example</u>

- A lamp shines on a screen of area $2.5 m^2$, which is 3m away. The intensity at the screen is $0.01 Wm^{-2}$.

a) Calculate the power of the incident beam.
b) If the screen is moved to a distance of 1.5m from the lamp what would the new intensity be?

<u>Multi-choice past paper questions</u>

<u>Old Higher 2001 Qu: 18</u>

18. The intensity of light from a point source is $20 W m^{-2}$ at a distance of 5·0 m from the source.

What is the intensity of the light at a distance of 25 m from the source?

A 0·032 $W m^{-2}$

B 0·80 $W m^{-2}$

C 1·2 $W m^{-2}$

D 4·0 $W m^{-2}$

E 100 $W m^{-2}$

Old Higher 2005 Qu: 17

17. The intensity of light can be measured in

A W

B $W\,m^{-1}$

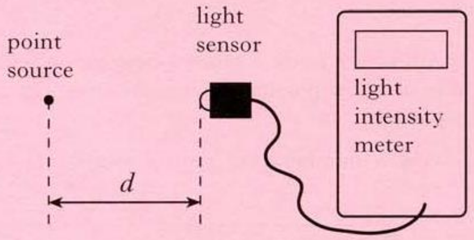
C $W\,m$

D $W\,m^{-2}$

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

Old Higher 2005 Qu: 17

13. The apparatus used to investigate the relationship between light intensity I and distance d from a point source is shown.



The experiment is carried out in a darkened room.

Which of the following expressions gives a constant value?

A $I \times d$

B $I \times d^2$

C $\frac{I}{d}$

D $\frac{I}{d^2}$

E $I \times \sqrt{d}$

Old Higher 2003 Qu: 17

17. A unit for the intensity of light is

A $J\,m^{-1}$

B $J\,m^{-2}$

C $J\,s^{-1}m^{-1}$

D $J\,s^{-1}m^{-2}$

E $J\,s^{-2}m^{-2}$.

Revised Higher Specimen Paper

19. Light from a point source is incident on a screen. The screen is 3·0 m from the source.

The irradiance at the screen is $8{\cdot}0\ W\ m^{-2}$.

The light source is now moved until it is 12 m from the screen.

The irradiance at the screen is now

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

B $1{\cdot}0\ W\ m^{-2}$

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

D $4{\cdot}0\ W\ m^{-2}$

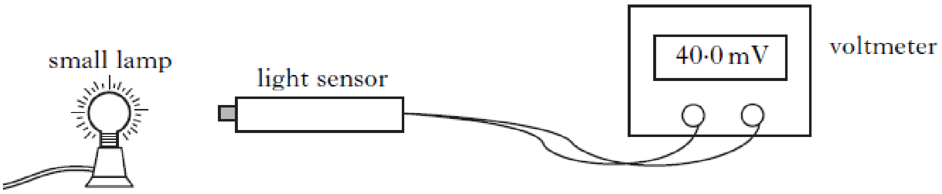
E $8{\cdot}0\ W\ m^{-2}$.

Section 2 Past Paper Questions

Old Higher 2008 Qu: 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 $8{\cdot}0 \times 10^{-5}\ m^2$.

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

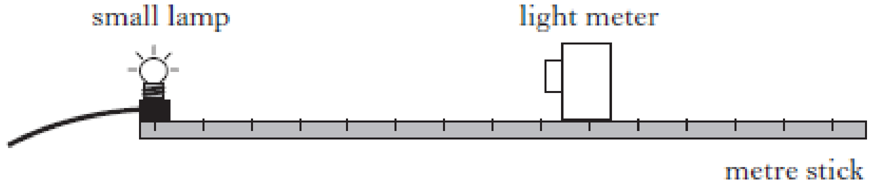
Can this new source be considered to be a point source of light?

