AS Level Physics

Chapter 10 – Waves

10.2.2 Electromagnetic Waves

Worked Example

UV Radiation

Exam Style Question 1

State two properties of electromagnetic waves which do not change across the whole of the spectrum.

Discuss two features of electromagnetic waves, other than just wavelength and frequency, which do change across the spectrum.

UV Radiation

Exam Style Question 1

State two properties of electromagnetic waves which do not change across the whole of the spectrum.

Discuss two features of electromagnetic waves, other than just wavelength and frequency, which do change across the spectrum.

Answer:

Properties of EM waves which do not change:

- All are transverse waves and so all can be polarised under suitable conditions.
- All can travel in a vacuum at the same speed.

Features of EM waves which do change across the spectrum:

- The sensitivity of the eye to certain wavelengths.
- The heating effect of the EM waves particularly of infra-red.

EM Waves

Exam Style Question 2

(i) Explain what is meant by infra-red radiation.

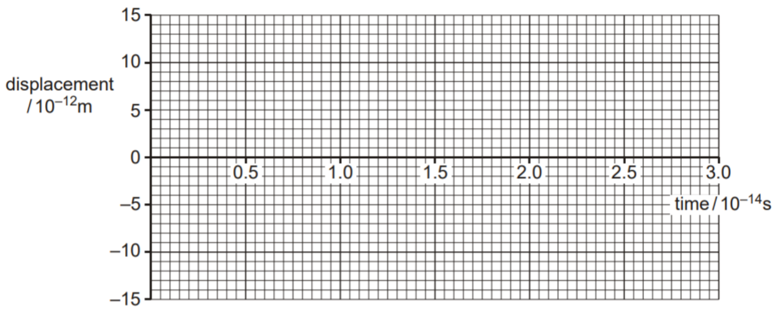
(ii) For infra-red radiation emitted at a frequency of $6.7 \times 10^{13}\ Hz$, calculate

1) Its wavelength,

2) Its period of oscillation.

(iii) Infra-red radiation is absorbed by molecular ions in a crystal causing them to vibrate at a frequency of $6.7 \times 10^{13}\ Hz$. The amplitude of oscillation of the ions is $8.0 \times 10^{-12}\ m$.

On the grid below sketch a graph showing the variation with time of the displacement of an ion.



EM Waves

Exam Style Question 2

(i) Explain what is meant by infra-red radiation.

Infra red is part of the EM spectrum with a lower frequency than visible light.

(ii) For infra-red radiation emitted at a frequency of $6.7 \times 10^{13}\ Hz$, calculate

1) Its wavelength,

Use $v = f\lambda$ and rearrange for λ.

We also know $v = 3 \times 10^{8}\ m\ s^{-1}$ because that is the speed of light and all EM waves travel at the speed of light.

$$\lambda = \frac{v}{f} = \frac{3 \times 10^{8}\ m\ s^{-1}}{6.7 \times 10^{13}\ Hz} = 4.48 \times 10^{-6}\ m$$

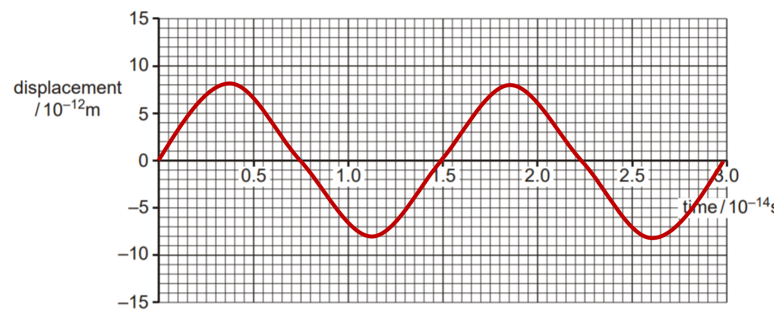
2) Its period of oscillation.

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

$$T = \frac{1}{f} = \frac{1}{6.7 \times 10^{13}\ Hz} = 1.49 \times 10^{-14}\ s$$

(iii) On the grid below sketch a graph showing the variation with time of the displacement of an ion.

We have the amplitude of oscillation of the ions to be $8.0 \times 10^{-12}\ m$ and the time period which is $1.5 \times 10^{-14}\ s$ therefore:



EM Waves

Exam Style Question 3

(a) Name one common property of EM waves not shared by other waves.

(b) Fig. 5.1 shows a block diagram of the seven regions of the electromagnetic spectrum, labelled A to G.

