Electromagnetic Waves

1. An exploding star in a distant galaxy emitted a burst of electromagnetic radiation. X-rays and ultraviolet radiation from this burst were detected simultaneously at the Earth.

State why the X-rays and ultraviolet radiation from this burst were detected simultaneously.

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[1]

2. Which of the following statements is/are correct about electromagnetic waves?

1 They can be plane polarised.
2 They can be refracted and diffracted.
3 They have the same speed in a vacuum and in glass.

A Only 1
B Only 3
C Only 1 and 2
D 1, 2 and 3

Your answer ☐ **[1]**

3. Radio waves and X–rays are both electromagnetic waves.
State one difference between radio waves and X–rays.

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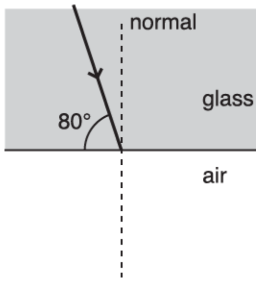
[1]

4. The speed of light in air is 3.0×10^8 m s^{-1} and the speed of light in glass is 2.0×10^8 m s^{-1}. A ray of monochromatic light in glass strikes the glass-air boundary at an angle of 80° to the boundary.



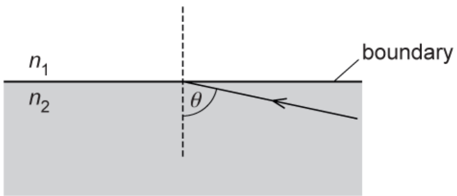
What is the angle made to the normal by the ray of light leaving the boundary?

A 6.6°
B 15°
C 41°
D 49°

Your answer

[1]

5. A ray of monochromatic light is incident at the boundary between two transparent materials of refractive index n_1 and n_2. The critical angle θ is equal to 80°.



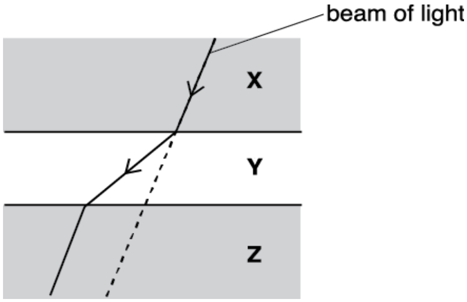
What is the ratio $\frac{n_1}{n_2}$?

A 0.17
B 0.98
C 1.02
D 5.76

Your answer

[1]

6. The diagram below shows the path of a narrow beam of light as it is refracted at the boundaries between three different transparent materials **X**, **Y** and **Z**.



The beam of light in **X** and the beam of light in **Z** are parallel.
The wavelength of the light in **X** is 640 nm.

Which statement is correct?

A The light travels faster in **X** than in **Y**.
B The wavelength of light in **Y** is shorter than 640 nm.
C Materials **X** and **Z** have the same value of refractive index.
D The refractive index of **Y** is greater than the refractive index of **X**.

Your answer ☐

[1]

7. The energy of a photon is 2.5 eV.

What is the principal radiation for this photon?

A infrared
B radio waves
C visible light
D x-rays

Your answer ☐ **[1]**

8. In which region of the electromagnetic spectrum is radiation of frequency 300 MHz?

A radio wave
B microwave
C visible
D X-ray

Your answer ☐

[1]

9. An electron has a de Broglie wavelength equal to the wavelength of X-rays.

What is the **best** estimate of the momentum of this electron?

A 10^{-30} kg m s^{-1}
B 10^{-27} kg m s^{-1}
C 10^{-23} kg m s^{-1}
D 10^{-18} kg m s^{-1}

Your answer **[1]**

10. In which region of the electromagnetic spectrum is radiation of wavelength 50 μm?

A visible
B infra-red
C microwave
D radio

Your answer

[1]

11. A student views the display of a laptop screen through a polarising filter. The intensity of the light changes when the filter is rotated.

Which property of light is demonstrated in this experiment?

A It has wavelength of about 5×10^{-7} m.
B It travels at the speed of light.
C It is a transverse wave.
D It is a longitudinal wave.

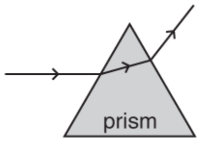
Your answer

[1]

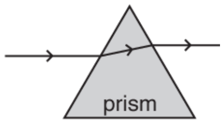
12. A narrow beam of light in air is directed at the surface of a triangular glass prism.

Which is the correct diagram for the light refracted by the prism?