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

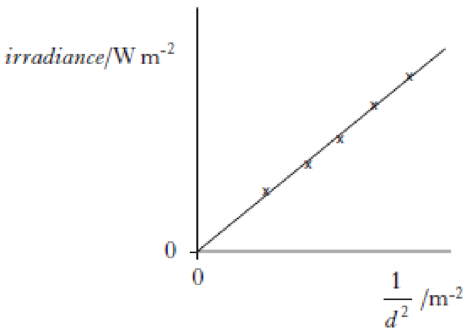
Revised Higher 2012 Qu: 17

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**

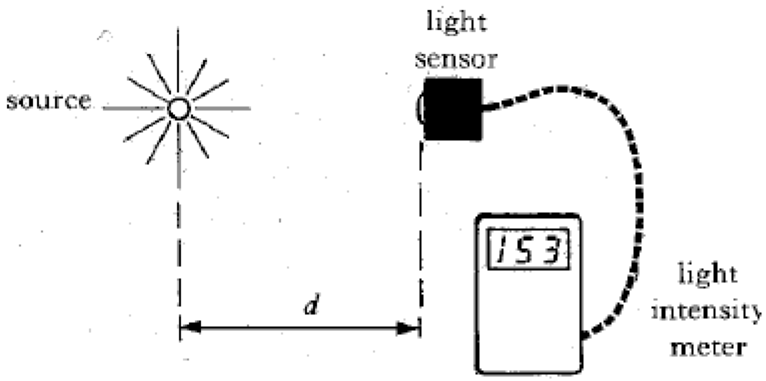
(*c*) The experiment is repeated with the laboratory lights switched on.

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

Intensity of radiation homework **Due date:______________**

1.

An experiment is carried out to investigate the relationship between the light intensity I from a point source and the distance d from the source. The experiment is done in a darkened room and a meter connected to a light sensor indicates the intensity, as shown below.



Which of the following expressions will give an approximately constant value?

A $I \times d$

B $I \times d^2$

C $\frac{I}{d}$

D $\frac{I}{d^2}$

E $I \times \sqrt{d}$

2.

A small lamp is placed 1 metre above a desk. At a point on the desk directly below the lamp, the intensity of the light is I. The lamp may be treated as a point source of light.

The lamp is now raised until it is 2 metres above the desk. What is the new intensity of light at the same point on the desk?

A $\frac{I}{4}$

B $\frac{I}{2\sqrt{2}}$

C $\frac{I}{2}$

D $\frac{I}{\sqrt{2}}$

E $\sqrt{2}\, I$

3.

The light intensity is 160 units at a distance of 0·50 m from a point source of light in a darkened room.

At 2·0 m from this source, the light intensity is

A 160 units

B 80 units

C 40 units

D 10 units

E 5 units.

4.

A space probe is positioned 3×10^{11} m from the Sun. It needs solar panels with an area of 4 m^2 to absorb sufficient energy from the Sun to keep it functioning correctly.

What area of solar panels would be needed to keep the probe functioning correctly if it is to be repositioned at a distance of 6×10^{11} m from the Sun?

A 1 m^2

B 2 m^2

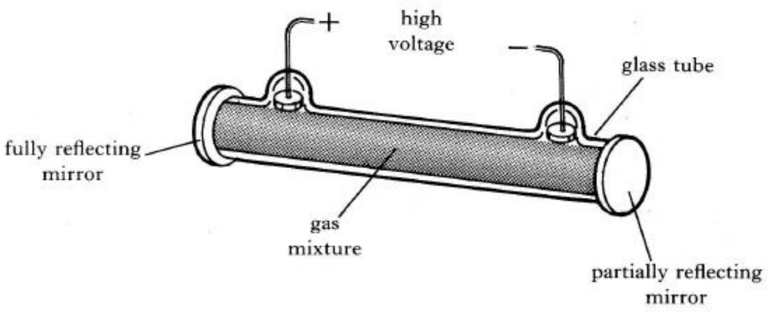
C 4 m^2

D 8 m^2

E 16 m^2

5.

The diagram shows a simplified view of a laser tube used in a gas laser.



In hospitals, pulsed lasers may be used to repair damage to the retina of the eye. The specification of a typical pulsed laser is given below:

gas used in laser	: argon
duration of pulse	: 0·50 ms
energy of one pulse	: 0·10 J
wavelengths of laser light emitted	: 488 and 514 nm.

The cross-sectional area of the laser beam at the retina is $1{\cdot}5 \times 10^{-9}\,m^2$.