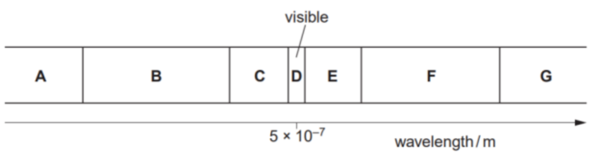


Fig. 5.1

Name the principal radiation in each of the regions A, C and F.

(c) An aerial mounted vertically transmits vertically polarised radio waves of frequency $1.0 \times 10^9\ Hz$. The waves are detected by a receiving aerial some distance away. Initially the receiving aerial is also mounted vertically as shown in Fig. 5.2.

The length of each aerial is half the wavelength of the radio waves.

(i) Calculate the wavelength of the waves.

(ii) Calculate the length of an aerial.

(iii) The receiving aerial is rotated through 180° about the axis joining the centres of the two aerials. See Fig. 5.2. Describe and explain how the output signal from the receiving aerial changes with the angle of rotation.

Fig. 5.2

EM Waves

Exam Style Question 3

(a) Name one common property of EM waves not shared by other waves.
EM waves can travel through a vacuum.

(b) Name the principal radiation in each of the regions A, C and F.
A: Gamma,
C: UV,
F: Microwave.

(c) (i) Calculate the wavelength of the waves.
Use $v = f\lambda$ and rearrange for λ.
(Remember that EM waves travel at the speed of light $(= 3.0 \times 10^8\ m\ s^{-1})$.

$$\lambda = \frac{v}{f} = \frac{3.0 \times 10^8\ m\ s^{-1}}{1.0 \times 10^9\ Hz} = 0.3\ m$$

Therefore wavelength of radio waves is $0.3m$.

(c) (ii) Calculate the length of an aerial.
We know that the length of each aerial is half the wavelength of the radio waves therefore the length of an aerial is:

$$aerial\ length = \frac{0.3\ m}{2} = 0.15\ m$$

(c) (iii) Describe and explain how the output signal from the receiving aerial changes with the angle of rotation.
The emitted waves is plane polarised as it is emitted from the transmitting aerial. So the receiving aerial receives a max signal when it is at $0°$. As the receiving aerial is rotated through an angle θ, the detecting aerial will receive a weaker signal. The signal falls to zero at $90°$ and then rises to max again at $180°$.

EM Waves

Exam Style Question 4

Ultra-violet radiation from the Sun is often divided into three regions UV-A, UV-B and UV-C.

(i) Describe the characteristics and dangers of UV-A, UV-B and UV-C radiations.

(ii) Explain how sunscreen protects the human skin.

EM Waves

Exam Style Question 4

(i) Describe the characteristics and dangers of UV-A, UV-B and UV-C radiations.

UV-A: causes tanning or skin ageing. Has a wavelength in the range of 400 nm – 315 nm.
UV-B: causes damage or sunburn or skin cancer. Has a wavelength in the range of 315 nm – 260 nm.
UV-C: This can cause cell mutation or destruction, and cancer. It's almost entirely blocked by the ozone layer. Has a wavelength in the range of 260 nm – 100 nm.

(ii) Explain how sunscreen protects the human skin.

Sunscreens provide some protection from UV in sunlight to block UV-B.

Polarisation

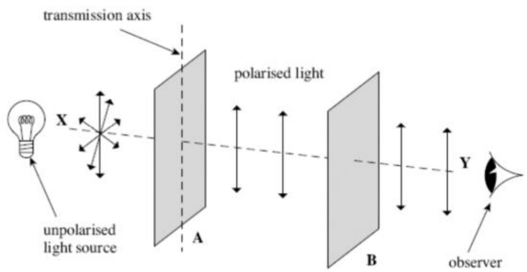
Exam Style Question 5

(a) Define the amplitude of a wave.

(b) (i) Other than electromagnetic radiation, give one example of a wave that is transverse.

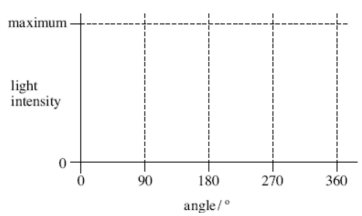
(ii) State one difference between a transverse wave and a longitudinal wave.

(c) The figure below shows two identical polarising filters, A and B, and an unpolarised light source. The arrows indicate the plane in which the electric field of the wave oscillates.



(i) If polarised light is reaching the observer, draw the direction of the transmission axis on filter B in the figure below.

(ii) The polarising filter B is rotated clockwise through 360º about line XY from the position shown in the figure above. On the axes below, sketch how the light intensity reaching the observer varies as this is done.



(d) State one application, other than in education, of a polarising filter and give a reason for its use.

Polarisation

Exam Style Question 5

(a)Define the amplitude of a wave.