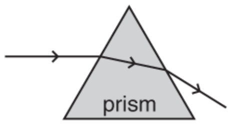
A



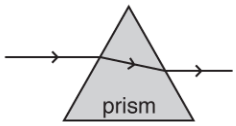
B



C



D



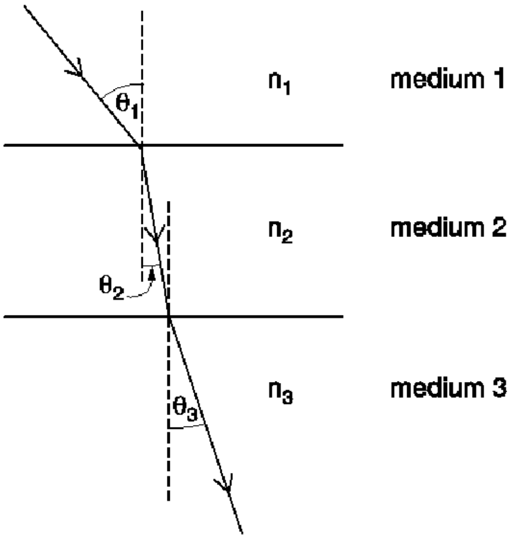
Your answer ☐ **[1]**

13. Which statement is **not** correct about an electromagnetic wave?

A It can be diffracted.
B It can be polarised.
C It is a longitudinal wave.
D It can travel through a vacuum.

Your answer ☐ **[1]**

14. A ray of light passes through three media with refractive indices n_1, n_2 and n_3. The speed of light in medium 1 is v_1, in medium 2 is v_2 and in medium 3 is v_3. The angle between the ray and the normal in medium 1 is θ_1, θ_2 in medium 2 and θ_3 in medium 3.



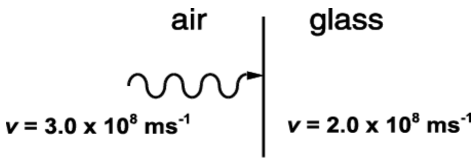
Which of the following statements is/are true?

A. The velocity of light in medium 3 is equal to the velocity of light in medium 1
B. $v_3 = v_1 \dfrac{\sin \theta_3}{\sin \theta_1}$
C. The frequency of light in medium 2 is less than the frequency in medium 1
D. $\dfrac{n_2}{n_1} = \dfrac{v_2}{v_1}$

Your answer ☐

[1]

15. A beam of monochromatic light passes from air into glass. The speed of the photons in air is 3.0 x 10^8 m s^{-1} and in glass is 2.0 x 10^8 m s^{-1}.



Which of the following statements is correct?

A. The energy of a photon in glass is 1.5 times the energy of the photon in air.
B. The energy of a photon in glass is the same as the energy of the photon in air.
C. The energy of a photon in glass is $\frac{2}{3}$ of the energy of the photon in air.
D. When the intensity of the monochromatic light beam is halved the energy of each photon of the beam in air is halved.

Your answer ☐

[1]

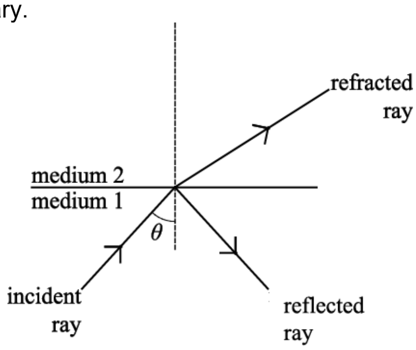
16. Which of the following statements is true about electromagnetic radiation?

A. Radio waves are in the highest energy range of the electromagnetic spectrum.
B. Visible light has a range of wavelengths in the order of 450 nm to 700 nm.
C. Ultra-violet waves cannot be plane polarised.
D. Gamma rays have a low frequency.

Your answer ☐

[1]

17. A ray of monochromatic light is incident at a boundary between medium 1 and medium 2. The ray is both refracted and reflected at the boundary.



Which of the following statements is / are true?

1. The refracted light and incident light have the same wavelength.
2. The speed of light in medium 2 is greater than the speed of light in medium 1.
3. The angle θ is the critical angle.

A. 1, 2 and 3
B. Only 1 and 2
C. Only 1
D. Only 2

Your answer ☐

[1]

18. Which of the following statements is / are true about photons?

1. The speed of a photon changes at the boundary between air and glass.
2. Photons are electrically neutral.
3. The energy of a photon depends only on its wavelength.

A. 1, 2 and 3 are correct
B. Only 1 and 2 are correct
C. Only 2 and 3 are correct
D. Only 1 is correct

Your answer ☐

[1]

19. Which of the following waves can be polarised and has a typical wavelength of about a few centimetres?

A microwaves
B ultraviolet
C sound
D visible light

Your answer ☐ **[1]**

20. The table shows the refractive index *n* of four transparent materials **A**, **B**, **C** and **D**.

Which material has the **smallest** critical angle?