Calculate the light intensity produced at the retina during a pulse of light from this laser.

14. Energy Level Diagrams

Learning Outcomes

- The bohr model of the atom
- Movement of electrons between energy levels.
- The terms ground state, energy levels, ionisation and zero potential energy for the Bohr model of the atom.
- Emission of photons due to movement of electrons between energy levels and dependence of photon frequency on energy difference between levels.
- The relationship between photon energy, Planck's constant and photon frequency.
- Absorption lines in the spectrum of sunlight provide evidence for the composition of the Sun's upper atmosphere.

Emission spectra

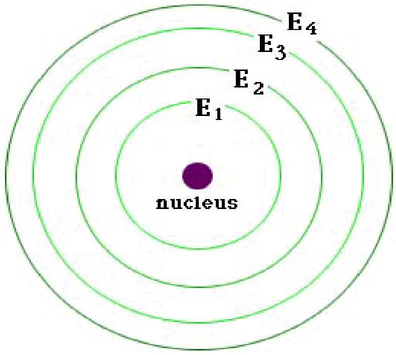
- An emission spectra is a range of colours given out by a light source. There are two kinds:

1. Continuous spectra – given by white light passing through a prism.
2. Line Spectra – some sources of light such as sodium and mercury vapour lamps do not produce continuous spectra when viewed through a spectroscope.

- They produce line spectra – coloured lines spaced out by different amounts.

Explanation of emission spectra – the Bohr Model

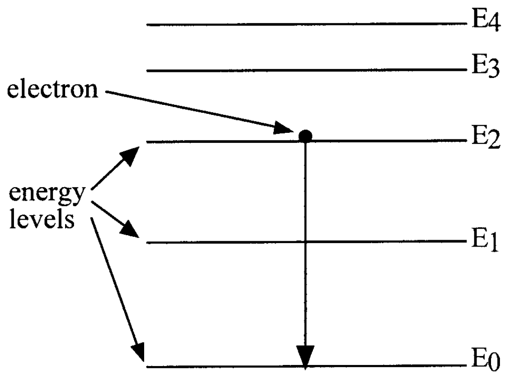
- A scientist called Niels Bohr suggested that electrons are confined to certain orbits outside the nucleus.
- He created the Bohr Model to explain emission spectra:



1. The electrons have different fixed energies in different orbits (E_1, E_2 etc)
2. They can move between each levels but cannot stop in between.

Energy level diagram

- We can look at the energy levels of an atom of say Hydrogen and present them in an energy level diagram:

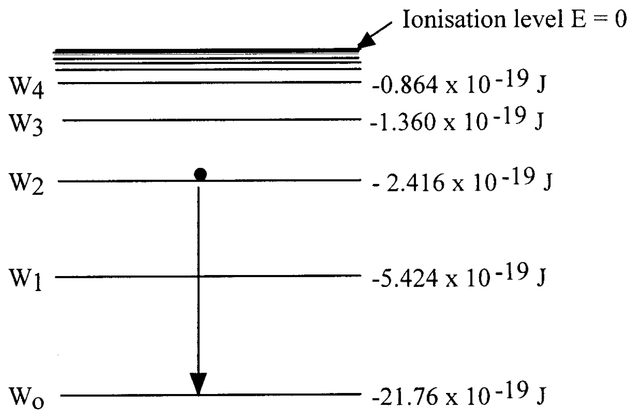


- In the smallest orbit, E_0, (also known as W_0)the electron has least energy and is said to be in the **ground state**.
- An electron which moves to a higher energy level is said to be in an **'excited state'.**
- If an electron gains enough energy it can reach the top level, the **ionisation level**.
- It is here at which the electron can leave the atom.

- If the difference in energy levels is denoted as ΔE, then the frequency of the emitted photon will be expressed as:

$$f = \frac{\Delta E}{h}$$

- The frequency of the emitted photon is therefore determined by the magnitude of the energy change.
- Frequencies of between 4 – 7 x 10^{14} Hz are in the visible spectrum – we can see them.
- Emitted photons between these frequencies are the colours shown on spectra lines.