Maximum displacement moved by a point on a wave from the equilibrium position.

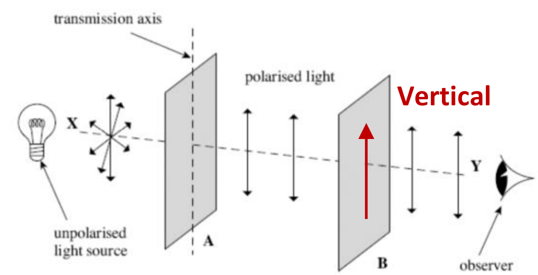
(b) (i) Other than electromagnetic radiation, give one example of a wave that is transverse.

Water waves, or
Waves in a ripple tank.

(b) (ii) State one difference between a transverse wave and a longitudinal wave.

Transverse waves oscillation is perpendicular to wave travel.
Transverse waves can be polarised.
All longitude waves require a medium.

(c) (i) If polarised light is reaching the observer, draw the direction of the transmission axis on filter B in the figure below.



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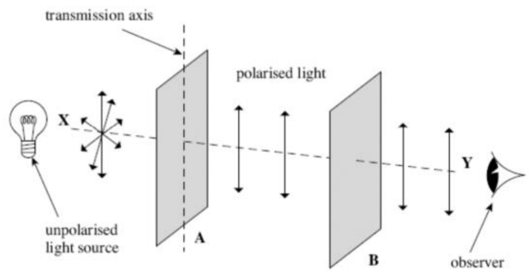

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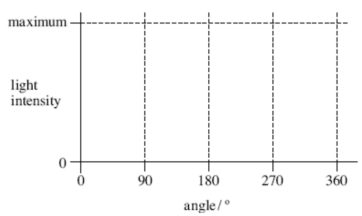
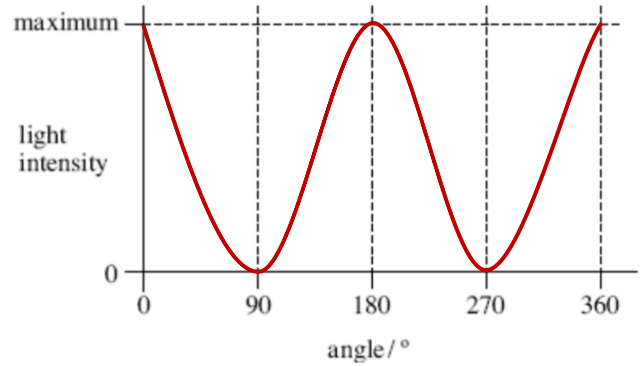


(d) State one application, other than in education, of a polarising filter and give a reason for its use.

Polarisation

Exam Style Question 5

(c) (ii) On the axes below, sketch how the light intensity reaching the observer varies as this is done.



(d) State one application, other than in education, of a polarising filter and give a reason for its use.

- 3D glasses to enhance viewing experience.
- Camera – to reduce glare and enhance the image.
- Polaroid glasses to reduce glare.

Polarisation

Exam Style Question 6

(a) Describe a plane polarised wave.

(b) Light reflected from the surface of water is partially plane polarised in the horizontal direction. The reflected light is totally plane polarised when the angle of reflection is about 53°.

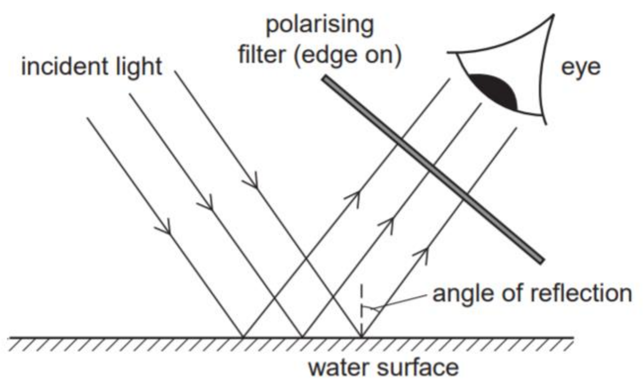


Fig. 7.1

Describe, referring to Fig. 7.1, the experiment that you would perform using a polarising filter (a sheet of Polaroid) to determine whether this statement is correct. Describe what you expect to observe.

(c) State Malus' law for the intensity I of a beam of plane polarised light transmitted through a polarising sheet with its transmission axis at an angle θ to the plane of polarisation. Explain the meaning of any other symbols that you use. Use Malus' law to explain the observations in the experiment of part (b).

Polarisation

Exam Style Question 6

(a)Describe a plane polarised wave.

When transverse wave oscillations occur in one direction and are perpendicular to the direction of motion.

