Young's double slit experiment is set up by students in a laboratory as shown in Figure 2. Monochromatic light is shone onto the slits which are placed at a large distance from the screen. The intensity pattern produced on the screen is a pattern of light and dark bands.

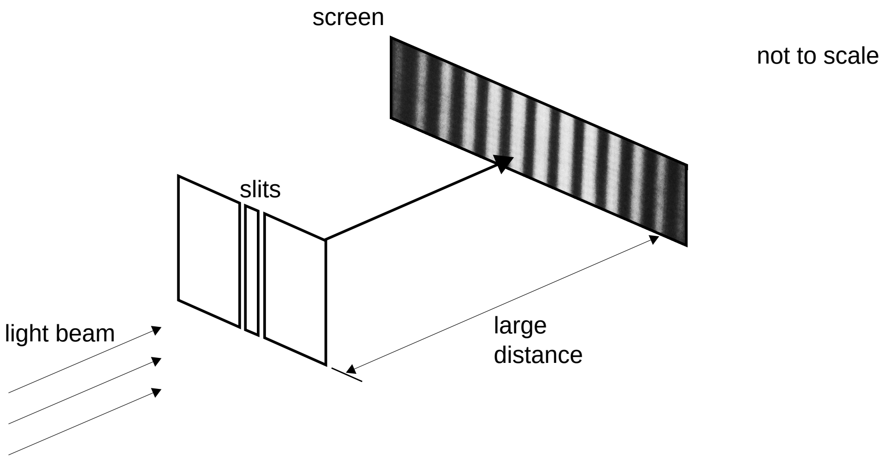


Figure 2

The students then wonder what will happen if the light used is white light rather than monochromatic light. All the students agree that there will be bands of colour on the screen, but have different opinions about the centre band. Pat expects a white band in the centre while Robyn believes a coloured band will be produced.

Question 5

Select which of the students is correct and justify your answer in the space below.

Pat / Robyn

3 marks

Question 11

In the space below describe how the wave-particle duality of electrons can be used to explain the quantised energy levels of the atom.

3 marks

Working space

END OF SECTION A
TURN OVER

Area of study 2 – Interactions of light and matter

Question 2

The table below contains some predictions for the behaviour of light incident on a shiny metal sheet. Complete the table by placing a 'Y' (Yes) or 'N' (No) in the appropriate boxes if the prediction is supported by the wave **and/or** particle model of light. Some answers have already been provided. It is possible for predictions to be supported by both models.

Prediction	Wave model	Particle model
The number of photoelectrons produced is proportional to the intensity of the incident beam.	Y	
Light of low intensity will give rise to the emission of photoelectrons later than light of high intensity.		N
Light of high intensity will produce photoelectrons with a greater maximum kinetic energy than light of low intensity.	Y	
Light of sufficient intensity of any frequency should produce the photoelectric effect.	Y	

4 marks

Figure 2 shows the energy levels of a sodium atom.

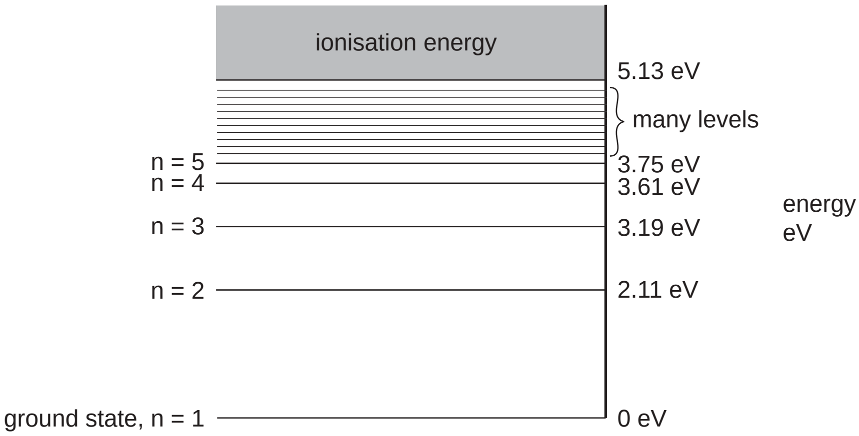


Figure 2

Figure 2 shows that electrons in a sodium atom can only occupy specific energy levels.

Question 6

Describe how the wave nature of electrons can explain this.

2 marks

In an experiment, monochromatic laser light of wavelength 600 nm shines through a narrow slit, and the intensity of the transmitted light is recorded on the screen some distance away as shown in Figure 2a. The intensity pattern seen on the screen is shown in Figure 2b.

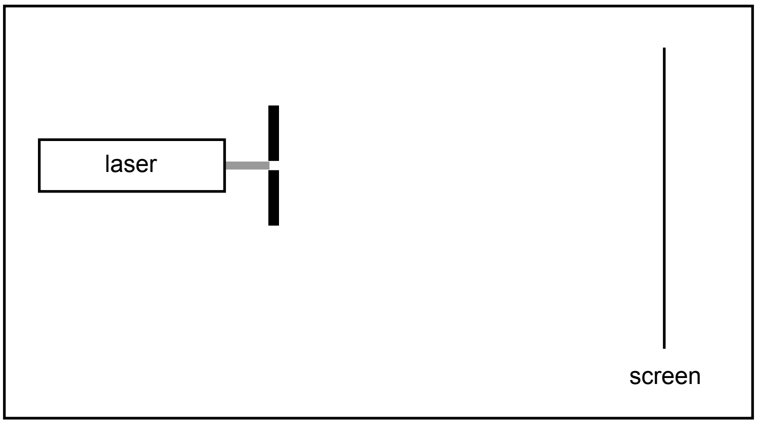


Figure 2a

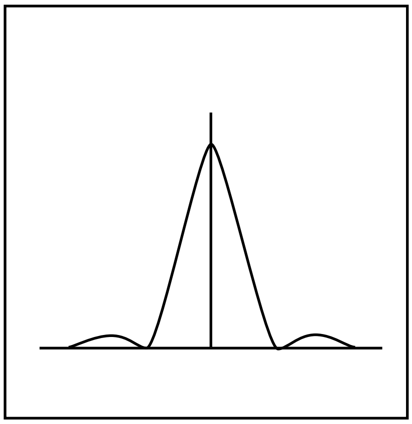
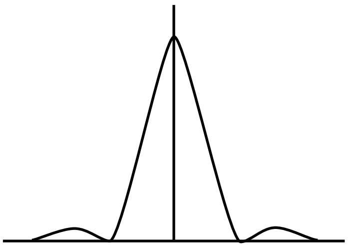


Figure 2b

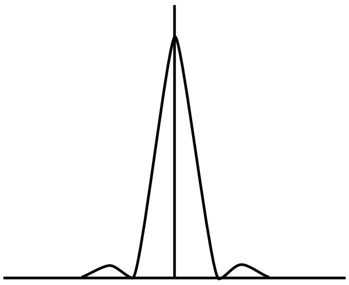
Question 6

Which one of the intensity patterns **(A–D)** below best indicates the pattern that would be seen if a wider slit was used?

