EDEXCEL A LEVEL PHYSICS · TOPIC 5

Waves and the Particle Nature of Light

FREE Online Physics A Level Course

physicswithkate.com

Name _____ **Date** _____

TIME ALLOWED	TOTAL MARKS	YOU WILL NEED
2 hours 10 minutes	112	a calculator, a ruler and a black or blue pen

Instructions

- Answer **all** questions in the spaces provided.
- Question 1 is multiple choice: tick **one** box for each part.
- Show your working in calculations, and include units where appropriate.
- Use $c = 3.00 \times 10^{8}$ m s^{-1}, $h = 6.6 \times 10^{-34}$ J s and $e = 1.6 \times 10^{-19}$ C.

Information

- The marks for each question are shown in brackets: use them as a guide to how long to spend.
- This test covers Edexcel A Level Physics Topic 5, Waves and the Particle Nature of Light.
- It is a long test: you can split it, doing Questions 1–11 and 12–16 in two sittings.
- In the questions marked with an asterisk (*), marks are awarded for structuring your answer logically.

Your score

Question	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13	Q14	Q15	Q16	Total	%
Out of	12	4	14	7	4	4	3	2	8	15	10	5	4	6	9	5	**112**	100
Your mark																		

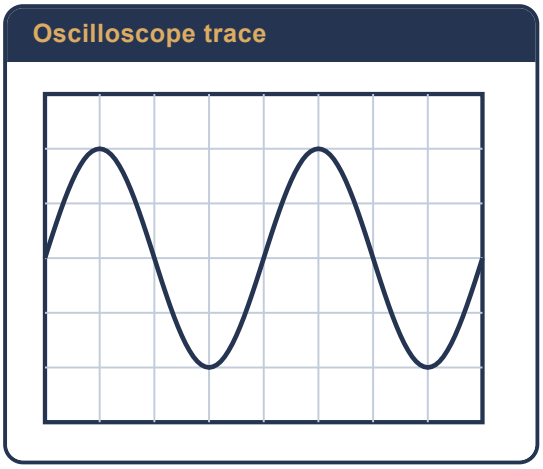
Marking your test The full mark scheme is at the back of this booklet. Try every question first, then mark your answers in a different colour.

1 Question 1

Multiple choice | 12 marks

For each part, put a tick (✓) in **one** box. Each part is worth 1 mark.

(a) A sound is investigated by connecting a microphone to an oscilloscope. On the *x*-axis, 1 division represents 5 ms.



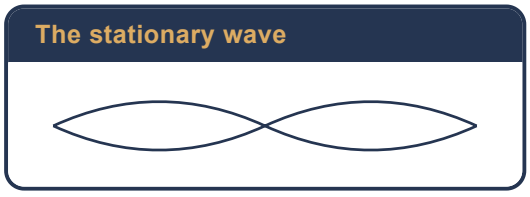
The frequency of the sound wave is

Tick (✓) **one** box.

A	0.05 Hz	☐	**B**	0.1 Hz	☐	**C**	50 Hz	☐	**D**	100 Hz	☐

(1)

(b) The diagram represents a stationary wave on a string. Which diagram correctly shows the positions of the nodes N and antinodes A?



Tick (✓) **one** box.

A A N A ☐

B N A N ☐

C N N N ☐

D A A A ☐

(1)

(c) Which of the following would increase the amount of detail (resolution) in an ultrasound scan?

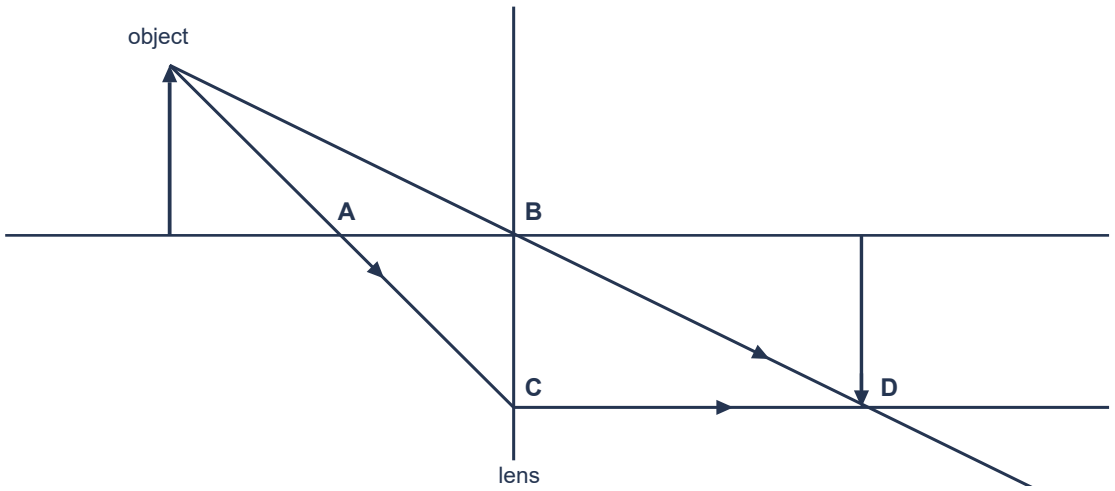
Tick (✓) **one** box.

- **A** faster wave speed ☐
- **B** larger wavelength ☐
- **C** lower frequency ☐
- **D** shorter pulses ☐

(1)

(d) The diagram shows how an image is formed of an object placed a small distance from a thin converging lens. Which of the labels A, B, C or D represents the focal point of the lens?

Ray diagram

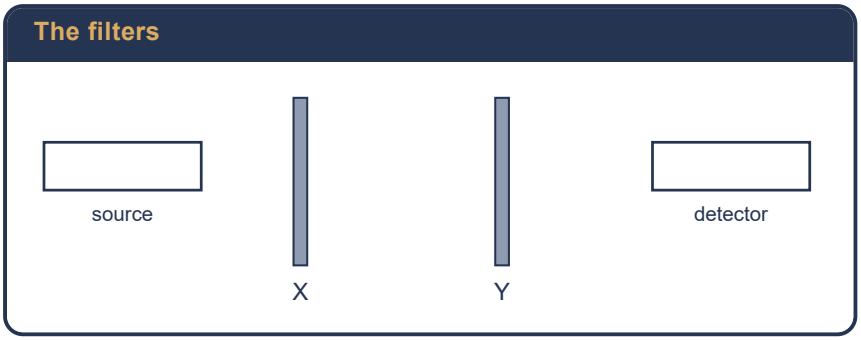


Tick (✓) **one** box.

- **A** ☐
- **B** ☐
- **C** ☐
- **D** ☐

(1)

(e) Two polarising filters X and Y are placed between a source of unpolarised light and a light detector. Their planes of polarisation are initially perpendicular to each other.



Which rotations of X and Y will give the **maximum** intensity of light at the detector?

Tick (✓) **one** box.