(b) Describe, referring to Fig. 7.1, the experiment that you would perform using a polarising filter (a sheet of Polaroid) to determine whether this statement is correct. Describe what you expect to observe.

Set up an apparatus of a tray of water on a table with natural light or light from a lamp directed at the water. Rotate the filter and this causes the intensity of the image to change. As the statement states the light is partially plane polarised in the horizontal direction therefore if the polaroid is vertical then you should get minimum intensity of the image. However, if the polaroid is horizontal then you should get maximum intensity of the image.

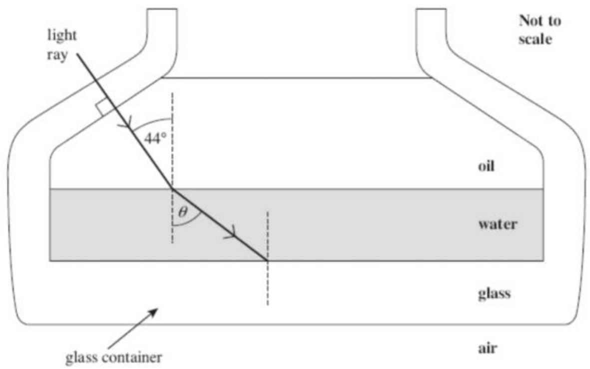
(c) State Malus' law for the intensity I of a beam of plane polarised light transmitted through a polarising sheet with its transmission axis at an angle θ to the plane of polarisation. Explain the meaning of any other symbols that you use. Use Malus' law to explain the observations in the experiment of part (b).

Malus' law is $I = I_0 \cos^2 \theta$
Where I_0 is the maximum intensity of the polarised beam.

In terms of the observations in the experiment of part (b) when θ is zero maximum intensity is transmitted. When θ is $90°$ minimum intensity is transmitted.

Exam Style Question 7

The figure below shows a layer of oil that is floating on water in a glass container. A ray of light in the oil is incident at an angle of 44° on the water surface and refracts.



The refractive indices of the materials are as follows.

- refractive index of oil = 1.47
- refractive index of water = 1.33
- refractive index of the glass = 1.47

(a) Show that the angle of refraction θ in the figure above is about 50°.

(b) The oil and the glass have the same refractive index. On the figure above, draw the path of the light ray after it strikes the boundary between the water and the glass and enters the glass. Show the value of the angle of refraction in the glass.

(c) Explain why the total internal reflection will not occur when the ray travels from water to glass.

(d) Calculate the critical angle for the boundary between the glass and air.

(e) On the figure above, complete the path of the ray after it strikes the boundary between the glass and air.

EM Waves

Exam Style Question 7

(a) Show that the angle of refraction θ in the figure above is about 50°.

Use $n_1 \sin\theta_1 = n_2 \sin\theta_2$

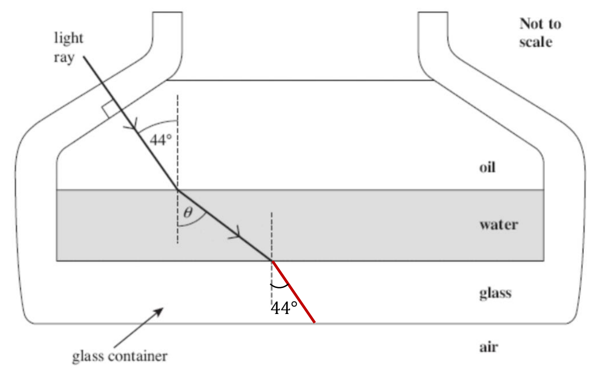
Where:

n_1 = the refractive index of oil.
θ_1 = the angle of incidence, i.
θ_2 = the angle of refraction, r.
n_2 = the refractive index of water.

$$1.47\sin(44°) = 1.33 sin\theta_2$$
$$sin\theta_2 = \frac{1.47\sin(44°)}{1.33}$$
$$sin\theta_2 = 0.7677803042$$
$$\theta_2 = \sin^{-1}(0.7677\ldots)$$
$$\theta_2 = 50.15°$$

(b) Show the value of the angle of refraction in the glass.

As the oil and glass have the same refractive index the light ray will refract 44° towards the normal.