Material	**A**	**B**	**C**	**D**
n	2.01	1.87	1.60	1.33

Your answer ☐ **[1]**

21. A narrow beam of unpolarised light is incident at the boundary between air and glass.

Fig. 18 shows the incident ray, the reflected ray and the refracted ray at the air-glass boundary.

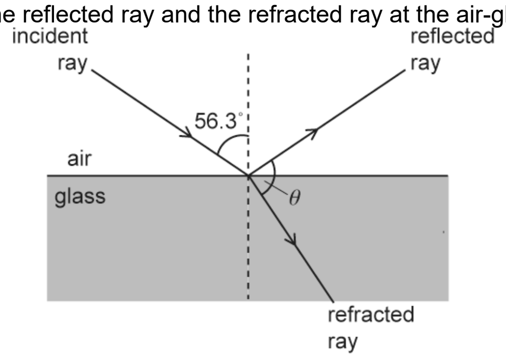


Fig. 18 (not to scale)

The refractive index of air is 1.00 and the refractive index of the glass is 1.50.
The angle of incidence of the light is 56.3°.

Calculate the time *t* taken for the refracted light to travel a **depth** of 6.0 cm of glass.

t = ______________________________ s **[2]**

22. In an experiment using microwaves, a metal grille **G** consisting of a series of long metal rods is placed between a transmitter **T** and a detector **D** as shown in Fig. 7.2.

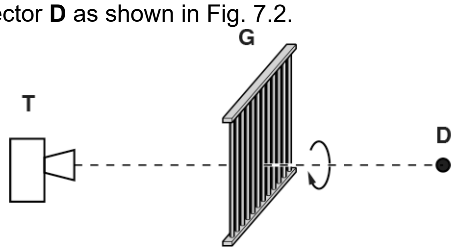


Fig. 7.2

The grille is slowly rotated through 180° about the line joining **T** and **D**. The detected signal at **D** varies from zero to maximum and back to zero again.

Explain why the detected signal behaves in this way.

-- **[2]**

23. The table shows the refractive index *n* of air and glass for blue light. It also shows the speed *v* and the wavelength *λ* of blue light in air.

	air	**glass**
refractive index *n*	1.00	1.53
speed of light v / m s^{-1}	3.00×10^8	
wavelength λ/m	4.69×10^{-7}	

Fig. 2.2 shows a semi-circular glass block with the blue light replaced by red light.

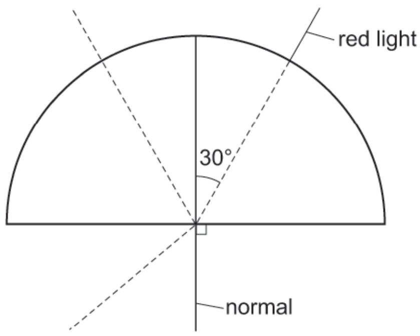


Fig. 2.2 (not to scale)

The dashed lines show the original paths of the blue light.

Draw on **Fig. 2.2** the path of the red light in the glass block and out of the glass block.

24. When a gardener aims water from a hosepipe at the ground, he notices that the water always splashes in many directions. Fig. 22.1 shows the splashes produced by a vertical jet of water hitting the ground.

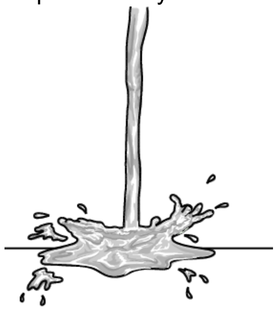


Fig. 22.1

Using ideas about momentum explain why the water splashes in many directions.

--- **[2]**

25. A narrow beam of unpolarised light is incident at the boundary between air and glass.

Fig. 18 shows the incident ray, the reflected ray and the refracted ray at the air-glass boundary.

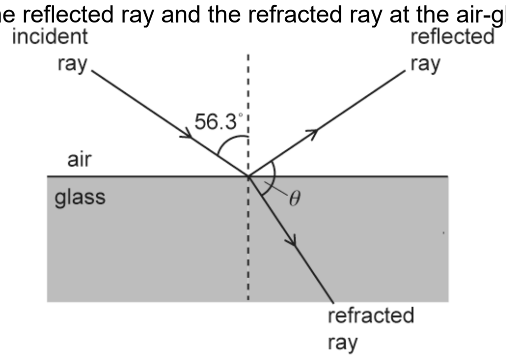


Fig. 18 (not to scale)

The refractive index of air is 1.00 and the refractive index of the glass is 1.50.
The angle of incidence of the light is 56.3°.

Describe how you can demonstrate in the laboratory that reflected light is plane polarised.

--- **[2]**

26. This question is about investigations involving an electromagnetic wave.

A vertical transmitter aerial emits a **vertically polarised** electromagnetic wave which travels towards a vertical receiver aerial. The wavelength of the wave is 0.60 m.