- **A** X: 90° clockwise · Y: 270° clockwise ☐
- **B** X: 90° clockwise · Y: 270° anticlockwise ☐
- **C** X: 180° clockwise · Y: 90° anticlockwise ☐
- **D** X: 180° clockwise · Y: 180° anticlockwise ☐

(1)

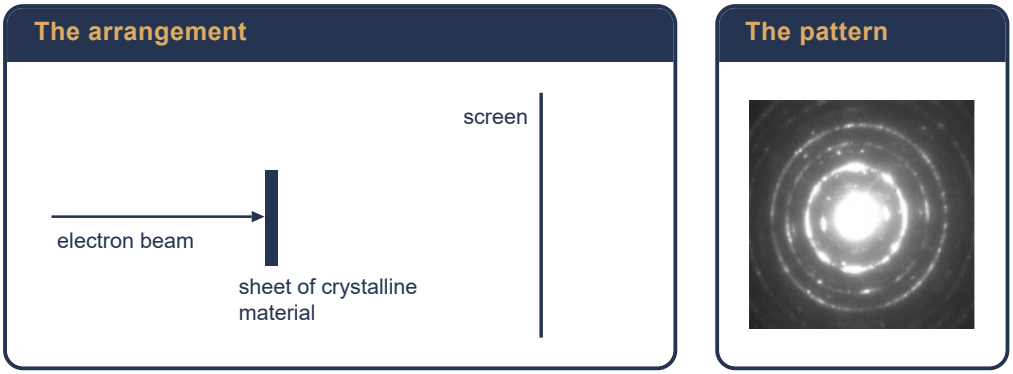
(f) The effect of diffraction is more noticeable, in everyday life, with sound than with light. This is because

Tick (✓) **one** box.

- **A** sound has a much longer wavelength than light. ☐
- **B** sound is a longitudinal wave, light is a transverse wave. ☐
- **C** sound is a mechanical wave, light is an electromagnetic wave. ☐
- **D** sound travels more slowly in air than light does. ☐

(1)

(g) A beam of electrons is directed at a sheet of crystalline material. The pattern shown is produced on the screen.



This pattern demonstrates

Tick (✓) **one** box.

A diffraction. ☐ **B** polarisation. ☐ **C** reflection. ☐ **D** refraction. ☐

(1)

(h) Which of the following experiments provides evidence for the particle nature of light?

Tick (✓) **one** box.

A The diffraction of electrons as they pass through a layer of graphite ☐

B The diffraction orders formed when light passes through a diffraction grating ☐

C The ejection of photoelectrons from zinc when ultraviolet light falls on it ☐

D The interference pattern formed in Young's double slit experiment ☐

(1)

(i) Which of the following characteristics of the photoelectric effect **cannot** be explained by the wave theory of light?

Tick (✓) **one** box.

- **A** The rate of transfer of energy from light to the metal surface is proportional to the intensity of the light. ☐
- **B** Increasing the intensity of light above the threshold frequency increases the rate of emission of photoelectrons. ☐
- **C** Increasing the intensity of light below the threshold frequency does not result in the emission of photoelectrons. ☐
- **D** The intensity of the light can be varied independently of its frequency. ☐

(1)

(j) Which of the following can be explained **only** by the wave nature of electromagnetic radiation?

Tick (✓) **one** box.

- **A** atomic line spectra ☐
- **B** electron diffraction ☐
- **C** photoelectric effect ☐
- **D** X-ray diffraction ☐

(1)

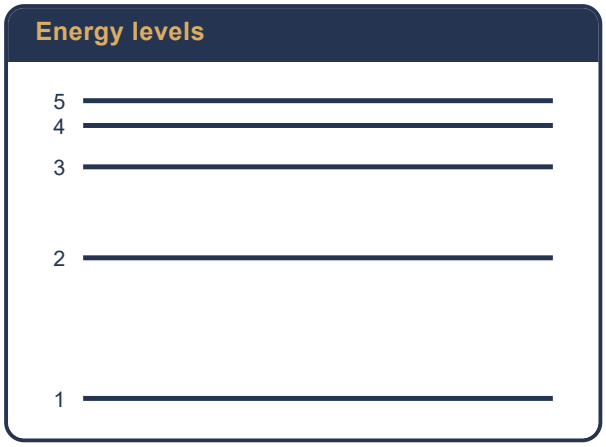
(k) The wave and particle models have both contributed to our understanding of light. Which row correctly matches properties of light to the model that best explains them?

Tick (✓) **one** box.

- **A** Wave: photoelectric effect · Particle: refraction ☐
- **B** Wave: diffraction · Particle: atomic line spectra ☐
- **C** Wave: atomic line spectra · Particle: photoelectric effect ☐
- **D** Wave: refraction · Particle: diffraction ☐

(1)

(l) The diagram shows five energy levels in an atom. Electromagnetic radiation is incident on the atom.



Which transition would be caused by the absorption of the **lowest** frequency of radiation?

Tick (✓) **one** box.

A 1 to 5 ☐ **B** 1 to 2 ☐ **C** 4 to 5 ☐ **D** 5 to 4 ☐

(1)

Total for this question: 12 marks

2 Question 2

4 marks

(a) Some radio signals have a frequency of 218.6 MHz. Calculate their wavelength.

Wavelength = _____ **m**

(2)

(b) State what is meant by:

(b) (i) frequency

(1)

(ii) wavelength.

(1)

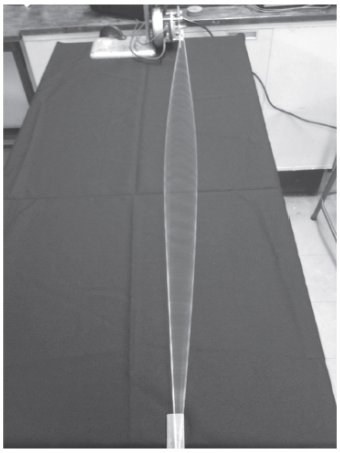
Total for this question: 4 marks

3 Question 3

14 marks

A student investigates the effect of changing the frequency of waves on a string held in tension. The string is fixed at one end and has a vibration generator attached to the other end. When the vibration generator is switched on, the wave shown in the photograph is produced.

The string



***(a)** Name the type of wave produced on the string and explain how it has been formed.

> Your answer should be clear and logically organised, using technical wording where appropriate.

(4)

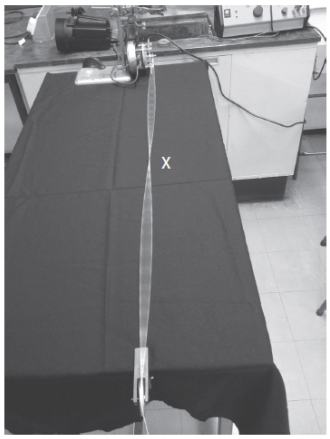
(b) The length of string between the vibration generator and the fixed end is 1.8 m. The string vibrates with a frequency of 330 Hz. Calculate the speed of the waves on the string.