An emission line

- An emission line in a spectrum occurs when an electron makes a transition between an excited energy level, say W_2, to a lower energy level, W_1, where:
- $W_2 – W_1 = h f$
- The emission line will appear brighter if more electrons make that particular transition.

An absorption line

- An absorption line in a spectrum occurs when an electron in energy level W_1 absorbs radiation of energy hf and is excited up to energy level W_2, where:
- $W_2 = W_1 + h f$

Frequency and wavelength (common PS question)

- As $f = \frac{\Delta E}{h}$ we can see that f and E are proportional.
- The bigger the ΔE the bigger the f.
- Using $v = f \lambda$ **(as v is constant)** we can deduce that the bigger the f the smaller the λ.

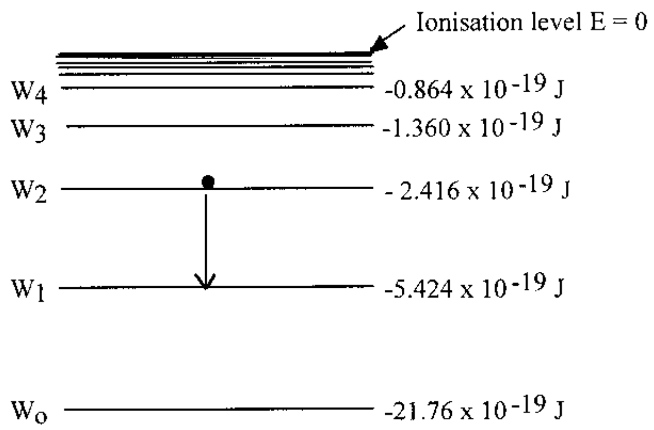
- In other words: ΔE increases = f increases = λ decreases
- Oppositely: ΔE decreases = f decreases = λ increases

Spectra

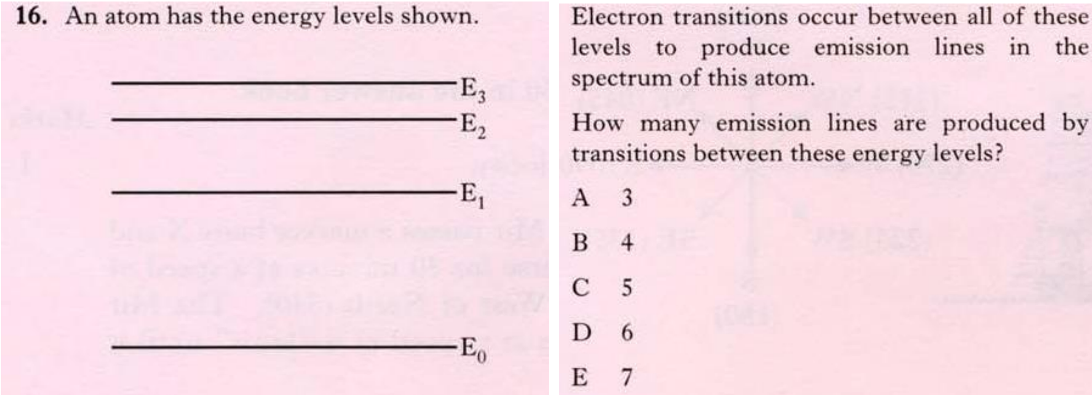
- Continuous spectra are produced by solids, liquids and **high pressure gases.**
- Line spectra are produced by **low pressure gases.**

Example 1

a) Calculate the frequency of the radiation for an electron making a transition from W2 to W1:
b) Find the wavelength of this radiation.



Example 2 – Old Higher 2004 Qu: 16


16. An atom has the energy levels shown.

Electron transitions occur between all of these levels to produce emission lines in the spectrum of this atom.

How many emission lines are produced by transitions between these energy levels?