Fig. 5.1 shows a short section of the oscillating electric field of the electromagnetic wave.

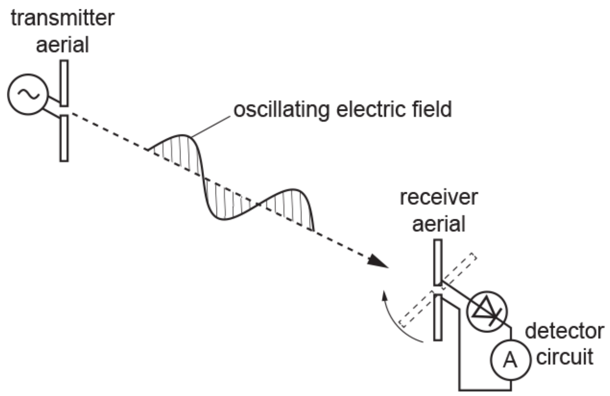


Fig. 5.1

Calculate the frequency *f* of the transmitted wave.

f = ... Hz **[2]**

27. The table shows the refractive index *n* of air and glass for blue light. It also shows the speed *v* and the wavelength *λ* of blue light in air.

	air	**glass**
refractive index *n*	1.00	1.53
speed of light *v* / m s^{-1}	3.00×10^{8}	
wavelength λ/m	4.69×10^{-7}	

i. Show that the frequency *f* of blue light in air is 6.40×10^{14} Hz.

[1]

ii. Complete the table by determining the missing values for v and λ for glass. Write your answers to 3 significant figures.

[2]

28. You are provided with a ray-box, a semi-circular block of plastic and other normal laboratory equipment. The outline of the block is shown below.

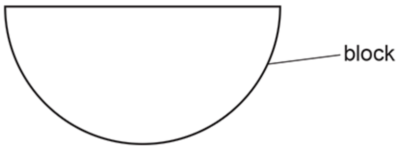


Fig 2.1

Describe how you could measure the refractive index *n* of the block using the critical angle method. Draw on the diagram and label it to make your answer clear.

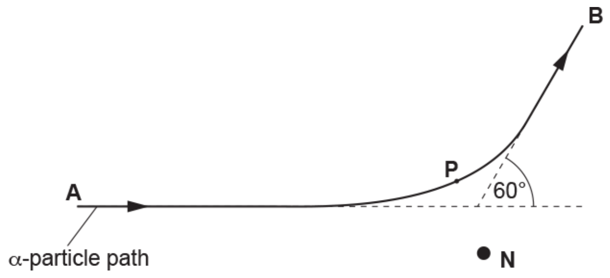
---

[3]

29. A beam of α-particles is incident on a thin gold foil. Most α-particles pass straight through the foil. A few are deflected by gold nuclei.

The diagram shows the path of one α-particle which passes close to a gold nucleus **N** in the foil. The α-particle is deflected through an angle of 60° as it travels from **A** to **B**.

P marks its position of closest approach to the gold nucleus.



The initial kinetic energy of each α-particle is 5.0 MeV.

Show that the magnitude of the initial momentum of each α-particle is about 10^{-19} kg m s^{-1}.
Take the mass of the α-particle to be 6.6×10^{-27} kg.

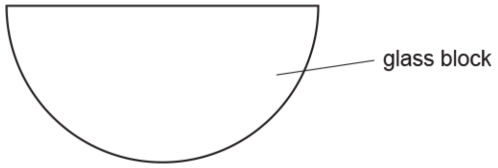
[3]

30 (a). Light travels from air to water. The refractive index of water is greater than the refractive index of air. Compare the speed, frequency and wavelength of light in air and in water.

---

[3]

(b). A student is given a semi-circular glass block.
Describe with the aid of a ray diagram how an experiment can be conducted to accurately determine the critical angle for light within the glass block and hence the refractive index of the glass.



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[3]

31. You are provided with a rectangular block of plastic.

Describe how you can use a ray-box (or a laser beam), together with other equipment available in the laboratory, to accurately determine the refractive index of the plastic block.

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[3]

32. Fig.17 shows a ray of light at the boundary between glass and water.

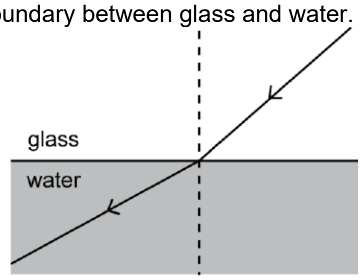

Fig. 17 (not to scale)

Use Fig. 17 to describe and explain how the wavelength of the light changes as light travels from glass to water.