Speed of the waves = _____ **m s^{-1}**

(3)

(c) The frequency of the vibration generator is changed from 330 Hz. The new wave on the string is shown.

The new wave



(c) (i) The student is able to touch the string at point X without disturbing the pattern. Explain why.

(2)

(ii) Calculate the new frequency of the vibration generator.

Frequency = _____ **Hz**

(1)

(iii) The vibrating string is now lit by a strobe lamp, without changing the frequency of the vibration generator. The lamp flashes at a frequency the student can vary. A section of the string now appears as two separate strands.

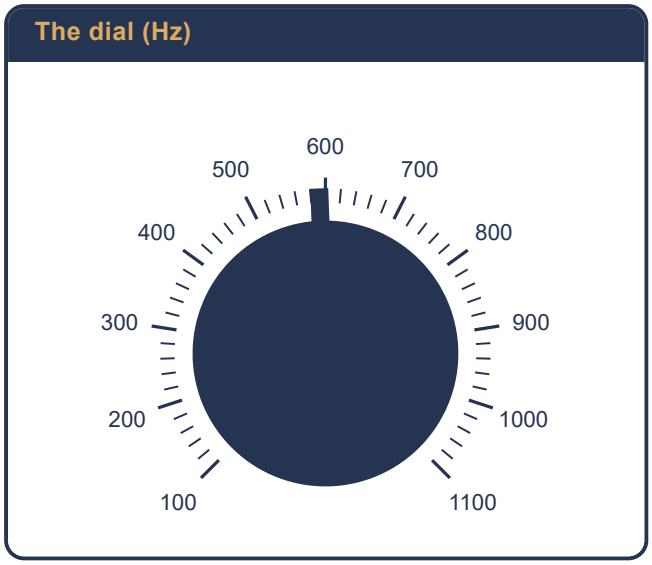
Under the strobe lamp



Calculate the maximum possible frequency of the strobe lamp that will cause the appearance of two separate strands, and explain why this is a maximum.

(2)

(d) The frequency of the vibration generator is adjusted by turning the dial shown. The student measures the frequency by reading from the scale on the dial.



Explain a disadvantage of this method of measuring the frequency.

(2)

Total for this question: 14 marks

4 Question 4

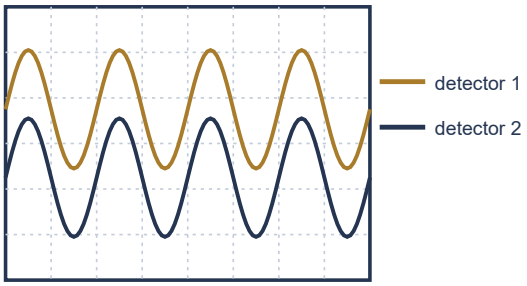
7 marks

An ultrasound source and two ultrasound detectors are set up as shown. The detectors are connected to an oscilloscope, and photograph 1 shows the traces recorded.

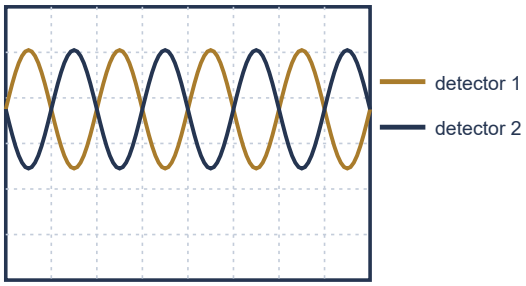
The arrangement



Photograph 1



Photograph 2

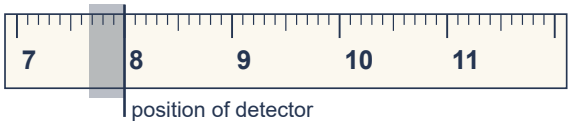


(a) Detector 2 is moved slightly further away from the source, and photograph 2 shows the traces now recorded. Explain the change in the traces between photograph 1 and photograph 2.

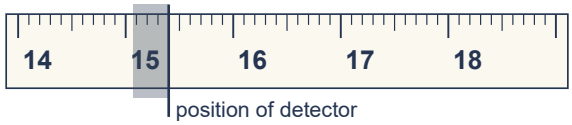
(3)

(b) Detector 2 is moved back alongside detector 1. It is then moved steadily away from the source. The traces in photograph 2 then photograph 1 are seen alternately, until **nine** such cycles have been seen. The detector moves along a metre rule: its initial and final positions are shown in photographs 3 and 4.

Photograph 3: start



Photograph 4: finish



Calculate, using the results of this experiment, the speed of sound in air. Frequency of ultrasound = 40.0 kHz.

Speed of sound in air = _____ **m s^{-1}**

(4)

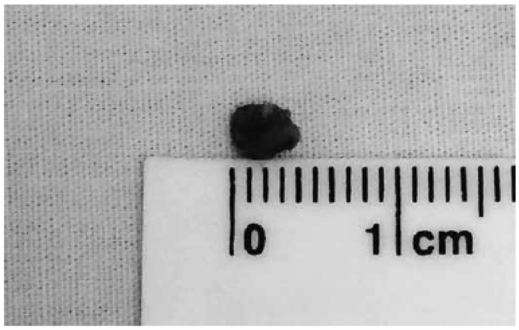
Total for this question: 7 marks

5 Question 5

4 marks

Kidney stones can form from the deposit of minerals in a human kidney. The photograph shows a kidney stone removed from a patient. It was detected using pulses of ultrasound of frequency 2.5 MHz.

The kidney stone



Justify whether this was a suitable frequency for detecting this kidney stone.

speed of sound in body tissue = 1500 m s^{-1}

(4)

Total for this question: 4 marks

6 Question 6

4 marks

A small camera uses a thin converging lens to focus images onto a light-sensitive detector inside the camera. When the camera focuses on a distant scene, the distance from the lens to the detector is 4.0 cm.

(a) Calculate the power of the lens in dioptres.

Power = _____ **D**

(1)

(b) The camera focuses on objects at different distances by changing the distance between the lens and the detector. How far must the lens be able to move if it can focus on objects at any distance between 2.0 m and infinity?

Distance the lens moves = _____ **mm**

(3)

Total for this question: 4 marks

7 Question 7

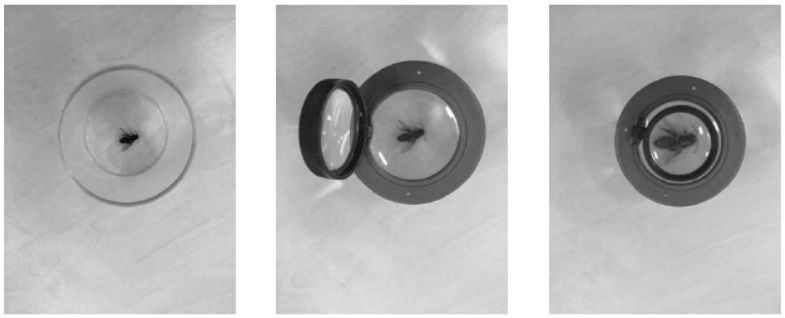
3 marks

A child's nature observation kit is used for looking at small creatures such as flies. The lid has a built-in lens, and an optional extra lens increases the magnification. The photographs show a fly with no lens, with one lens and with both lenses.