A 3

B 4

C 5

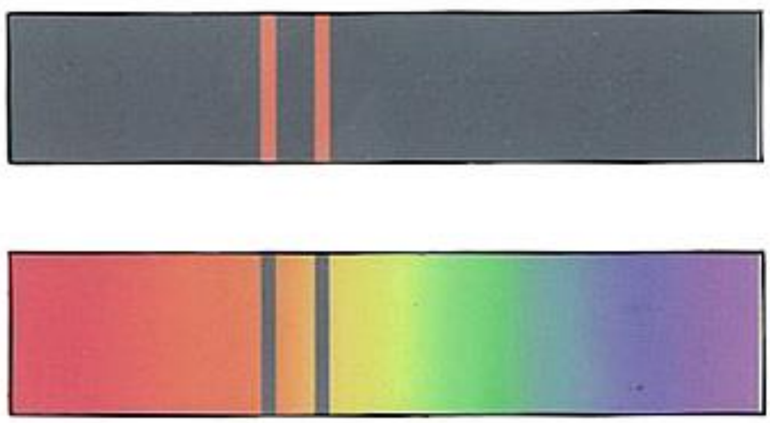
D 6

E 7

Absorption Spectrum

- The absorption spectrum of an element consists of black lines on a continuous spectrum.
- The lines are in exactly the same positions as the bright lines of the emission spectrum

  Emission (above) and Absorption (below) spectrum



Absorption lines in the Sun

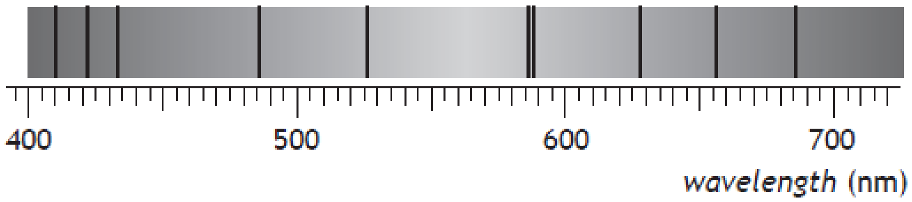
- Absorption lines occur in the Sun's spectrum because the gases in the Sun's outer atmosphere absorb photons of certain frequencies.
- This gives dark lines and allows the elements which make up the Sun to be determined.
- The dark lines are called **Fraunhofer lines.**

Example – CfE Higher 2015

MARKS

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.



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

Multi-choice Past Paper Questions

Old Higher 2000 Qu: 20

20. The diagram below represents possible energy levels of an atom.

P ________________ $-5{\cdot}2 \times 10^{-19}$ J

Q ________________ $-9{\cdot}0 \times 10^{-19}$ J

R ________________ $-16{\cdot}4 \times 10^{-19}$ J

S ________________ $-24{\cdot}6 \times 10^{-19}$ J

Which of the following statements is/are true?

I There are four emission lines in the spectrum produced as a result of transitions between the energy levels shown.

II The radiation emitted with the shortest wavelength is produced by an electron falling from level P to level S.

III The zero energy level in an energy level diagram is known as the ionisation level.

A I and II only

B I and III only

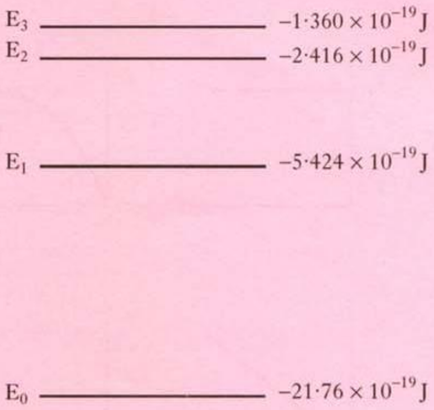
C II and III only

D III only

E I, II and III

Old Higher 2006 Qu: 18

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



The highest frequency of radiation emitted due to a transition between two of these energy levels is

A $1{\cdot}59 \times 10^{14}$ Hz

B $2{\cdot}46 \times 10^{15}$ Hz

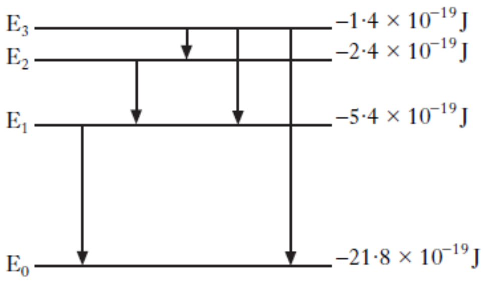
C $3{\cdot}08 \times 10^{15}$ Hz

D $1{\cdot}63 \times 10^{20}$ Hz

E $2{\cdot}04 \times 10^{20}$ Hz.