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[3]

33. A narrow beam of unpolarised light is incident at the boundary between air and glass.

Fig. 18 shows the incident ray, the reflected ray and the refracted ray at the air-glass boundary.

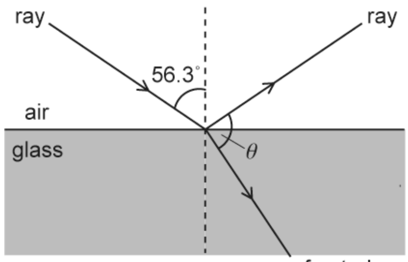

Fig. 18 (not to scale)

The refractive index of air is 1.00 and the refractive index of the glass is 1.50.
The angle of incidence of the light is 56.3°.

Show that the angle θ between the refracted ray in the glass and the reflected ray in the air is 90.0°.

[3]

34 (a). A student investigates the path of a light ray through ethanol. Fig. 8.1 shows ethanol in a rectangular glass container. Light of wavelength 5.2×10^{-7} m is incident on the container as shown.

Fig. 8.1 (not to scale)

The table below shows the refractive indices *n* and speeds of light *v* in various transparent media.

medium	***n***	***v* / m s^{-1}**
air	1.00	3.00×10^8
ethanol		2.20×10^8
glass	1.52	
vacuum	1.00	3.00×10^8

(i) Complete the table by calculating the missing values of *n* and *v*. **[2]**

(ii) Determine the wavelength λ of the light in glass.

λ = ... m **[1]**

(b). Fig. 8.2 shows an enlarged version of a section of the left hand side of the glass container.

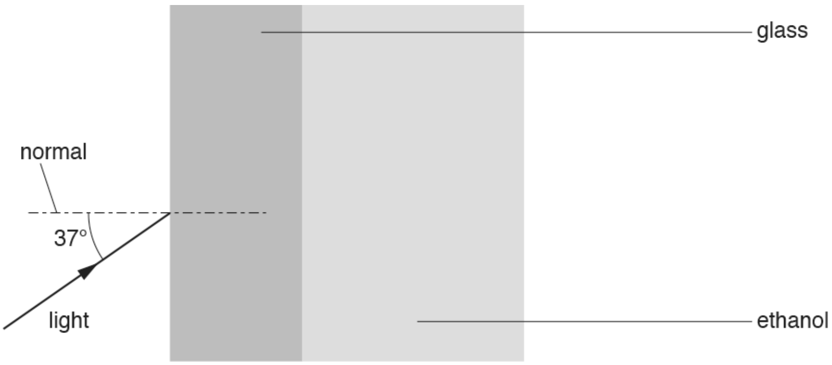

Fig. 8.2 (not to scale)

(i) The light is incident on the glass at an angle of 37°.
Determine the angle of refraction θ in the glass.

θ = ________________________ ° **[2]**

(ii) Without any further calculation, sketch the ray of light as it passes through the glass into the ethanol. **[1]**

35. An astronomer uses a spectrometer and diffraction grating to view a hydrogen emission spectrum from a star. The light is incident normally on the grating.

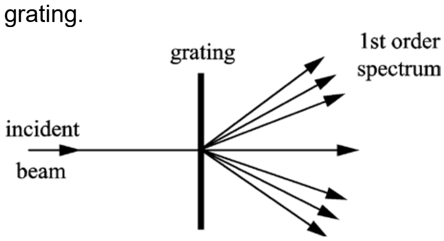

Fig. 6.1

These three emission lines all arise from transitions to the same final energy level. The part of the energy level diagram of hydrogen relevant to these transitions is shown in **Fig. 6.2**.

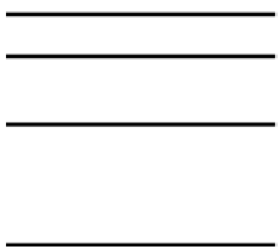

Fig. 6.2

i. Draw lines between the energy levels to indicate the transitions which cause the three emission lines and label them with their wavelengths.

[1]

ii. There are other possible transitions between the energy levels shown in **Fig. 6.2**. The least energetic of these produces photons of 4.8×10^{-20} J.

Calculate the wavelength of these photons.

State in which region of the electromagnetic spectrum this wavelength is found.

wavelength .... m

region: ....

[3]

36. Microwaves and X-rays are examples of electromagnetic waves.

i. The following are possible wavelengths of electromagnetic waves.

0.2 km 2 m 2 cm 0.2 mm 2 µm 200 nm 200 pm

Select from the list above a typical wavelength of a microwave and an X-ray.

microwave

X-ray

---

[2]

ii. One property of electromagnetic waves is that they are transverse waves.

State **two** other properties.

1. ______________________________

2. ______________________________

[2]

37. Sound waves cannot be polarised, but they do show diffraction.

i. State why sound waves **cannot** be polarised.