The kit



No lens, one lens, both lenses



A student measures the focal length of each lens and of the two lenses together.

Lens	Focal length / cm
Lens in the lid	12
Optional lens	17.5
Both lenses together	7.0

A fly is 5.0 cm from the combined lenses. Calculate the magnification produced by the two lenses together.

Magnification = _____

(3)

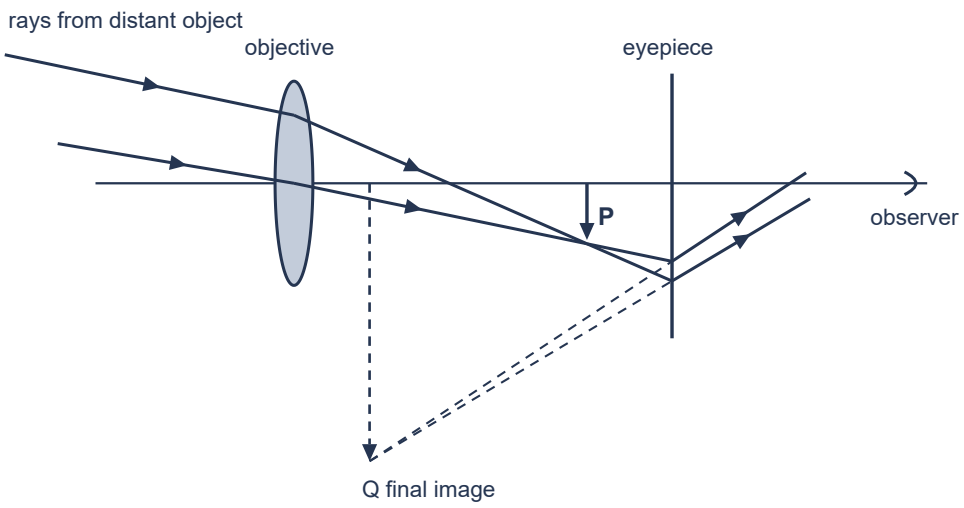
Total for this question: 3 marks

8 Question 8

2 marks

A telescope consists of a converging lens (the objective) of power 0.820 D and a second lens (the eyepiece). The objective produces an image at P. This image becomes the object for the eyepiece, which produces a final image at Q.

The telescope (not to scale)



Show that the focal length of the objective lens is about 1200 mm.

(2)

Total for this question: 2 marks

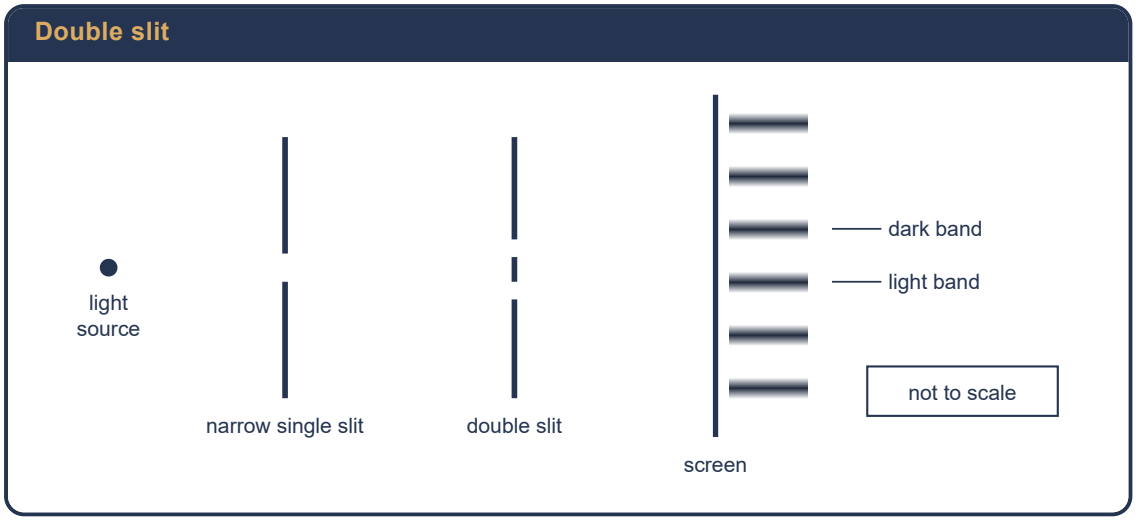
9 Question 9

8 marks

(a) State what is meant by the principle of superposition of waves.

(2)

(b) The arrangement shown demonstrates superposition. When a monochromatic light source is used, a series of dark and light bands is formed on the screen.



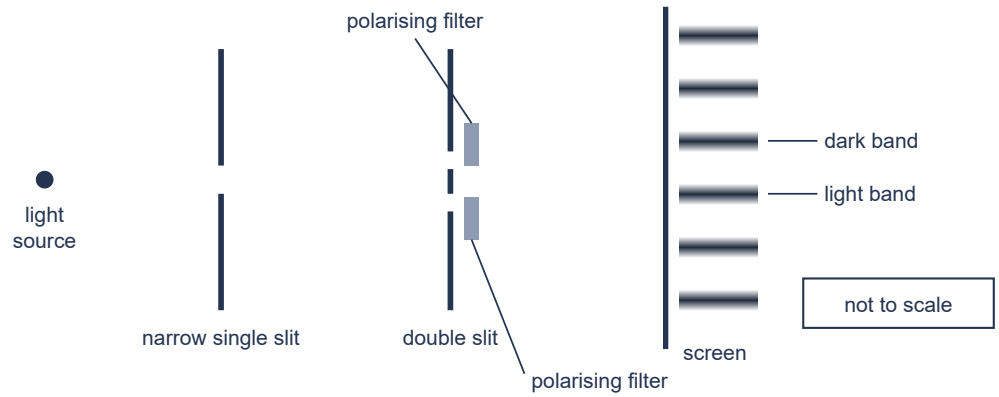
(b) (i) * Explain how the dark and light bands are formed by light reaching the screen from the two slits.

> Your answer should be clear and logically organised, using technical wording where appropriate.

(3)

(ii) Polarising filters are placed behind the slits, as shown. When their planes of polarisation are parallel, the bands are still seen. If one filter is rotated through 90°, there are no dark bands and the screen is lit evenly.

Double slit with polarising filters



Explain why there are no dark bands when one filter has its plane of polarisation at 90° to the other.