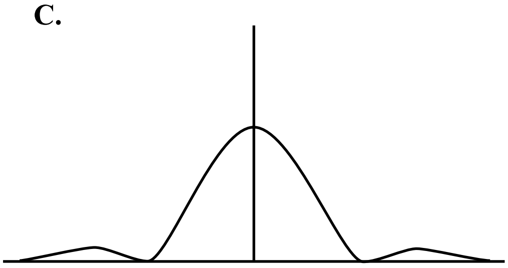
A.



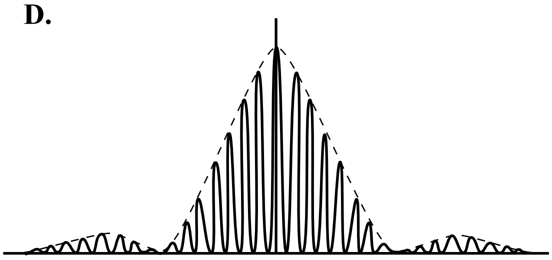
B.



C.



D.



2 marks

Figure 5a shows part of the emission spectrum of hydrogen in more detail.

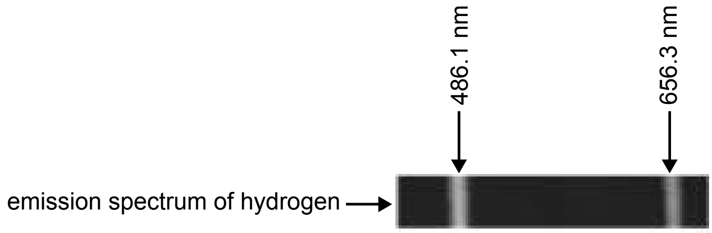


Figure 5a

With a spectroscope, Val examines the spectrum of light from the sun. The spectrum is continuous, with colours ranging from red to violet. However there were black lines in the spectrum, as shown in Figure 5b.

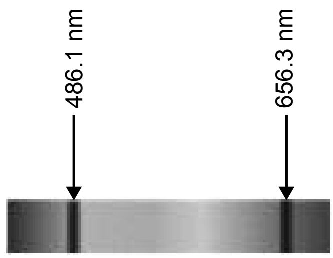


Figure 5b

Question 9

Explain why these dark lines are present in the spectrum from the sun.

3 marks

Use the following information to answer Questions 3–5.

A group of students is studying Young's double slit experiment using microwaves (λ = 3.0 cm) instead of light.

A microwave detector is moved along the line PQ, and the maxima and minima in microwave intensity are recorded.

The experimental apparatus is shown in Figure 1.

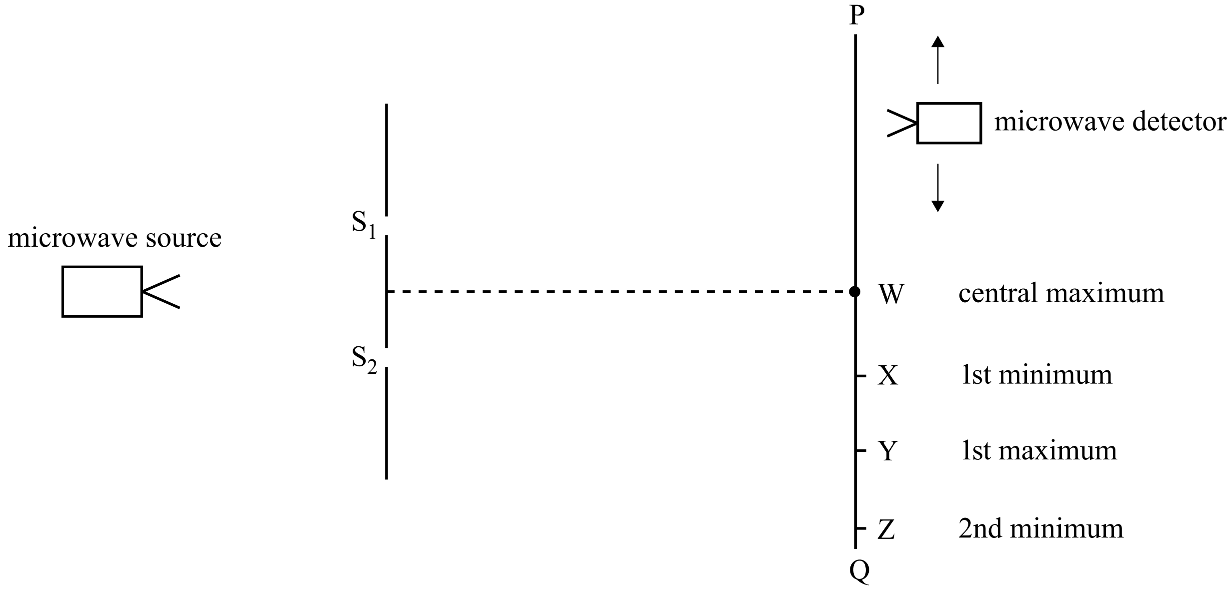


Figure 1

Question 4

Explain why there is a maximum in microwave intensity detected at point Y.

2 marks

Area of study 2 – Interactions of light and matter

Question 1

At the time of Young's double-slit experiment there were two competing models of the nature of light.

Explain how Young's experiment supported one of these models compared with the other.

3 marks

Question 2

Einstein's explanation of the photoelectric effect reopened the question about the nature of light.

Explain briefly how the results of the photoelectric effect experiment supported a competing model to the one supported by Young's experiment.

3 marks

The following information relates to Questions 3 and 4.

Louise and Thelma set up the apparatus shown in Figure 1. It consists of a laser providing light of a single wavelength, which passes through two narrow slits and produces a pattern of bright and dark bands on a screen some distance away.