---
[1]

ii. Describe and explain how you could demonstrate the diffraction of sound waves in the laboratory.

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[3]

38. Fig. 6.1 shows a single photomultiplier tube and its internal components. The tube can detect gamma photons in high-energy physics experiments.

A single gamma photon incident on the scintillator crystal generates many photons of blue light. These visible light photons travel to the photocathode where they are converted into photoelectrons. The number of electrons is then multiplied in the photomultiplier tube with the help of electrodes called dynodes. A short pulse of electric current is produced at the output end of the photomultiplier tube.

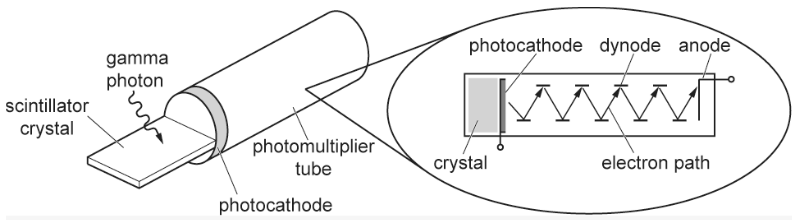

Fig. 6.1

Fig. 6.2 shows a section through the scintillator crystal in air.

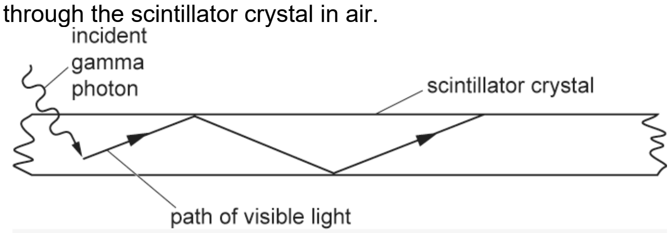

Fig. 6.2

i. The refractive index of the scintillator crystal for visible light is 1.69. The refractive index of air is 1.00. Calculate the critical angle *C* for this crystal.

C = ________________________ ° **[2]**

ii. Explain why the visible light inside the scintillator crystal follows the path shown in Fig. 6.2.

---

[2]

39 (a). Electromagnetic radiation is incident on a negatively charged zinc plate. Electrons are emitted from the surface of the plate when a weak intensity ultraviolet source is used. Electrons are not emitted at all when an intense visible light from a lamp is used.

Explain these observations.

---

[4]

(b). The **maximum** wavelength of the electromagnetic radiation incident on the surface of a metal which causes electrons to be emitted is 2.9×10^{-7} m.

Calculate the maximum kinetic energy of electrons emitted from the surface of the metal when each incident photon has energy of 5.1 eV.

maximum kinetic energy = ... J **[3]**

(c). Electromagnetic radiation of constant wavelength is incident on a metal plate. Photoelectrons are emitted from the metal plate. Fig. 19.1 shows an arrangement used to determine the maximum kinetic energy of electrons emitted from a metal plate.

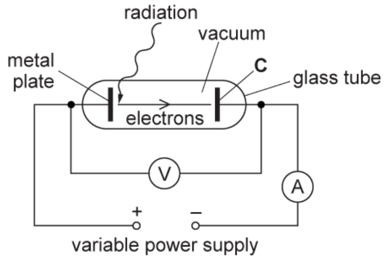

Fig. 19.1

The metal plate and the electrode **C** are both in a vacuum. The electrode **C** is connected to the negative terminal of the variable power supply.

Fig. 19.2 shows the variation of current *I* in the circuit as the potential difference *V* between the metal plate and **C** is increased from 0 V to 3.0 V.

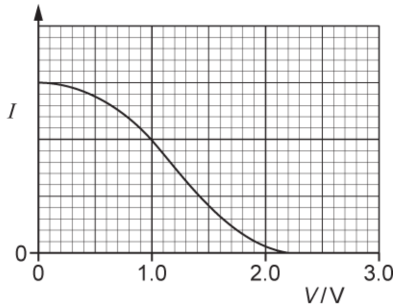

Fig. 19.2

Explain why the current decreases as *V* increases and describe how you can determine the maximum kinetic energy of the emitted electrons.

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[3]

40 (a). The International Space Station (ISS) orbits the Earth at a height of 4.1×10^5 m **above** the Earth's surface.

The radius of the Earth is 6.37×10^6 m. The gravitational field strength g_0 at the Earth's surface is 9.81 N kg^{-1}.

Both the ISS and the astronauts inside it are in free fall.

Explain why this makes the astronauts feel **weightless**.

[1]

(b).

i. Calculate the value of the gravitational field strength *g* at the height of the ISS above the Earth.

g = ... N kg^{-1} **[3]**

ii. The speed of the ISS in its orbit is 7.7 km s^{-1}. Show that the period of the ISS in its orbit is about 90 minutes.