EM Waves

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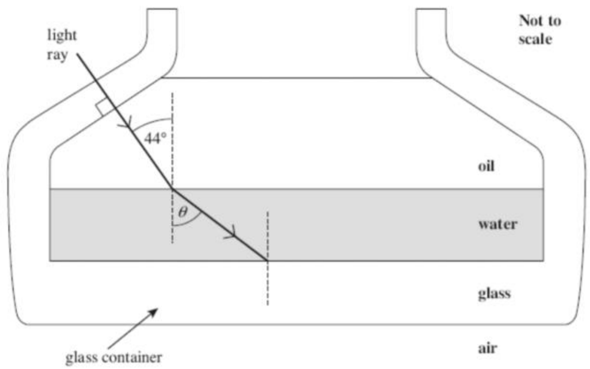

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(c) Explain why the total internal reflection will not occur when the ray travels from water to glass.

(d) Calculate the critical angle for the boundary between the glass and air.

(e) On the figure above, complete the path of the ray after it strikes the boundary between the glass and air.

EM Waves

Exam Style Question 7

(c) Explain why the total internal reflection will not occur when the ray travels from water to glass.

TIR can only occur when the light ray travels from higher refractive index to a lower refractive index however we are going from a lower refractive index to a higher refractive index (e.g. water to glass) so TIR doesn't occur.

(d) Calculate the critical angle for the boundary between the glass and air.

Remember TIR occurs between the glass boundary to the air boundary because the light ray travels from a higher refractive index (glass $n = 1.47$) to a lower refractive index (air $n = 1$).

Use $\boldsymbol{n = \frac{1}{sinC}}$

Where:

n = the refractive index of the incident substance

C = critical angle

And rearrange for C.

$$sinC = \frac{1}{n}$$

$$sinC = \frac{1}{1.47}$$

$$C = sin^{-1}\left(\frac{1}{1.47}\right)$$

$$C = 42.86°$$

Exam Style Question 7

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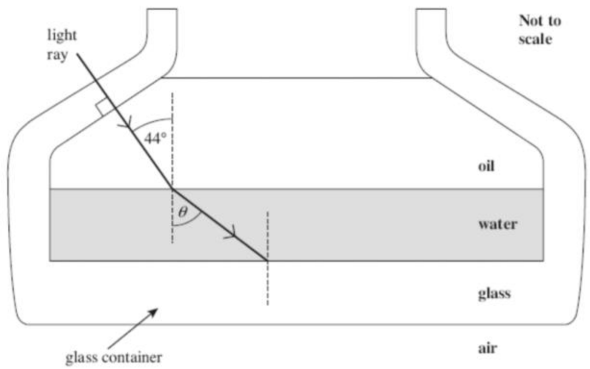

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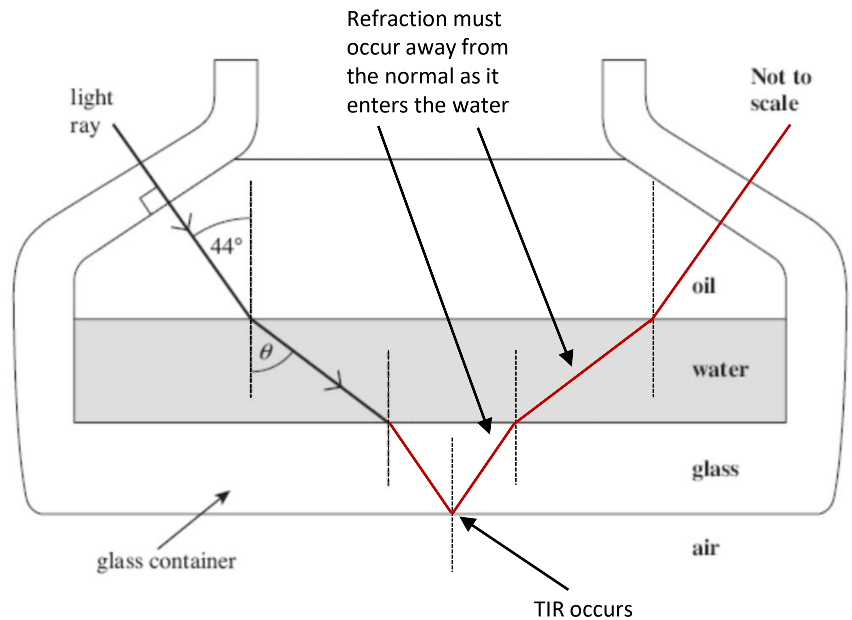
EM Waves

Exam Style Question 7

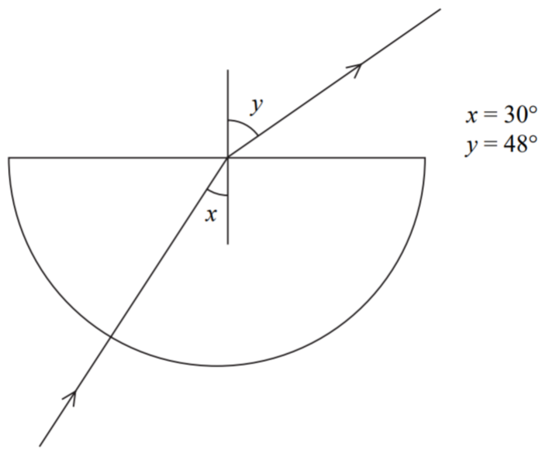
(e) On the figure above, complete the path of the ray after it strikes the boundary between the glass and air.