Old Higher 2007 Qu: 17

17. 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

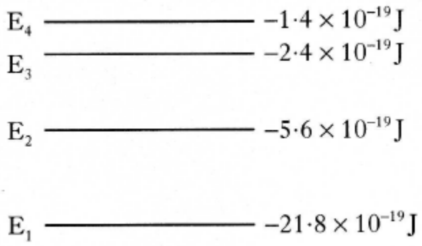
E E_3 to E_0.

Section 2 Past Paper Questions

Old Higher 2003 Qu: 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.



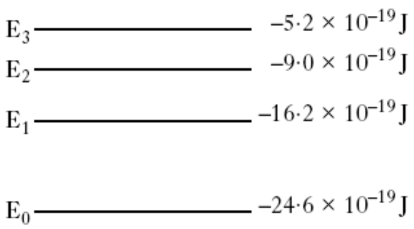
(i) The transition between which two of these energy levels produces radiation with the longest wavelength? You must justify your answer.

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

Old Higher 2009 Qu: 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) 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**

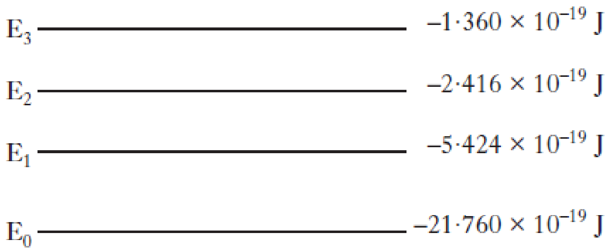
(ii) An electron is excited from energy level E_2 to E_3 by absorbing light energy.

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

Old Higher 2011 Qu: 30(b)

(*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**

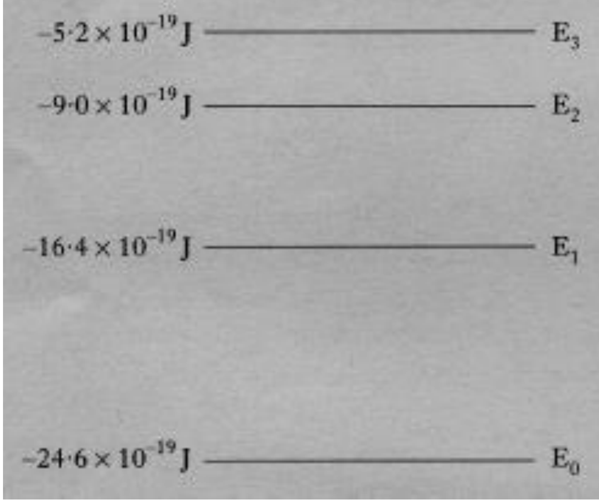
(ii) The absorption of this wavelength produces a faint dark line in the continuous spectrum from the Sun.

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

Energy level diagrams homework Due date:______________

1.

The diagram below shows the energy levels in an atom.



An electron is excited from energy level E_2 to level E_3 by absorbing energy. What is the frequency of light being used to excite the electron?

A $1{\cdot}74 \times 10^{-15}$ Hz

B $5{\cdot}73 \times 10^{14}$ Hz

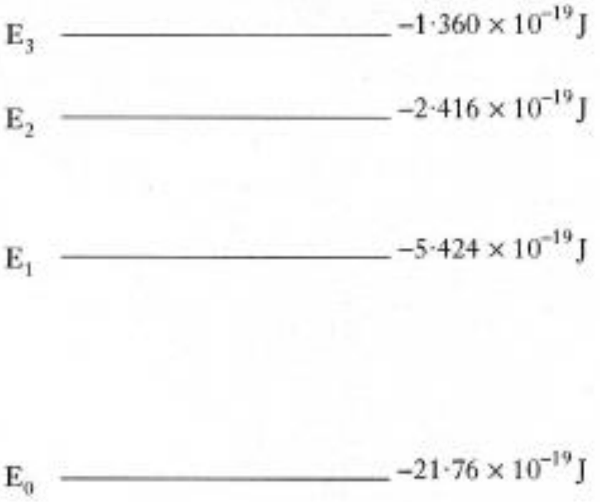
C $1{\cdot}69 \times 10^{15}$ Hz

D $2{\cdot}14 \times 10^{15}$ Hz

E $2{\cdot}92 \times 10^{15}$ Hz

2.