[2]

(c). Use the information in **(b)(ii)** and the data below to show that the root mean square (r.m.s.) speed of the air molecules inside the ISS is approximately 15 times smaller than the orbital speed of the ISS.

- molar mass of air = 2.9×10^{-2} kg mol^{-1}
  temperature of air inside the ISS = 20 °C

[3]

(d). The ISS has arrays of solar cells on its wings. These solar cells charge batteries which power the ISS. The wings always face the Sun.

Use the data below and your answer to **(b)(ii)** to calculate the **average** power delivered to the batteries.

- The total area of the cells facing the solar radiation is 2500 m^2.
- 7% of the energy of the sunlight incident on the cells is stored in the batteries.
- The intensity of solar radiation at the orbit of the ISS is 1.4 kW m^{-2} outside of the Earth's shadow and zero inside it.
- The ISS passes through the Earth's shadow for 35 minutes during each orbit.

average power = ... W **[4]**

41. A grain of a radioactive powder which emits gamma rays accidentally falls onto the workbench.

A sensitive gamma-ray detector is used to look for this grain. The grain can be assumed to be a point source which emits radiation **uniformly in all** directions.

The background count-rate before the accident was negligible.

The detector registers a count-rate of 20 s^{-1} when it is 1.0 m from the grain.

i. Explain why the count-rate rises to 320 s^{-1} when the detector is moved to 0.25 m from the grain

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---

[2]

ii. A thin lead sheet is now placed on the bench over the grain. This causes the count-rate to halve to 160 s^{-1}. The detector is moved from its position at 0.25 m towards the grain until the count-rate returns to 320 s^{-1}.

1 State the value of the count-rate if the sheet is now removed.

count-rate = ... s^{-1} **[1]**

2 Calculate the distance of the detector from the grain.

distance = ... m **[2]**

42 (a). State the *principle of superposition* of waves.

---

[1]

(b). Fig. 16.1 shows an arrangement to demonstrate the interference of monochromatic light.

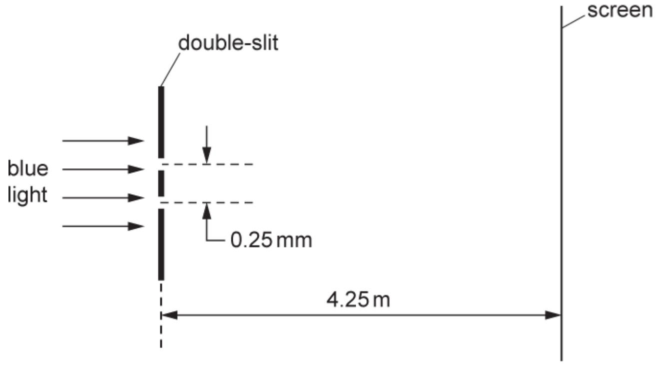


Fig. 16.1

Coherent blue light from a laser is incident at a double-slit. The separation between the slits is 0.25 mm. A series of dark and bright lines (fringes) appear on the screen. The screen is 4.25 m from the slits.
Fig. 16.2 shows the dark and bright fringes observed on the screen.

Fig. 16.2

The pattern shown in Fig. 16.2 is **drawn to scale**.

i. Use Fig. 16.2 to determine accurately the wavelength of the blue light from the laser.

wavelength = ... m **[3]**

ii. The blue light is now replaced by a similar beam of red light.
State and explain the effect, if any, on the fringes observed on the screen.

---

[2]

43. * A student carries out two investigations with these electromagnetic waves.

In **investigation 1**, the student rotates the receiver aerial about the horizontal axis joining the two aerials, as shown in **Fig. 5.1**.

In **investigation 2**, the student places a metal sheet behind the receiver aerial. The student moves the sheet backwards and forwards along the horizontal axis joining the two aerials, as shown in **Fig. 5.2**.

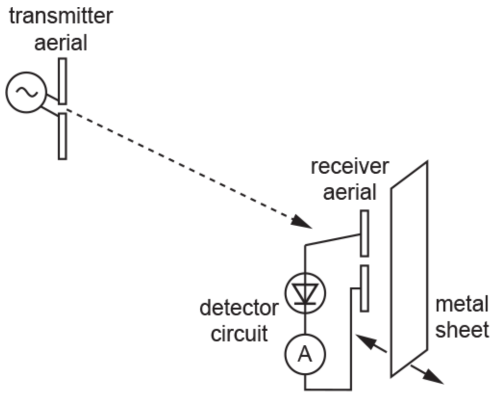


Fig. 5.2

For each of these two investigations:

- Explain why the ammeter sometimes gives a maximum reading and sometimes a zero (or near zero) reading.
- State the orientations of the receiver aerial in **investigation 1**, and the positions of the metal sheet in **investigation 2**, where these maximum and zero readings would occur.