(3)

Total for this question: 8 marks

10 Question 10

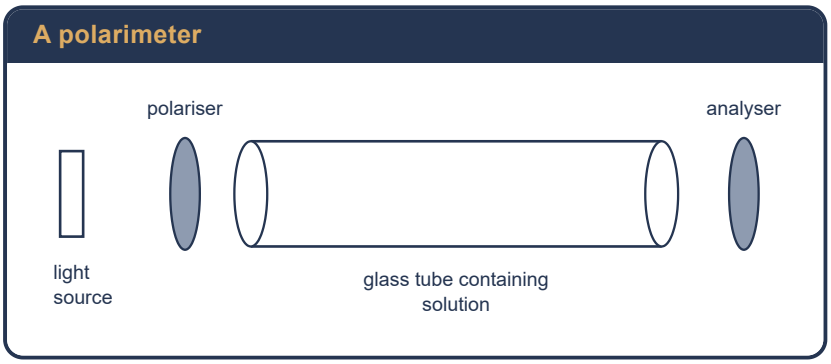
15 marks

Some solutions rotate the plane of polarisation of polarised light. The amount of rotation depends on the concentration of the solution. A polarimeter finds the concentration by measuring how much the plane of polarisation has been rotated.

(a) Describe what is meant by the plane of polarisation of polarised light.

(2)

(b) The diagram shows the parts of a polarimeter. The polariser and analyser are both polarising filters.



To find the concentration of a solution:

1. The polarimeter is set up with no solution present. Light from the source is polarised by the polariser.
2. The analyser is rotated until light from the source can no longer be seen.
3. The solution is placed in the tube between the polariser and the analyser.
4. The analyser is rotated until light from the source is again no longer seen.
5. The angle through which the analyser was rotated in step 4 is measured.

(b) (i) Explain why light from the source can no longer be seen in step 2.

(2)

(ii) For one solution the angle measured in step 5 is 55°. Explain why the plane of polarisation may have been rotated by more than 55°, and suggest another possible angle of rotation.

Possible angle of rotation = _____ °

(3)

(iii) The experiment would give the same results if the analyser were set for **maximum** intensity in steps 2 and 4. Suggest the advantage of rotating the analyser until no light is seen.

(2)

(c) A sodium lamp is often used as the light source, because its two bright spectral lines at 589.0 nm and 589.6 nm make it effectively monochromatic. Explain how the spectral lines are created with specific wavelengths.

(6)

Total for this question: 15 marks

11 Question 11

10 marks

When food is cooked in a microwave oven, microwave radiation is absorbed by water molecules, increasing the internal energy of the food.

(a) The photograph shows a microwave leakage detector. It is held next to the oven to check that no microwave radiation is leaking. Suggest why microwave radiation leaking to the surroundings could be dangerous to people.

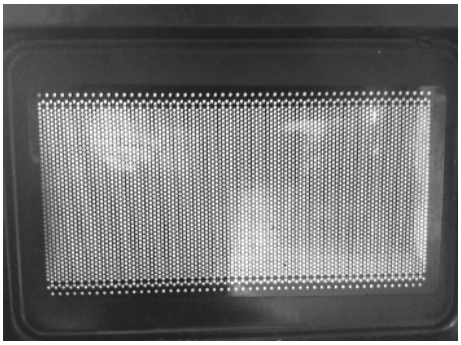
Leakage detector



(2)

(b) The inside walls of the oven are solid metal. The door is two sheets of glass with a layer of metal between them. The metal has many small holes, so the food can be seen while it cooks without exposing the user to dangerous microwaves. It has been suggested that, because of diffraction, light can pass through the holes but microwaves cannot.

The oven door



(b) (i) Explain what is meant by diffraction.

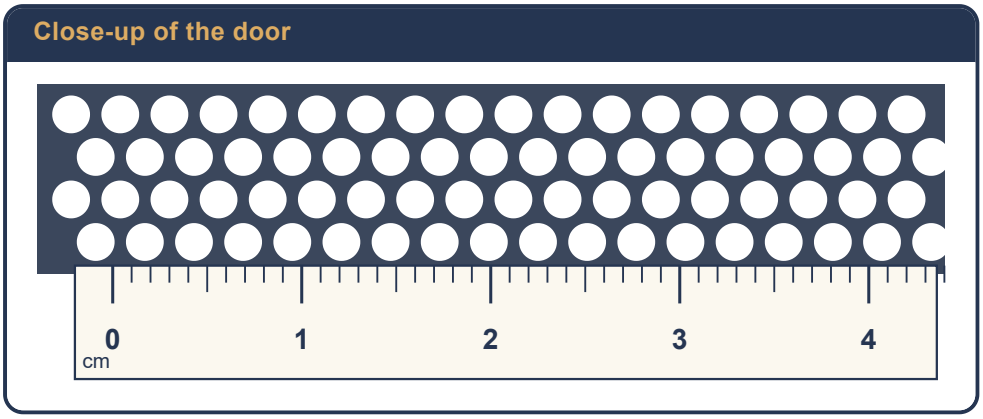
(2)

(ii) Calculate the wavelength of the microwave radiation used in the oven. Microwave frequency = 2.5 GHz.

Wavelength = _____ **m**

(2)

(iii) The picture shows a close-up of the door next to a ruler. Use it to determine the diameter of the holes.



Diameter = _____ **mm**

(1)

(iv) * Discuss the suggestion that, because of diffraction, light can pass through the holes but microwaves cannot.

> Your answer should be clear and logically organised, using technical wording where appropriate.

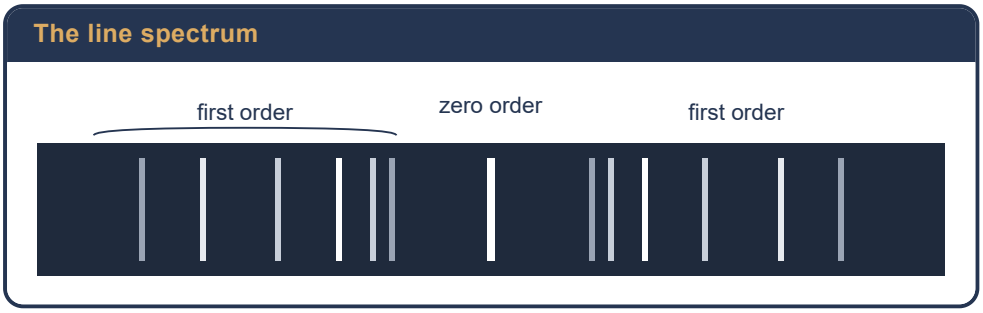
(3)

Total for this question: 10 marks

12 Question 12

5 marks

In a spectrometer, light from a tube of hot gas passes through a diffraction grating. The diagram shows the zero order and the first-order maxima of the line spectrum produced.