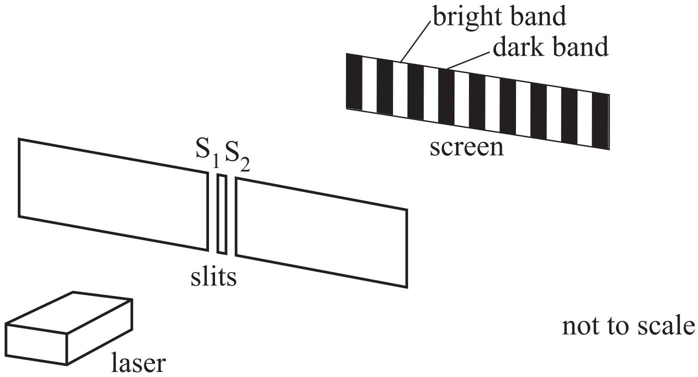


Figure 1

Question 3

Before doing the experiment, Louise believes that the central band (the one exactly opposite the centre point between the two slits) is a dark band. Thelma believes that this is a bright band.

Who is correct? Outline your reasoning clearly.

3 marks

The following information relates to Questions 5–7.

The photoelectric effect occurs when photons falling on a metal surface cause the emission of electrons. Einstein's equation for the photoelectric effect can be written as follows.

$$E_{K\,max} = hf - W$$

Kristy and Adrian have set up an experiment to study the energy of photoelectrons emitted from a potassium plate. Their apparatus consists of

- a light source
- a set of filters, each of which allows through only one wavelength
- an evacuated tube containing a potassium plate onto which the light falls, and a collector electrode.

A variable DC source allows a voltage (stopping voltage) to be applied between the potassium plate and the collector electrode. A voltmeter (V_s) measures this voltage, and a microammeter (A) reads the current.

Their apparatus is shown in Figure 3.

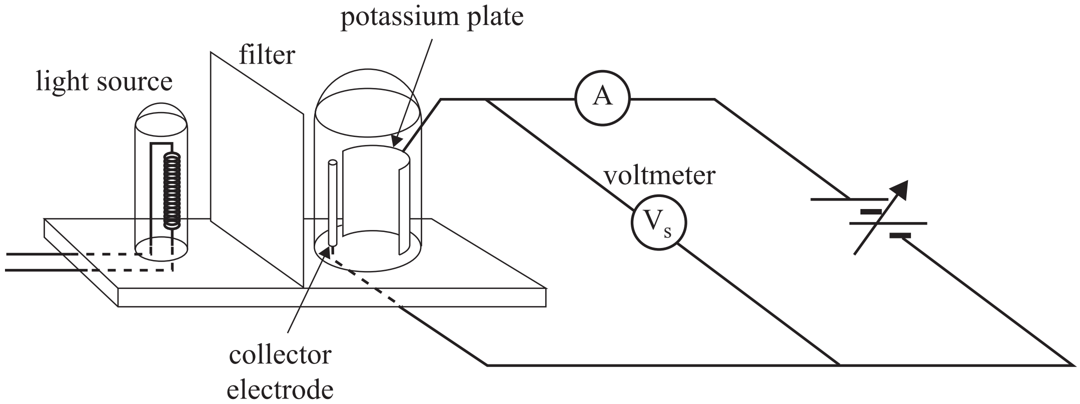


Figure 3

Question 5

Explain **in words** the physical meaning of the terms $E_{K\,max}$, f, and W in the equation above. Your explanation must show how each term relates to the experiment in Figure 3.

$E_{K\,max}$

f

W

3 marks

Area of study 2 – Interactions of light and matter

Question 1

Over the last few centuries, scientists have proposed two conflicting models to explain the nature of light.

- the wave model
- the particle model

Name a historical experiment that supports the wave model rather than the particle model. Explain how the experiment supports the wave model rather than the particle model.

3 marks

The photoelectric effect experiment supports the particle model of light rather than the wave model of light.

The following are observed in a photoelectric effect experiment.

Observation 1: The number of emitted electrons (the photocurrent) depends on the intensity of the incident light.

Observation 2: The energy of emitted electrons depends only on the frequency of the incident light and is independent of the intensity.

Observation 3: The energy of the emitted electrons depends on the metal surface involved.

The particle model can account for all the above three observations.

The wave model can explain two of these observations but not a third.

Question 2

Select the observation that the wave model **cannot** explain.

Explain how the particle model satisfactorily explains this observation.

Observation number

3 marks

The following information relates to Questions 5 and 6.

Students set up the following apparatus as shown in Figure 2 to study the photoelectric effect.

They have a number of photocells with different metal plates in them.

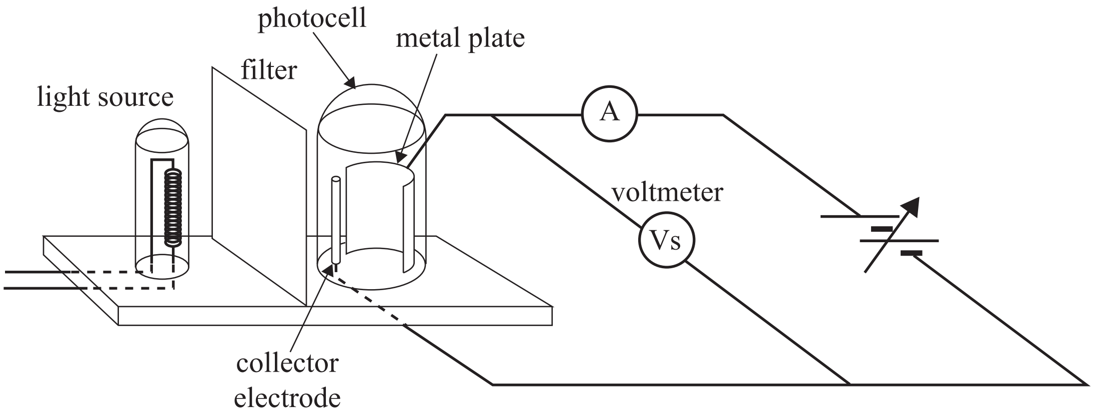


Figure 2

With a selenium plate in place, and using their data, the students draw the graph of maximum kinetic energy of photoelectrons versus frequency of light incident on the selenium plate. This is shown in Figure 3.