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



The highest frequency of radiation emitted due to a transition between two of these energy levels is

A $2{\cdot}04 \times 10^{20}$ Hz

B $1{\cdot}63 \times 10^{20}$ Hz

C $3{\cdot}08 \times 10^{15}$ Hz

D $2{\cdot}46 \times 10^{15}$ Hz

E $1{\cdot}59 \times 10^{14}$ Hz.

3.

The photon energies for three different radiations are as follows.

Radiation 1: $2{\cdot}78 \times 10^{-19}$ J
Radiation 2: $4{\cdot}97 \times 10^{-19}$ J
Radiation 3: $6{\cdot}35 \times 10^{-19}$ J

Which one of the following is true?

A The wavelength of radiation 1 is longer than that of radiation 2.

B The wavelength of radiation 3 is longer than that of radiation 2.

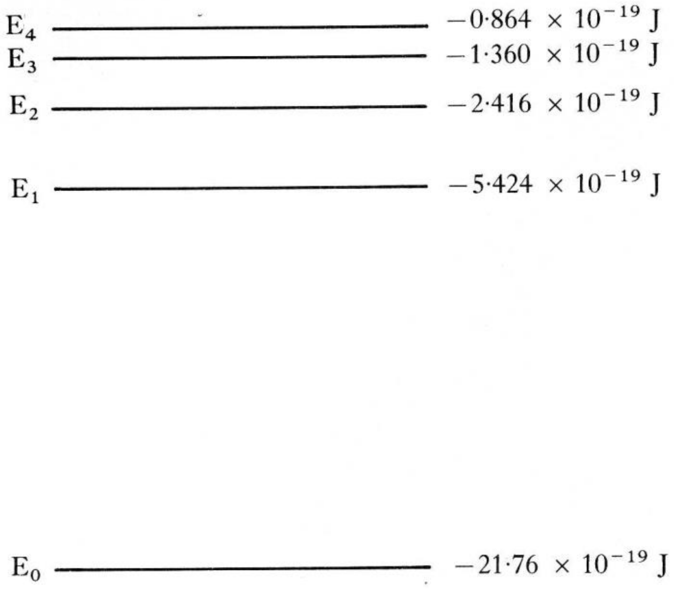
C The frequency of radiation 1 is higher than that of radiation 2.

D The frequency of radiation 1 is higher than that of radiation 3.

E The frequency of radiation 2 is higher than that of radiation 3.

4.

The diagram below shows the energy levels for the hydrogen atom.

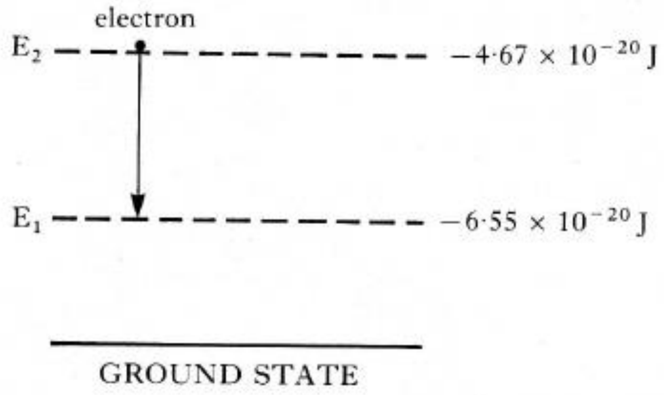


(*a*) Between which two energy levels would an electron transition lead to the emission of radiation of **highest** frequency?

(*b*) Calculate the frequency of the radiation in part (*a*).

5.

A laser radiates energy when electrons are stimulated to fall from energy level E_2 to energy level E_1 as shown in the diagram.