(a) One of the lines has a wavelength of 650 nm. It is seen in the first-order spectrum at an angle of 19.9° from the zero order. Calculate the number of lines per metre of the diffraction grating.

Number of lines per metre = _____ m^{-1}

(3)

(b) Explain one precaution that could be taken to make the measurement of the angle more accurate.

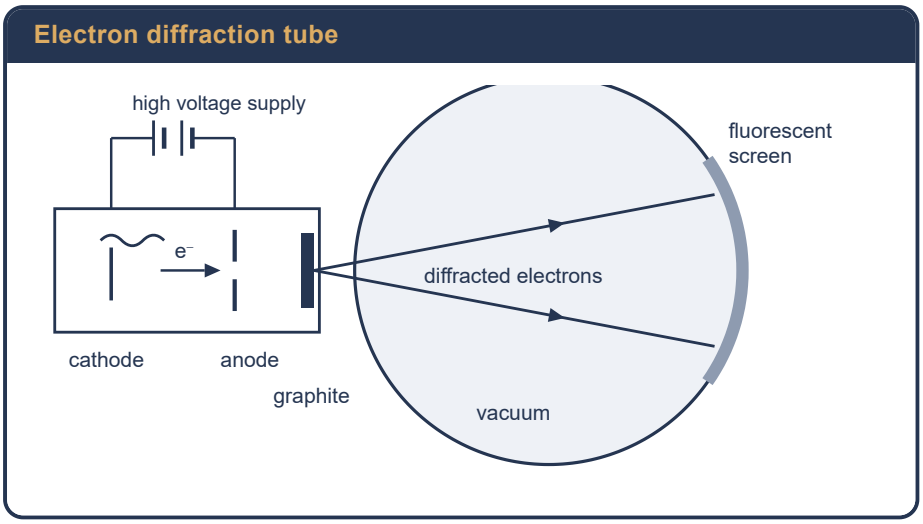
(2)

Total for this question: 5 marks

13 Question 13

4 marks

The diagram shows an arrangement used to demonstrate the diffraction of electrons.



(a) Sketch and describe the pattern seen on the fluorescent screen.

(2)

(b) State and explain how the pattern would change if the accelerating voltage were increased.

(2)

Total for this question: 4 marks

14 Question 14

6 marks

Experiments on the photoelectric effect show that:

• the kinetic energy of the photoelectrons released depends on the frequency of the incident light, not on its intensity
• light below a certain threshold frequency cannot release photoelectrons.

How do these conclusions support a particle theory, but not a wave theory, of light?

(6)

Total for this question: 6 marks

15 Question 15

9 marks

The table gives the photoelectric work functions of several metals.

Metal	Work function / eV
Potassium	2.2
Zinc	4.2
Iron	4.5
Silver	4.7

Planck constant $h = 6.6 \times 10^{-34}$ J s charge on an electron $e = 1.6 \times 10^{-19}$ C $c = 3.0 \times 10^{8}$ m s^{-1}

(a) Explain what is meant by the work function.

(1)

(b) Convert the work function of zinc to joules.

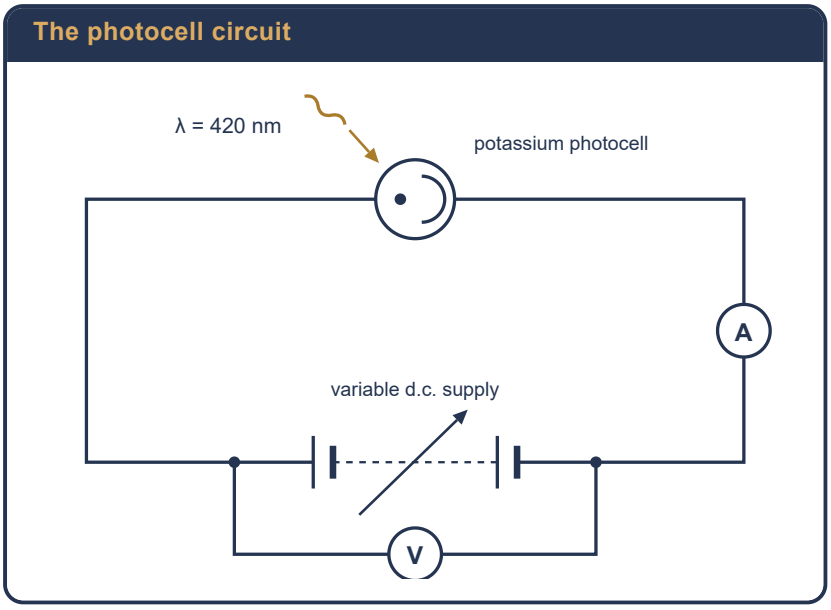
Work function of zinc = _____ **J**

(1)

(c) Which of the metals has the highest threshold frequency? Explain your answer.

(2)

(d) The diagram shows an arrangement used to measure the stopping voltage for a photocell. This cell uses potassium as the emitter and is lit by violet light of wavelength 420 nm.



(d) (i) Calculate the energy of a photon of this light. Give your answer in both J and eV.

Energy = _____ **J**

Energy = _____ **eV**

(2)

(ii) Calculate the maximum kinetic energy of the photoelectrons emitted from the potassium.

Maximum kinetic energy = _____ **eV**

(2)

(iii) Calculate the stopping voltage for this experiment.

Stopping voltage = _____ **V**

(1)

Total for this question: 9 marks

16 Question 16

5 marks

The energy of the *n*th level of the hydrogen atom is given by the equation $E_n = -13.6 \text{ eV} \div n^2$

(a) Calculate the energies of the $n = 1$ and $n = 3$ levels.

$E_1 =$ _____ **eV**

$E_3 =$ _____ **eV**

(2)

(b) Calculate the wavelength of the spectral line emitted by hydrogen when electrons fall from the $n = 3$ level to the $n = 1$ level.

Wavelength = _____ **m**

(3)

Total for this question: 5 marks

END OF TEST

Now mark your answers using the mark scheme that follows.

MARK SCHEME

Waves and the Particle Nature of Light · Topic Test

[1] in the Mark column means one mark for that line.

accept / allow notes (gold) are other answers that also score.

reject / do not accept notes (red) are answers that do not.