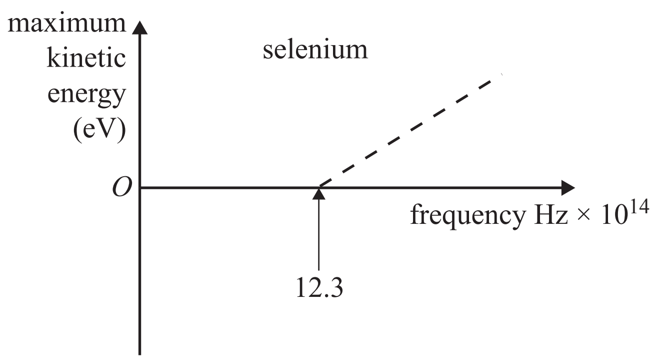


Figure 3

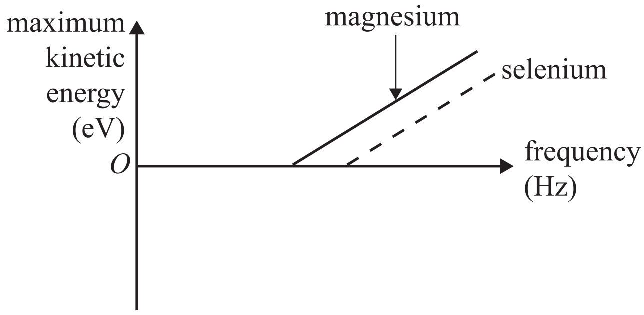
The students now use a photocell with a magnesium plate.
The work function of magnesium (3.7 eV) metal is less than that of selenium (5.1 eV).

The dotted line on each graph shows the original graph for selenium.

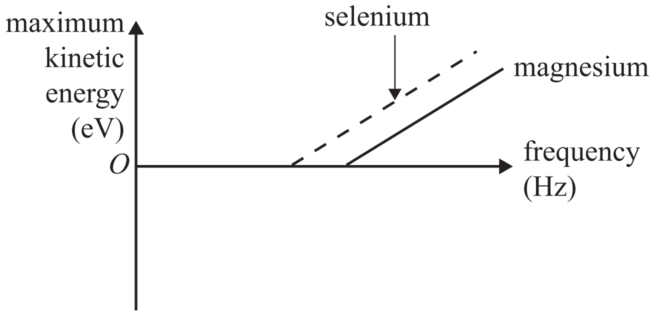
Question 6

Which one of the following graphs will now show their results? Explain your answer.

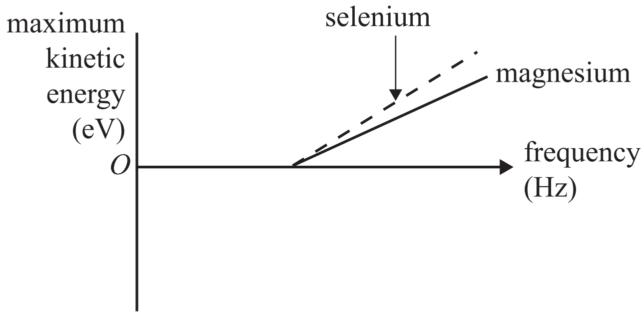
A.



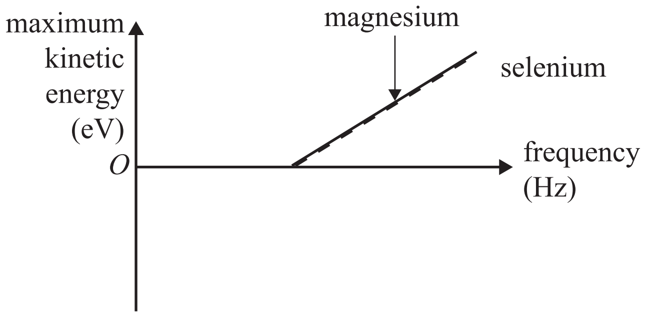
B.



C.



D.



3 marks

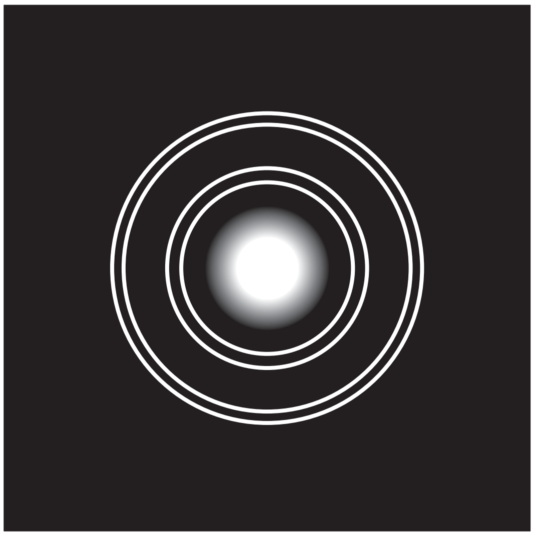
SECTION A – Area of study 2 – continued

Question 8

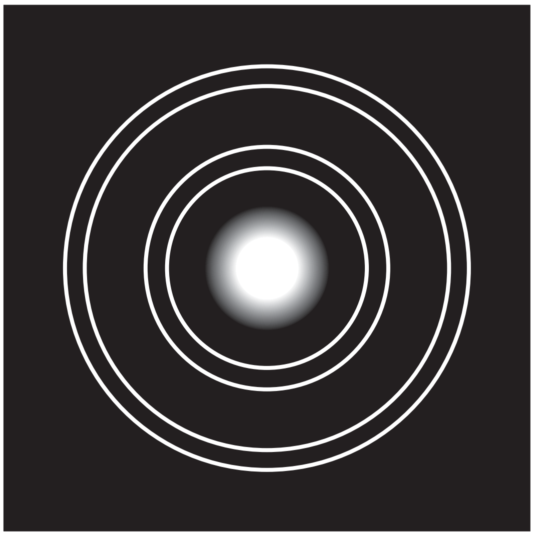
The students now increase the accelerating voltage and hence the speed of the electrons.

Which one of the options below now best shows the pattern they will observe on the screen?