EM Waves

Exam Style Question 8

A student carries out an experiment to measure the refractive index of glass. She does this by shining a ray of light through a semi-circular glass block and into the air as shown.



(a) Calculate the refractive index from air to glass $_a\mu_g$.

(b) (i) The student steadily increases the angle x in glass and finds that eventually the light does not pass into the air. Explain this observation.

(ii) Calculate the largest value of angle x that allows the light to pass out of the block into the air.

EM Waves

Exam Style Question 8

(a)Calculate the refractive index from air to glass $_a\mu_g$.

Use $n = \frac{\sin i}{\sin r}$

Because we are calculating the refractive index from air to glass we have to do:

$$n = \frac{\sin(48°)}{\sin(30°)} = 1.48$$

(b) (i) The student steadily increases the angle x in glass and finds that eventually the light does not pass into the air. Explain this observation.

As x increases, y increases. At a certain angle, called the critical angle, $y = 90°$ the light travels along the boundary.

For angles greater than the critical angle total internal reflection occurs.

(ii) Calculate the largest value of angle x that allows the light to pass out of the block into the air.

Use $\sin C = \frac{1}{n}$

$$\sin C = \frac{1}{1.48}$$

$$C = \sin^{-1}\left(\frac{1}{1.48}\right)$$

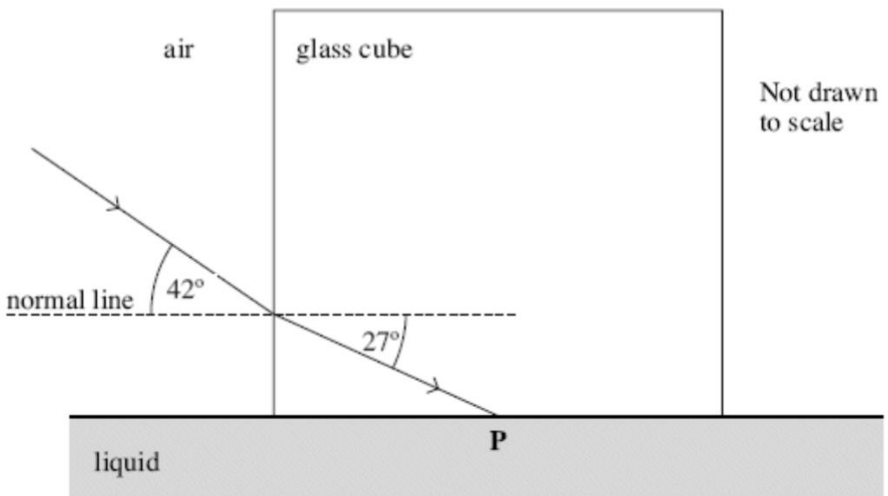
$$C = 42.5$$

So the largest value of angle x that allows the light to pass out of the block into the air is $42°$.

EM Waves

Exam Style Question 9

A glass cube is held in contact with a liquid and a light ray is directed at a vertical face of the cube. The angle of incidence at the vertical face is then decreased to $42°$ as shown in the figure below. At this point the angle of refraction is $27°$ and the ray is totally internally reflected at P for the first time.



(a) Complete the figure above to show the path of the ray beyond P until it returns to air

(b) Show that the refractive index of the glass is about 1.5.

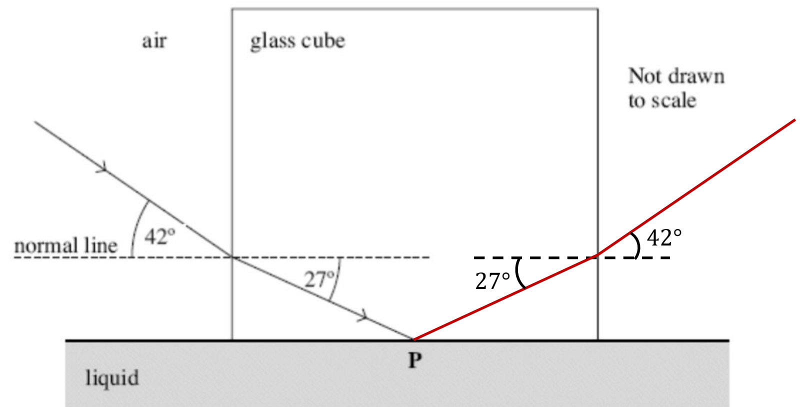
(c) Calculate the critical angle for the glass-liquid boundary.