1 Question 1 — mark scheme

Multiple choice · 12 marks

PART	ANSWER	MARK
(a)	**C** 50 Hz KEY EQUATION $f = 1 \div T$ one cycle = 4 divisions = 20 ms	1
(b)	**C** N, N, N *Both fixed ends and the crossing point in the middle have zero amplitude: all three are nodes.*	1
(c)	**D** shorter pulses *Shorter pulses separate echoes from close-together boundaries. A, B and C all mean a longer wavelength, which gives less detail.*	1
(d)	**A** *The ray from the object through A leaves the lens parallel to the axis, so A is the focal point.*	1
(e)	**C** X 180° clockwise, Y 90° anticlockwise *Their planes end up 270° (≡ 90°) further apart, so they are now parallel. In A, B and D they are still crossed.*	1
(f)	**A** *Diffraction is greatest when the gap is about the same size as the wavelength. Doorways are close to the wavelength of sound.*	1
(g)	**A** diffraction	1
(h)	**C** the photoelectric effect *A shows electrons behaving as waves; B and D show light behaving as a wave.*	1
(i)	**C** KEY EQUATION $hf = \varphi + \frac{1}{2}mv^2_{max}$ below threshold, one photon never has enough energy	1
(j)	**D** X-ray diffraction *B is about electrons, not electromagnetic radiation. A and C need photons.*	1
(k)	**B** wave: diffraction; particle: atomic line spectra	1

(l)	**C** 4 to 5 KEY EQUATION $\Delta E = hf$ the smallest gap going **up** *D is the same gap, but going down is emission.*	1

Total: 12 marks

2 Question 2 — mark scheme — 4 marks

PART	ANSWER	MARK
(a)	Use of $c = f\lambda$ with $c = 3.00 \times 10^8$ m s^{-1} KEY EQUATION $v = f\lambda$	1
	$\lambda = 1.37$ m *$3.00 \times 10^8 \div 2.186 \times 10^8 = 1.37$ m*	1
(b)(i)	Frequency: the number of oscillations / vibrations / cycles / waves per second (or in unit time) *do not accept 1 ÷ period unless period is defined* *accept number of wavelengths per second*	1
(ii)	Wavelength: the distance travelled during one complete oscillation / cycle **or** the shortest distance between two points in phase **or** the distance between identical points on adjacent waves *accept distance between adjacent peaks / crests / troughs* *reject just "distance between peaks" or "length of a wave"*	1

Total: 4 marks

3 Question 3 — mark scheme — 14 marks

PART	ANSWER	MARK
***(a)**	A standing / stationary wave *QWC: clear, logically organised answer using technical wording*	1
	Waves from the generator are reflected at the fixed end **or** waves travel in both directions KEY EQUATION **superposition:** $y = y_1 + y_2$	1
	The two waves meet and <u>superpose</u>	1
	Producing points where the waves are in phase and points where they are in antiphase **or** points of zero and maximum amplitude **or** nodes and antinodes	1

(b)	Wavelength = 2 × 1.8 m (= 3.6 m) KEY EQUATION $v = f\lambda$ one loop is half a wavelength	1
	Use of speed = wavelength × frequency	1
	Speed = 1200 m s^{-1} *330 × 3.6 = 1188 m s^{-1}*	1
(c)(i)	X is a node, so it has zero amplitude / the string isn't moving there	1
	So no energy is absorbed by the finger **or** the waves carry on after superposing	1
(ii)	660 Hz *two loops in the same length: wavelength halved, so frequency doubled (330 × 2)*	1
(iii)	The string is caught twice per cycle (at both extremes): 2 × 660 = 1320 Hz *allow error carried forward from (c)(ii)*	1
	Any faster and the string would be caught at points other than its maximum displacement	1
(d)	The scale divisions are 20 Hz **or** the pointer is wide **or** the dial only shows the nominal output	1
	So the reading lacks precision (scale) **or** lacks accuracy (output)	1

Total: 14 marks

4 Question 4 — mark scheme — 7 marks

PART	ANSWER	MARK
(a)	At first the waves are in phase	1
	As detector 2 moves there is a path difference	1
	They are in antiphase in photograph 2 because the detector has moved half a wavelength (or an odd number of half wavelengths) KEY EQUATION **path difference = $(n + \frac{1}{2})\lambda$** antiphase	1
(b)	Distance moved = 15.4 − 8.0 = 7.4 cm KEY EQUATION $v = f\lambda$	1
	Wavelength = 7.4 cm ÷ 9 (= 0.822 cm)	1
	Use of $v = f\lambda$	1

	v = 329 m s^{-1} *40 000 × 0.00822 = 329 m s^{-1}*	1

Total: 7 marks

5 Question 5 — mark scheme — 4 marks

PART	ANSWER	MARK
	Use of $v = f\lambda$ KEY EQUATION $v = f\lambda$	1
	$\lambda = 6 \times 10^{-4}$ m (0.6 mm) *1500 ÷ 2.5 × 10^6 = 6.0 × 10^{-4} m*	1
	Stone is about 4 mm across (from the photograph)	1
	Suitable: the wavelength is much less than (less than half) the size of the stone, so the resolution is good enough	1

Total: 4 marks

6 Question 6 — mark scheme — 4 marks

PART	ANSWER	MARK
(a)	$P = 1 \div 0.040 = 25$ D KEY EQUATION $P = 1 \div f$ f in metres *reject 0.25: the focal length was left in cm*	1
(b)	Correct use of the lens equation with $f = 0.040$ m KEY EQUATION $1/u + 1/v = 1/f$	1
	Image distance for an object at 2.0 m: $v = 0.0408$ m *1/v = 25 − 0.5 = 24.5*	1
	Lens moves 0.0408 − 0.0400 = 0.0008 m (0.8 mm) *PWK correction: the school scheme used 1.5 m (giving 1 mm). The question says 2.0 m.*	1

Total: 4 marks

7 Question 7 — mark scheme — 3 marks

PART	ANSWER	MARK
	Use of $1/u + 1/v = 1/f$ KEY EQUATION **$1/u + 1/v = 1/f$** real is positive *1/v = 1/7.0 − 1/5.0 so v = −17.5 cm (a virtual image)*	1
	Use of magnification = $v \div u$ KEY EQUATION **$m = v \div u$**	1
	Magnification = 3.5 *17.5 ÷ 5.0 = 3.5*	1

Total: 3 marks

8 Question 8 — mark scheme — 2 marks

PART	ANSWER	MARK
	Use of $P = 1 \div f$ KEY EQUATION **$P = 1 \div f$**	1
	$f = 1 \div 0.820 = 1.22$ m = 1220 mm *accept 122 cm. A "show that" needs more figures than the 1200 given.*	1

Total: 2 marks

9 Question 9 — mark scheme — 8 marks

PART	ANSWER	MARK
(a)	Two or more waves meet (at a point)	1
	The resultant displacement is the sum of the individual displacements	1
***(b)(i)**	In phase (path difference $n\lambda$): constructive interference / superposition KEY EQUATION **path difference = $n\lambda$ (bright) $(n + ½)\lambda$ (dark)** *QWC: clear, logically organised answer using technical wording*	1
	In antiphase (path difference $(n + ½)\lambda$): destructive interference / superposition	1
	A light band forms where they arrive in phase, **or** a dark band forms where they arrive in antiphase	1
(ii)	The oscillations of the light from the two filters are now perpendicular to each other	1