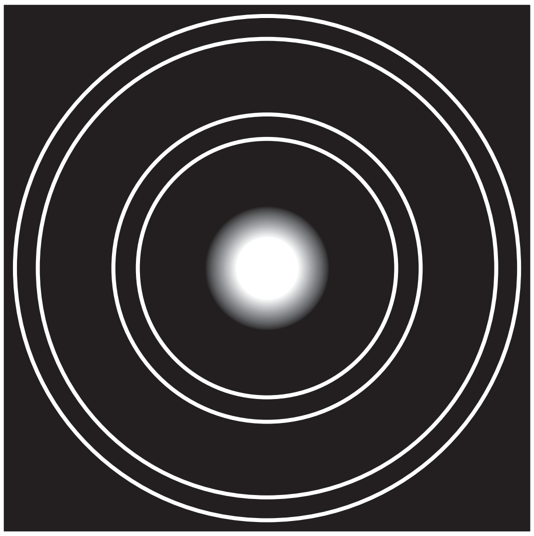
Explain your answer.



option A



option B (identical to original pattern)



option C

2 marks

Figure 5a shows the diffraction with electrons of 600 eV. The students now replace the electron gun with an X-ray source. Then they observe the pattern shown in Figure 5b below.

Figures 5a and 5b are drawn to the same scale.

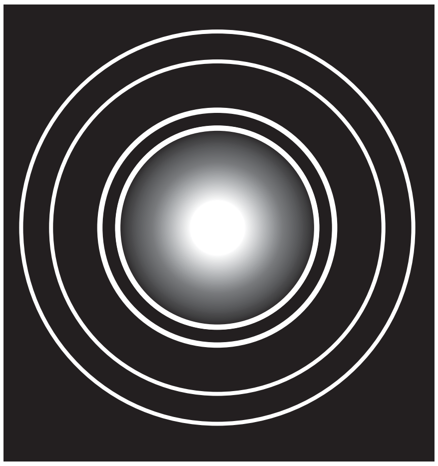


Figure 5a

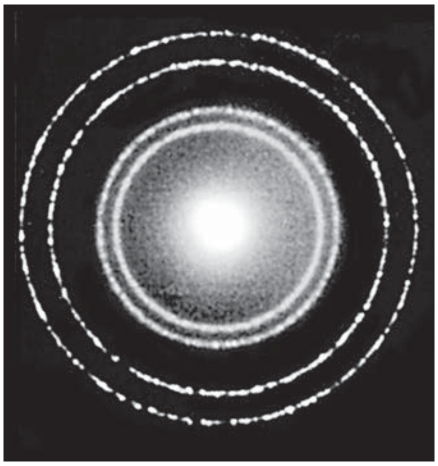


Figure 5b

Question 9

Explain why the electrons and the X-rays produce a very similar pattern.

2 marks

Use the following information to answer Questions 5–9.

Students set up the apparatus shown in Figure 2 to study the photoelectric effect.

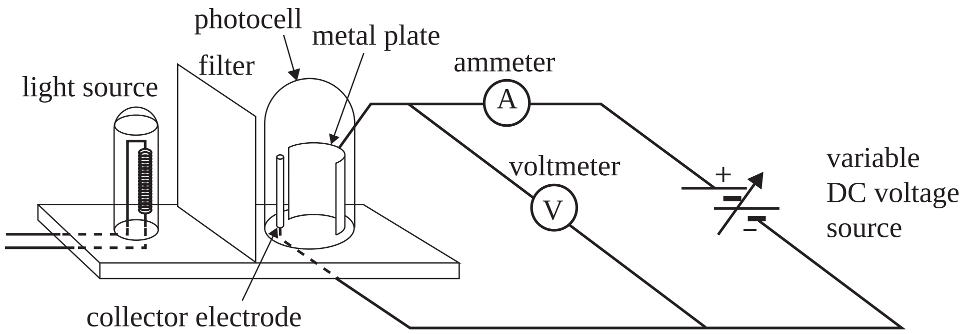


Figure 2

The apparatus consists of

- a source of white light
- a set of filters that only allow light of selected wavelengths to pass through
- a metal plate and a collector electrode enclosed in an evacuated (no air) glass case
- a voltmeter (V), ammeter (A) and variable DC voltage source in a circuit, as shown in Figure 2.

With a particular filter in place, the students gradually increase the voltage as measured by the voltmeter, V, from zero.

They plot the current measured through the ammeter, A, as a function of the voltage measured by the voltmeter, V. This is shown in Figure 3.

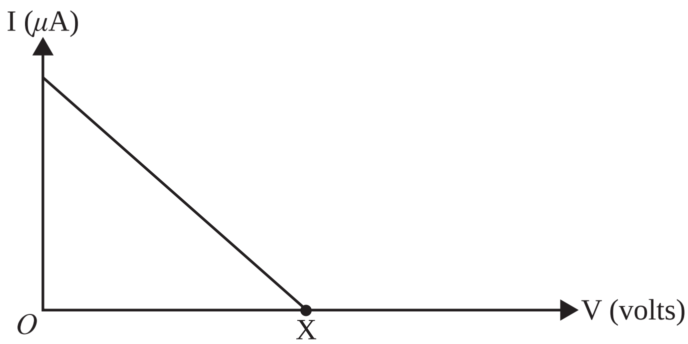


Figure 3

Question 5

Explain why the current drops to zero at point X.

2 marks

Question 4

Figure 6 shows the energy level diagram for the hydrogen atom.

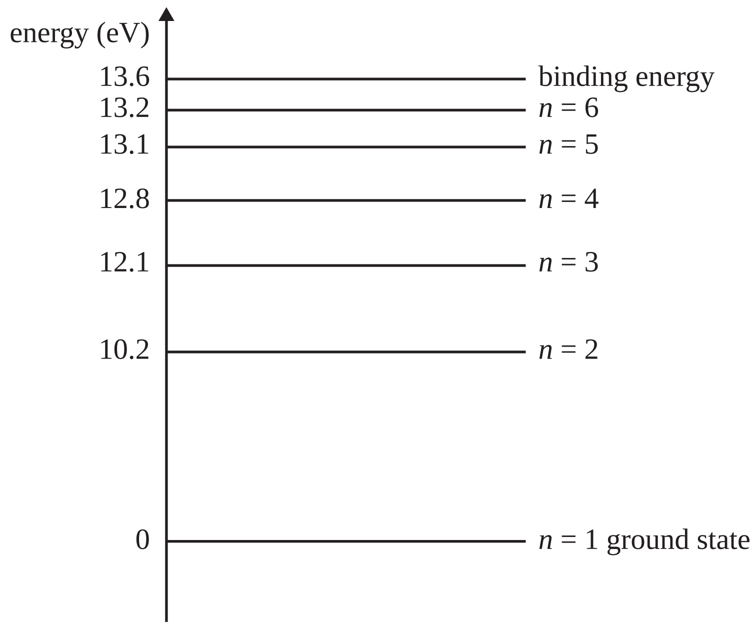


Figure 6

The energy levels of the hydrogen atom are discrete (quantised) and there are no stable levels between them.

b. In terms of the properties of the electron, explain why only certain energy levels are stable.