(d) Calculate the refractive index of the liquid.

EM Waves

Exam Style Question 9

(a)Complete the figure above to show the path of the ray beyond P until it returns to air.



(b) Show that the refractive index of the glass is about 1.5.

Use $n = \frac{\sin i}{\sin r}$

$$n = \frac{\sin(42°)}{\sin(27°)} = 1.47 \approx 1.5$$

(c) Calculate the critical angle for the glass-liquid boundary.

TIR occurs when the angle of incidence **exceeds the critical angle.**

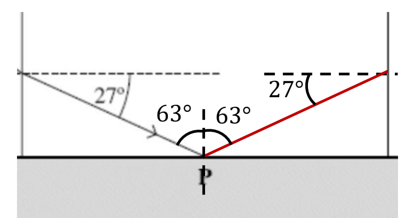
So we know that the angle of total internal reflection is:

$27° + 27° = 54°$

$180° - 54° = 126°$

$incident\ angle, i = \frac{126°}{2} = 63°$

So critical is slightly less than $63°$.



EM Waves

Exam Style Question 9

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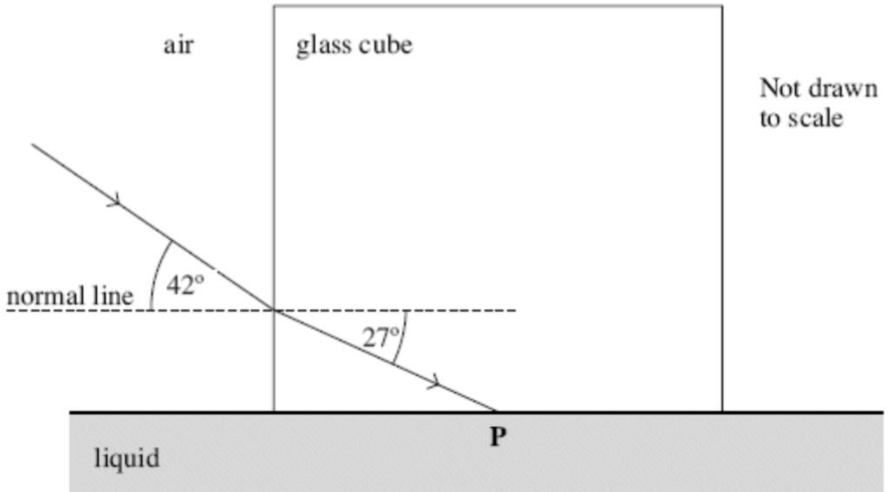

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(d) Calculate the refractive index of the liquid.

EM Waves

Exam Style Question 9

(d) Calculate the refractive index of the liquid.

Use $n_1 \sin\theta_1 = n_2 \sin\theta_2$

We know that from glass to water TIR takes place and the critical angle is slightly under $63°$. So just use $63°$ as the critical angle to make the problem simpler and at the critical angle the refracted ray angle is $90°$. Therefore:

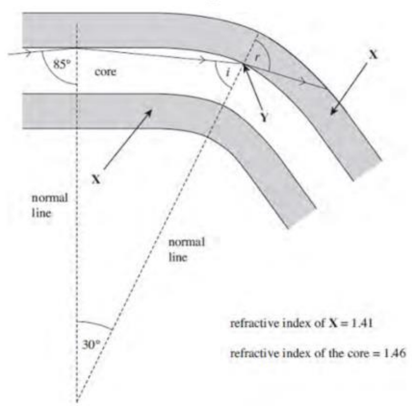
$$(1.5)\sin(63°) = n_l \sin(90°)$$
$$n_l = \frac{(1.5)\sin(63°)}{\sin(90°)}$$
$$n_l = 1.34$$

EM Waves

Exam Style Question 10

Figure 1 shows a cross-section through an optical fibre used for communications.

Figure 1



(a) (i) Name the part of the fibre labelled X

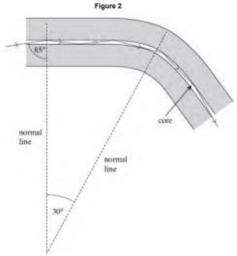
(ii) Calculate the critical angle for the boundary between the core and X.

(b) (i) The ray leaves the core at Y. At this point the fibre has been bent through an angle of $30°$ as shown in Figure 1. Calculate the value of the angle i.