	So there are no opposite components to cancel each other out **or** the waves do not interfere	1
	So zero amplitude is not possible *Or, if the source is taken as polarised: one filter is crossed with it and absorbs the light, so light reaches the screen from one slit only, so there is no interference and no zero amplitude. Same 3 marks.*	1

Total: 8 marks

10 Question 10 — mark scheme — 15 marks

PART	ANSWER	MARK
(a)	Polarised light has all its oscillations in a single plane: that is the plane of polarisation	1
	The plane includes the direction the light is travelling	1
(b)(i)	The analyser is at 90° to the polariser KEY EQUATION $I = I_0 \cos^2 \theta$ θ = 90° gives zero	1
	So the light is absorbed *accept the converse argument about transmission*	1
(ii)	If the plane is rotated by an extra multiple of 180°, it is the same plane again	1
	So the analyser is again at 90° to it and the light is absorbed again	1
	A suitable angle, e.g. 235° or 415° *55° + 180° = 235°*	1
(iii)	Near maximum, the intensity hardly changes as you turn, **or** it is easier to judge when no light is seen than when it is brightest	1
	So using maximum intensity gives a greater (percentage) uncertainty in the angle	1
(c)	Electrons / atoms have discrete (specific) energy levels KEY EQUATION $E = hf = hc \div \lambda$ photon energy = difference between two levels	1
	Electrons are excited / move to higher levels	1
	Electrons fall (de-excite) to lower levels	1
	They emit the energy as photons, with energy equal to the difference between the levels	1
	Photon energy = *hf* **or** *hc* ÷ λ	1

	Only specific energy differences are possible, so only specific wavelengths / frequencies are emitted	1

Total: 15 marks

11 Question 11 — mark scheme — 10 marks

PART	ANSWER	MARK
(a)	The human body contains water molecules **or** the body is like the food	1
	So cells / tissues would gain internal energy (be heated)	1
(b)(i)	Waves spread out	1
	After passing through a gap **or** around an obstacle	1
(ii)	Use of $c = f\lambda$ with $c = 3.0 \times 10^8$ m s^{-1} KEY EQUATION $v = f\lambda$	1
	$\lambda = 0.12$ m *$3.0 \times 10^8 \div 2.5 \times 10^9 = 0.12$ m*	1
(iii)	Diameter = 2 mm	1
*(iv)	Diffraction is greatest when the wavelength is about the same as the gap size *QWC: clear, logically organised answer using technical wording*	1
	The holes are much bigger than the wavelength of light **and** smaller than the microwave wavelength	1
	So there is little diffraction of light (it passes straight through) **or** the microwaves are diffracted through a large angle but their intensity is very small *this point must follow on from the relevant part of the one above*	1

Total: 10 marks

12 Question 12 — mark scheme — 5 marks

PART	ANSWER	MARK
(a)	Use of $n\lambda = d \sin\theta$ KEY EQUATION $n\lambda = d \sin\theta$	1
	Use of lines per metre = $1 \div d$	1
	520 000 lines per metre (5.2×10^5 m^{-1}) *$d = 650 \times 10^{-9} \div \sin 19.9° = 1.91 \times 10^{-6}$ m; $1 \div d = 5.2 \times 10^5$*	1

(b)	Measure the angle to the first order on both sides and divide by 2	1
	So any zero error is eliminated *Or: measure a larger angle (e.g. a higher order), so the percentage uncertainty is smaller. Same 2 marks.*	1

Total: 5 marks

13 Question 13 — mark scheme — 4 marks

PART	ANSWER	MARK
(a)	Sketch: concentric rings with a bright spot in the centre *the sketch must be labelled* 	1
	Bright rings are where the diffracted electrons interfere constructively, dark rings where they interfere destructively	1
(b)	The rings get closer together (smaller radius) KEY EQUATION $\lambda = h \div p$ faster electrons, more momentum, shorter wavelength	1
	Because the electrons' de Broglie wavelength has decreased	1

Total: 4 marks

14 Question 14 — mark scheme — 6 marks

PART	ANSWER	MARK

Any 6 of these points, 1 mark each:

KEY EQUATION $hf = \varphi + \frac{1}{2}mv^2_{max}$ one photon, one electron

- Particle theory: $E = hf$, so light comes in packets (photons)
- One photon releases one electron, giving it kinetic energy
- Increase f and the electrons have more kinetic energy
- Lower f: eventually the kinetic energy would be zero, so no electrons are released (the threshold)
- Wave theory: the energy depends on intensity (amplitude²)
- So more intense light should give more kinetic energy: this is **not** seen
- More intense light gives more electrons, but no change in the maximum kinetic energy
- Waves are continuous, so once enough energy is absorbed electrons should be released at any frequency: this is **not** seen
- Compares the effect of frequency with the kinetic energy

Total: 6 marks

15 Question 15 — mark scheme — 9 marks

PART	ANSWER	MARK
(a)	The minimum energy needed to remove an electron from the surface of a metal	1
(b)	6.7×10^{-19} J *$4.2 \times 1.6 \times 10^{-19} = 6.72 \times 10^{-19}$ J. Accept the answer without working.*	1
(c)	Silver	1
	It needs the most energy to remove an electron, and a photon's energy is hf, so it needs the highest frequency KEY EQUATION $\varphi = hf_0$ *the explanation must refer to photon energy*	1
(d)(i)	Use of $E = hc \div \lambda$: 4.71×10^{-19} J KEY EQUATION $E = hf = hc \div \lambda$ *$6.6 \times 10^{-34} \times 3.0 \times 10^{8} \div 420 \times 10^{-9}$. Working must be shown for 2 marks.*	1
	2.95 eV *$4.71 \times 10^{-19} \div 1.6 \times 10^{-19}$*	1

(ii)	Use of $KE_{max} = hf - \varphi$ KEY EQUATION $hf = \varphi + \frac{1}{2}mv^2_{max}$	1
	0.75 eV (or 1.2×10^{-19} J) *2.95 − 2.2 = 0.75 eV. Working must be shown for 2 marks.*	1
(iii)	0.75 V KEY EQUATION $eV_s = KE_{max}$	1

Total: 9 marks

16 Question 16 — mark scheme — 5 marks

PART	ANSWER	MARK
(a)	$n = 1$: $E = -13.6$ eV *ignore signs*	1
	$n = 3$: $E = -1.51$ eV *−13.6 ÷ 9*	1
(b)	Energy difference = 12.1 eV KEY EQUATION $E = hc \div \lambda$	1
	Use of $E = hc \div \lambda$ (after converting to joules)	1
	$\lambda = 1.0 \times 10^{-7}$ m *$12.09 \times 1.6 \times 10^{-19} = 1.93 \times 10^{-18}$ J; $\lambda = 6.6 \times 10^{-34} \times 3.0 \times 10^{8} \div 1.93 \times 10^{-18} = 1.02 \times 10^{-7}$ m*	1

Total: 5 marks

END OF MARK SCHEME