3 marks

END OF SECTION A
TURN OVER

Question 23 (5 marks)

Students aim X-rays with a photon energy of 80 keV at a thin metal foil. The resulting diffraction pattern is shown in Figure 29.

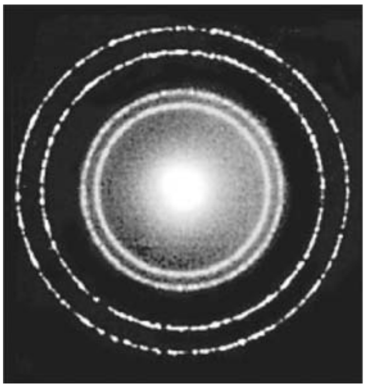


Figure 29

b. The students are aware that electrons can also be used to form diffraction patterns. They wish to use a beam of electrons to form a diffraction pattern with fringe spacings identical to those in Figure 29. Student A says that the fringe spacing will be identical if the electrons have the same momentum as the X-rays. Student B says that the fringe spacing will be identical if the electrons have the same energy as the X-rays.

Which student is correct? Explain your answer. 3 marks

END OF SECTION A

Question 20 (5 marks)

A group of students carry out an experiment where light of various frequencies is shone onto a metal plate. The maximum kinetic energy of the emitted electrons for each frequency is recorded and the results are plotted to produce the graph shown in Figure 30. Take Planck's constant as 6.63×10^{-34} J s.

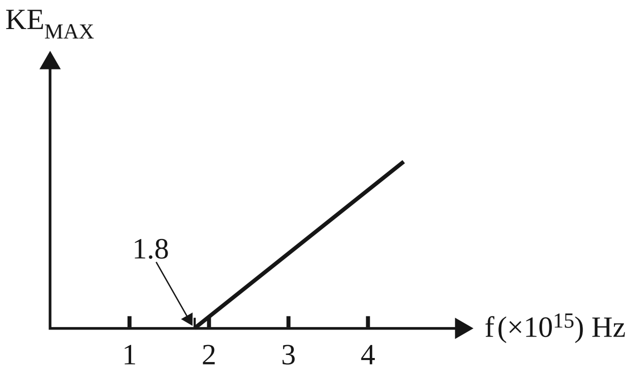


Figure 30

b. The intensity of the light is increased and the experiment is repeated with the same frequencies. The students find that the graph of frequency against maximum kinetic energy for this second experiment is exactly the same as for the first experiment.

Explain why this result provides evidence for the particle-like nature of light. 3 marks

Question 21 (8 marks)

Thuy is doing some experiments on the diffraction of photons. She is using a beam of photons with an energy of 4.1 eV.

The beam is incident on a small circular aperture and the resulting diffraction pattern is produced on a photon-sensitive screen behind the aperture. This pattern is shown in Figure 31.

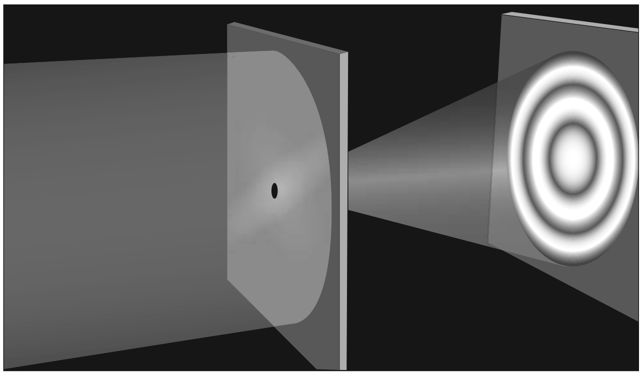


Figure 31

b. A second experiment is then performed with the same light beam incident on a circular aperture with a larger diameter.

Complete the following sentence by circling the correct words that are shown in **bold** font. 1 mark

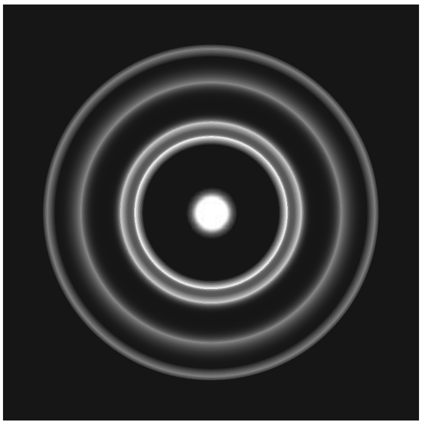
Corresponding rings in the second diffraction pattern would have diameters that are **larger than / the same size as / smaller than** the rings in the original pattern.

c. Give your reasoning for your answer to **part b.** 2 marks

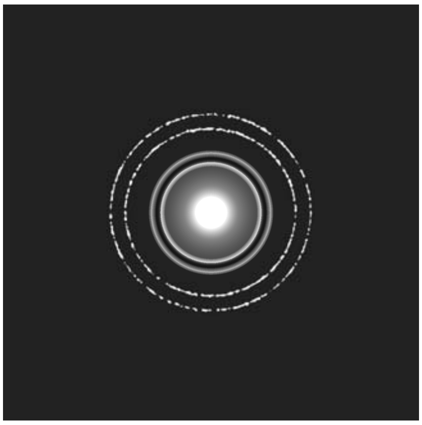
d. Thuy now carries out another experiment, comparing the diffraction of X-ray photons and electrons.

A beam of X-ray photons is incident on a small circular aperture. The experiment is then performed with a beam of electrons incident on the same aperture.

The X-ray photons and electrons have the same energy. The diffraction patterns (shown in Figure 32) have the same general shape, but very different spacings.



X-ray photon diffraction



electron diffraction

Figure 32
not to scale

Explain why the electron diffraction pattern has a different spacing from the X-ray diffraction pattern, even though the electrons and the photons have the same energy. 3 marks

Area of study – Interactions of light and matter

Question 17 (4 marks)

Two students, Karina and Kim, are investigating double-slit interference. They have a 633 nm wavelength laser and a slide with two narrow slits. They set up their experimental arrangement as shown in Figure 18 and see a pattern of alternating bright and dark bands on their screen.