----

[6]

44. * Students are given a glass block and a ray box to determine the refractive index of glass. The students measure the angle of incidence *i* and the angle of refraction *r*. The table shows the results collected by the students.

i / ° + 0.5°	10	20	30	40	50	60	70	80
r / ° ± 0.5°	6	13	20	25	31	35	39	41

The refractive index of air is 1.00.

Describe, with the help of a labelled diagram, how the students may have conducted the experiments in the laboratory.

Discuss how you could use the data from the table to graphically determine a value for the refractive index of glass.

--- **[6]**

45. A scientist is investigating the interference of light using very thin transparent material.
A sample of the transparent material is placed in a vacuum.
Fig. 16.2 shows the path of two identical rays of light **L** and **M** from a laser.

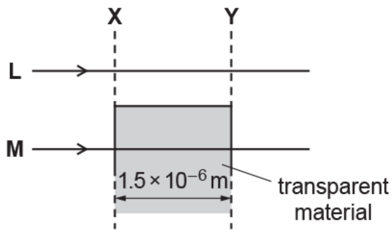


Fig. 16.2

The refractive index of the material is 1.20. The thickness of the material is 1.5×10^{-6} m.
The wavelength of the light in vacuum is 6.0×10^{-7} m.

i. Show that the difference in time t for the two rays to travel between the dashed lines **X** and **Y** is 1.0×10^{-15} s.

t = ... s **[3]**

ii. Calculate the period T of the light wave.

t = ... s **[2]**

iii. The rays of light are in phase at the dashed line **X**.

Use your two answers above to state the phase difference φ in degrees between the light rays at **Y**.

φ = ... ° **[1]**

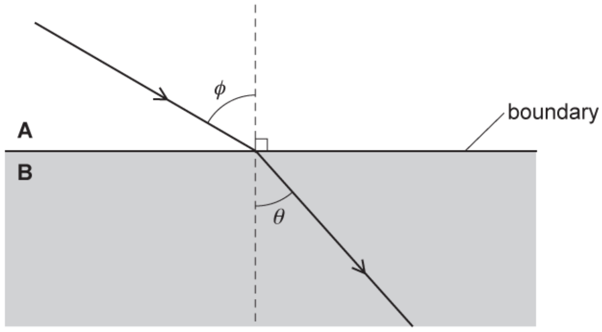
46. Light can be refracted. Light can also show total internal reflection.

i. Define **refractive index** of a material.

---

[1]

ii. The diagram below shows the path of light in two transparent materials **A** and **B**.



Not to scale

The refractive index of **B** is 1.3 times greater than the refractive index of **A**.
The wavelength of the light in **A** is λ_A and the wavelength of the light in **B** is λ_B.

1. Explain how λ_B compares with λ_A.

---

[3]

2. Calculate the angle of refraction θ when the angle φ is 60°. Show your working.

θ = ... ° **[2]**

3. The angle φ is now varied between 0° and 90° with the light still travelling from material A towards the boundary.

Explain whether or not total internal reflection will be observed at the boundary between the two materials.

---

[1]

47. The table shows the refractive index *n* of air and glass for blue light. It also shows the speed *v* and the wavelength *λ* of blue light in air.

	air	**glass**
refractive index *n*	1.00	1.53
speed of light *v* / m s^{-1}	3.00 × 10^{8}	
wavelength λ/m	4.69 × 10^{-7}	

A semi-circular block of glass is placed in air.
Fig. 2.1 shows the path of blue light through the air and the semi-circular glass block.

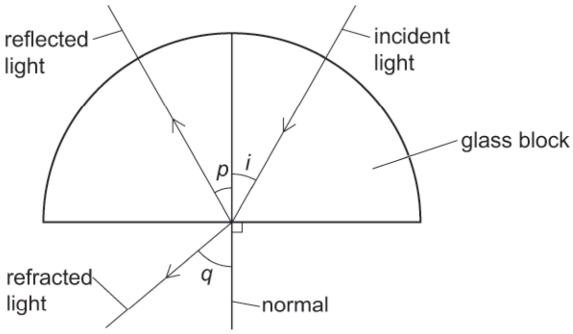


Fig. 2.1 (not to scale)

i. The angle *i* is 30°.
1. Determine angle *p*.

p = ... ° **[1]**

2. Determine angle *q*, using the information from the table in **(a)**.

q = ... ° **[2]**

ii. The angle *i* is increased from 30° to 60°.
Describe and explain how angles *p* and *q* will change. In your answer, include the term **critical angle**.

---

[4]

END OF QUESTION PAPER