(ii) Calculate the angle r.

(c) The core of another fibre is made with a smaller diameter than the first, as shown in Figure 2. The curvature is the same and the path of a ray of light is shown.

Figure 2



State and explain one advantage associated with a smaller diameter core.

EM Waves

Exam Style Question 10

(a)(i) Name the part of the fibre labelled X.
Cladding.

(a) (ii) Calculate the critical angle for the boundary between the core and X.

Use $n_1 \sin\theta_1 = n_2 \sin\theta_2$

Remember at the critical angle the refracted ray is $90°$ therefore:

$$(1.46)\sin C = (1.41)\sin(90°)$$

$$\sin C = \frac{(1.41)\sin(90°)}{1.46}$$

$$\sin C = 0.9657\ldots$$

$$C = \sin^{-1}(0.9657\ldots)$$

$$C = 74.96°$$

Therefore the critical angle is $75°$.

(b) (i) Calculate the value of the angle i.

Step 1: i is inside a big triangle. So normal rules for a triangle apply such as angles in a triangle add up to $180°$.

Step 2: As the light enters, it forms a $85°$ angle which is TIR. Therefore the angles are equal and the angle on the other side is also $85°$.

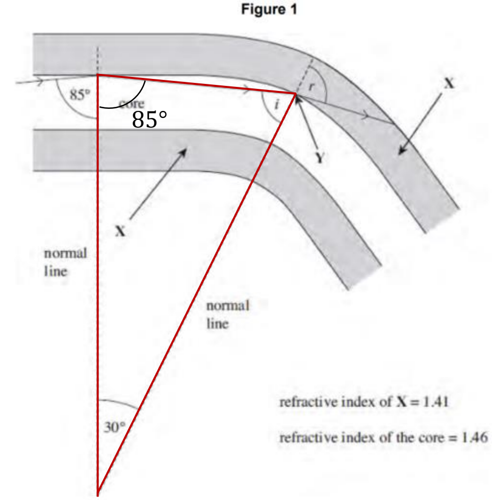
Step 3: Add up the angles we know:

$$85° + 30° = 115°$$

Step 4: As angles in a triangle add up to $180°$ to calculate i we do:

$$i = 180° - 115° = 65°$$

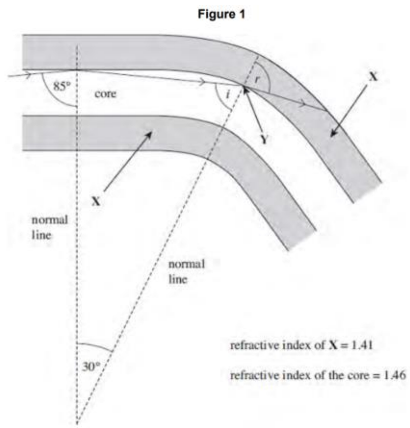
Figure 1



EM Waves

Exam Style Question 10

Figure 1 shows a cross-section through an optical fibre used for communications.



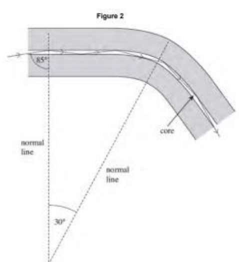
(a) (i) Name the part of the fibre labelled X

(ii) Calculate the critical angle for the boundary between the core and X.

(b) (i) The ray leaves the core at Y. At this point the fibre has been bent through an angle of $30°$ as shown in Figure 1. Calculate the value of the angle i.

(ii) Calculate the angle r.

(c) The core of another fibre is made with a smaller diameter than the first, as shown in Figure 2. The curvature is the same and the path of a ray of light is shown.



State and explain one advantage associated with a smaller diameter core.

EM Waves

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(b) (ii) Calculate the angle r.

Use $n_1 \sin\theta_1 = n_2 \sin\theta_2$

$$(1.46)\sin(65°) = (1.41)\sin r$$
$$\sin r = \frac{(1.46)\sin(65°)}{1.41}$$
$$\sin r = 0.93844\ldots$$
$$r = 69.79225878°$$

Therefore the angle of r is $70°$.

(c) State and explain one advantage associated with a smaller diameter core.

- Less light is lost so better quality signal and less distortion.
- Increased probability of TIR which means less change of angle between each reflection.
- Reflects more in a given length of fibre and keeps incident angle larger than the critical angle. Therefore, the angle of incidence is less likely to fall below the critical angle. So, there is less refraction out of the core, and this improves data transfer resulting in the data to be carried quicker.

Please see '10.2.1 Electromagnetic Waves notes' pack for revision notes.

For more revision notes, tutorials and worked examples please visit www.tutorpacks.co.uk.