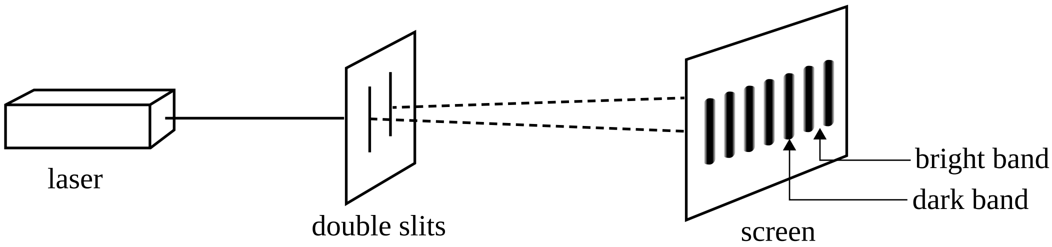


Figure 18

a. Before they put the slide in place, they direct the laser beam onto the screen and mark the bright spot due to the laser on their screen. Kim believes that this point will be a dark band when the slide is put in place. Karina believes it will be a bright band.

Is this point a bright band or a dark band? Give a reason for your choice. 3 marks

Question 20 (4 marks)

Physicists use the expression 'wave-particle duality' because light sometimes behaves like a particle and electrons sometimes behave like waves.

a. What evidence do we have that light can behave like a particle? Explain how this evidence supports a particle model of light. 2 marks

b. What evidence do we have that electrons can behave like waves? Explain how this evidence supports a wave model of electrons. 2 marks

Question 21 (5 marks)

a. Use the model of quantised states of the atom to explain why only certain energy levels are allowed. 3 marks

b. Illustrate your answer with an appropriate diagram. 2 marks

END OF SECTION A
TURN OVER

18 c. Amelia and Rajesh replace the double slits with a single slit of width *w*, as shown in Figure 23. They find that the width of the central maximum of the diffraction pattern is *y*.

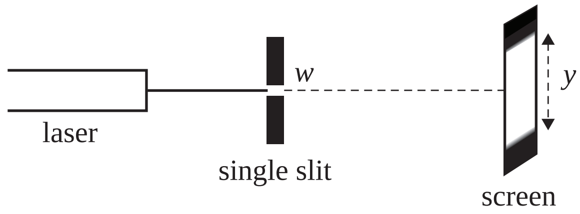


Figure 23

They replace the single slit with another single slit of width 2*w*.

Which one of the following (**A.–D.**) will Amelia and Rajesh observe in the diffraction pattern? Explain your answer. 2 marks

A. The width will be *y*, but twice the intensity.

B. The width will be *y*, but half the intensity.

C. The width will be approximately 2*y*.

D. The width will be approximately $\frac{1}{2}y$.

Question 19 (10 marks)

Emily is conducting an experiment to investigate the photoelectric effect. The apparatus is shown in Figure 24. It consists of a light source, a filter and a photocell (a metal plate with a collecting electrode in a vacuum tube).

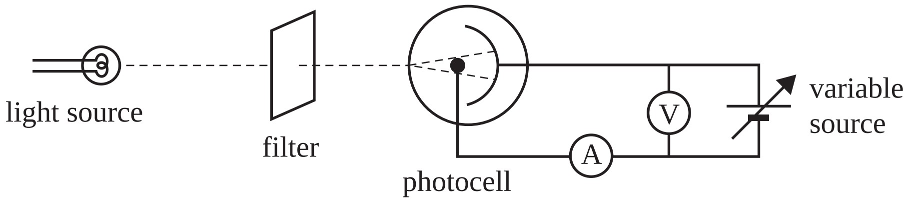


Figure 24

Emily uses various filters to shine a particular wavelength on the photocell.
She increases the voltage (V) until the current just goes to zero and records this voltage. Emily repeats this process for different frequencies.

c. Explain how the recorded voltage measurements give information about the emitted photoelectrons. 2 marks

d. For each frequency, Emily doubles the intensity of the incident light.

Describe the graph Emily will now obtain in comparison with the original graph. Do these two graphs support the wave model or particle model of light? Justify your answer. 3 marks

Area of study – Interactions of light and matter

Question 17 (7 marks)

A teacher uses a microwave set that has wavelength $\lambda = 3.0$ cm to demonstrate Young's experiment. The apparatus is shown in Figure 26.

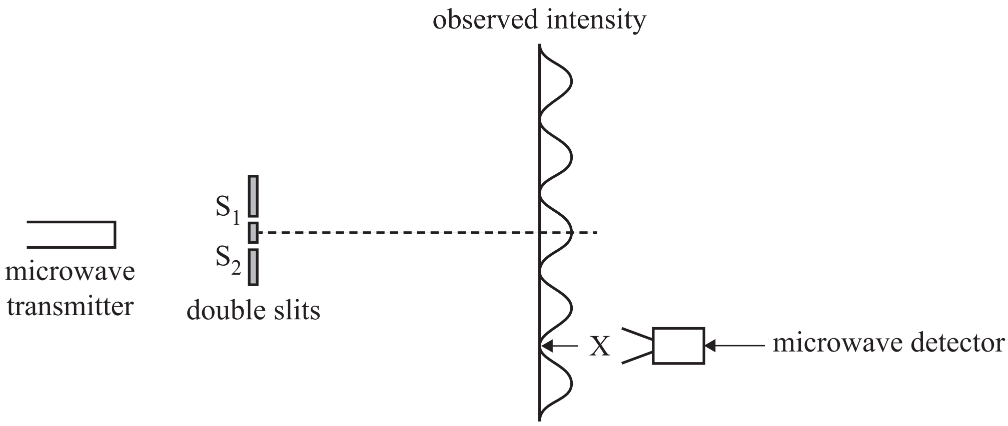


Figure 26

b. Explain the importance of Young's experiment in the development of the wave model of light. 3 marks

c. The teacher replaces the double slit with a single slit of width *w* and measures the width, *y* cm, of the diffraction pattern at point P, as shown in Figure 27.