(i) What are the frequency and wavelength of the radiation emitted?

Homework Numerical Answers

The Standard Model:

1. A
2. D
3. B
4. (a)(i) - (ii) - (b) 1e or +1e or e (c)(i) - (ii) 1.9 x 10^{-20} s
5. (a) - (b)(i) - (ii) – 1/3e (c)(i) - (ii) - (d) 3.4 x 10^{-10} s

Electric fields and potential difference:

1. B
2. **v= 29.63x10^6 m/s**
3. (a)(i) **E_k = 8.03x10^{-16}J (ii) V = 5021.9V (b) –**
4. (a) 4 x 10^{-15} J (b) 2.22 x 10^6 ms^{-1} (c) 3.33 x 10^{-15} N

Radioactive decay, fission and fusion:

1. D
2. D
3. D
4. –
5. 2.51 x 10^{-26} kg
6. 11.7 x 10^{-27} kg

Refractive index, TIR and Critical Angle:

1. C
2. B
3. E
4. (a)(i) 1.29 (ii) -
   (b)(i) 33.7^0 (ii) - (20.9^0)

5. (a) 1.49 (b) (i) 44.0^0 (ii) –

Interference:

1. C
2. C
3. (a)(i) - (ii) 676 mm
4. – (λ= 0.34m)
5. 0.04 m

Diffraction grating:

1. E
2. (i) 4.03 x 10^{-6} m (ii) -
3. 6.91 x 10^{-7} m / 691 nm
4. 11

Photoelectric effect:

1. B
2. A
3. C
4. (a) - (b)(i) 1×10^{-19} J (ii) 2.28×10^{-19} J (c) 0.625 V

Intensity of radiation:

1. B
2. A
3. D
4. E
5. 1.33×10^{11} Wm^{-2}

Energy level diagrams:

1. B
2. C
3. A
4. (a) - (b) 3.15×10^{15} Hz
5. 453 nm; 6.6×10^{14} Hz

Particles and Waves revision   Past Paper questions

Year	Questions Multi-Ch	Section B
2000	14, 16, 17, 18, 20	27, 28, 29
2001	14, 15, 17, 18, 19,20	23(b),27,28(b) 29(a)
2002	15,16,17,19	27,28, 29(b)(ii)
2003	15,16,17,18,20	27,28(a),29(a)
2004	10,14,15,16,18	27,28(b),29(c)(ii),30
2005	7,8,13,14,15,16,17,18,19,20	28, 29
2006	14,15,16,17,18,19	24,27(NOT (a)(i)),28, 29(b)
2007	14,15,17	24,28,29,30,31(a)
2008	8,13,14,15,16,17,18,19,20	27,28,29
2009	8,15,16	27,28,29,30(a)
2010	7,8,14,15,18	27,28(b),29(NOT(b)) 30(a),(b)
2011	8,15,16,17,19	27,28(b),29,30
2012	14,15,16,17,18,19	23,28,29,30(c)
2013	8,14,15,16,17,20	28,29(NOT(c)),30, 31(a)
2014	15,16,19	28,29,30,31
2015	8,14,15,16,17,18,19	29(a),30,31
Rev. Spec	15,16,17,18,19	26,27,28,29,31
Rev. 2012	9,10,11,12,13,14,15,16	23,26,27,28,29,30
Rev. 2013	10,11,12,13,14,15,16	26,27,28,29
Rev. 2014	8,9,10,11,13,14	25(b),26,27,28,29
Rev. 2015	8,9,10,11,12,13,14,15,16	25(a)&(b)(i),26,27,28,29
CfE Spec	7,8,9,10,11,12,13,15,	7,8,9,10,11,12
CfE 2015	9,10,11,12,13,14,15,16	4(a)&(b),6,7,8,9
CfE 2016	8,9,10,11,12,13,14,15,16	6,7,8,9,10
CfE 2017	8,9,10,11,12,13,14,15	6,7,8,9,10,11
CfE 2018	8,9,10,11,12,13,14	6,7,8,9,10
CfE 2019	11,12,13,14,15,16,17,18,19	7,8,9,10,11