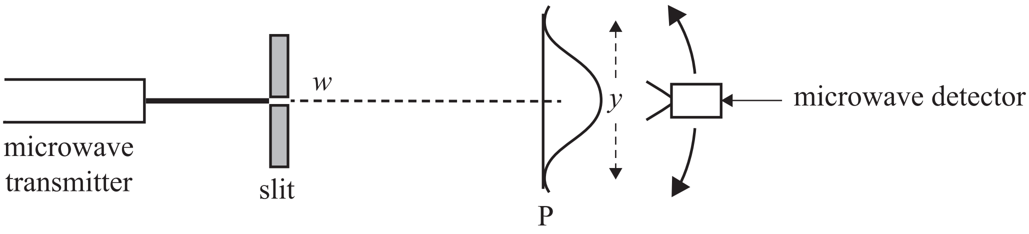


Figure 27

The microwave set has two wavelength settings: 3.0 cm and 6.0 cm. The teacher changes the setting from 3.0 cm to 6.0 cm.

Describe the effect of changing the wavelength setting on the pattern as observed. Explain your answer. 2 marks

Question 18 (11 marks)

Students set up the apparatus shown in Figure 28 to study the photoelectric effect. The apparatus consists of a light source, a filter and a photocell (a metal emitting plate on which light falls and a collecting electrode/collector, all enclosed in a vacuum tube).

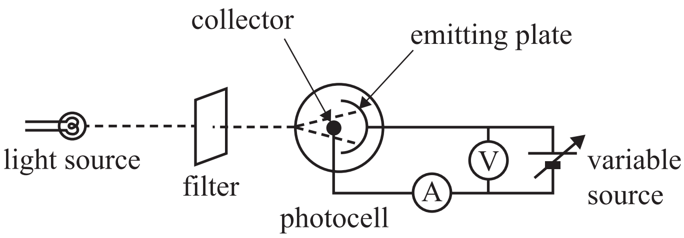


Figure 28

The students then begin the experiment with the collector negative, with respect to the emitting plate. They gradually reduce the voltage to zero and then increase it to positive values. They measure the current in ammeter A and plot the graph as shown in Figure 29.

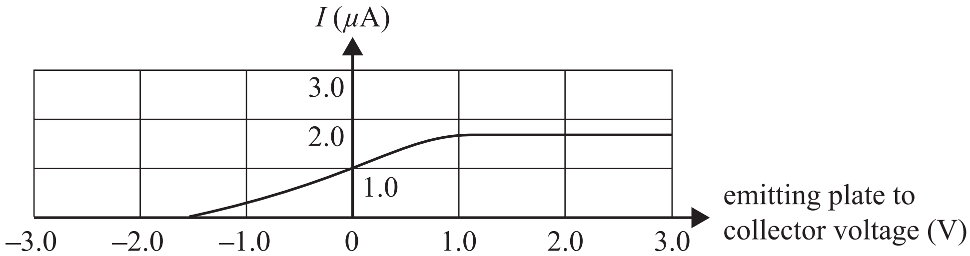


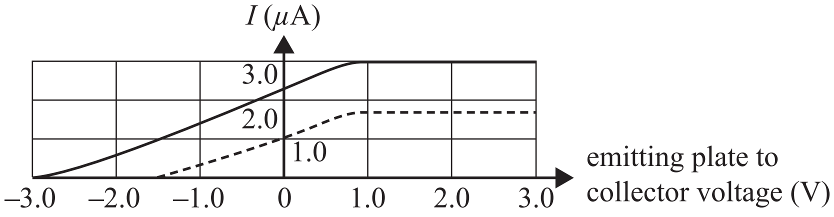
Figure 29

d. Explain why the graph in Figure 29 is a flat, straight line beyond V = +1.0 V. 2 marks

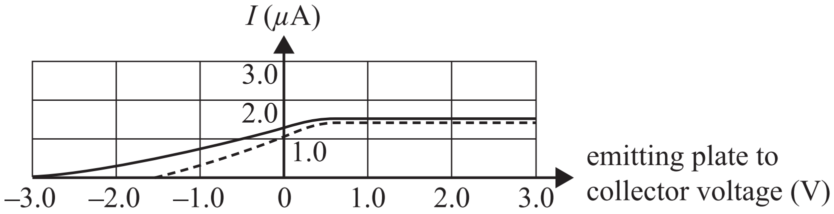
e. The students double the intensity of the light, keeping the frequency the same, and plot the results on a graph, with the original current shown as a dashed line.

Which one of the following graphs (**A.–D.**) will they now obtain? 1 mark

A.



B.



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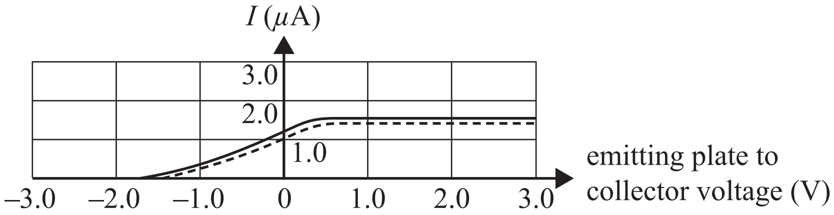

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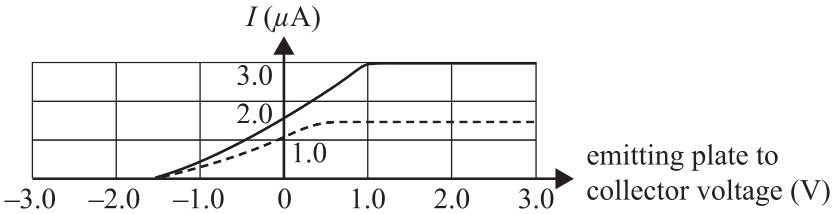


f. Explain your answer to **part e.**, with reference to the particle model and the wave model of light. 3 marks

Question 21 (4 marks)

De Broglie suggested that the quantised energy states of atoms could be explained in terms of electrons forming standing waves.

Describe how the concept of standing waves can help explain the quantised energy states of an atom. You should include a diagram.

END OF SECTION A
TURN OVER

Question 15 (7 marks)

A Physics teacher intends to demonstrate wave phenomena to her students. She takes her students to the school oval to listen to a 680 Hz sound.

The speed of sound in air is 340 m s^{-1}.

The teacher now sets up two loudspeakers placed 4 m apart with the sound in phase. Seven students are placed in a row 24 m from the loudspeakers, as shown in Figure 14. Each student is 1.5 m away from the next student.

Student 4 is in the middle and is exactly the same distance from each loudspeaker.

When a single loudspeaker is sounding, all the students hear very close to the same intensity.

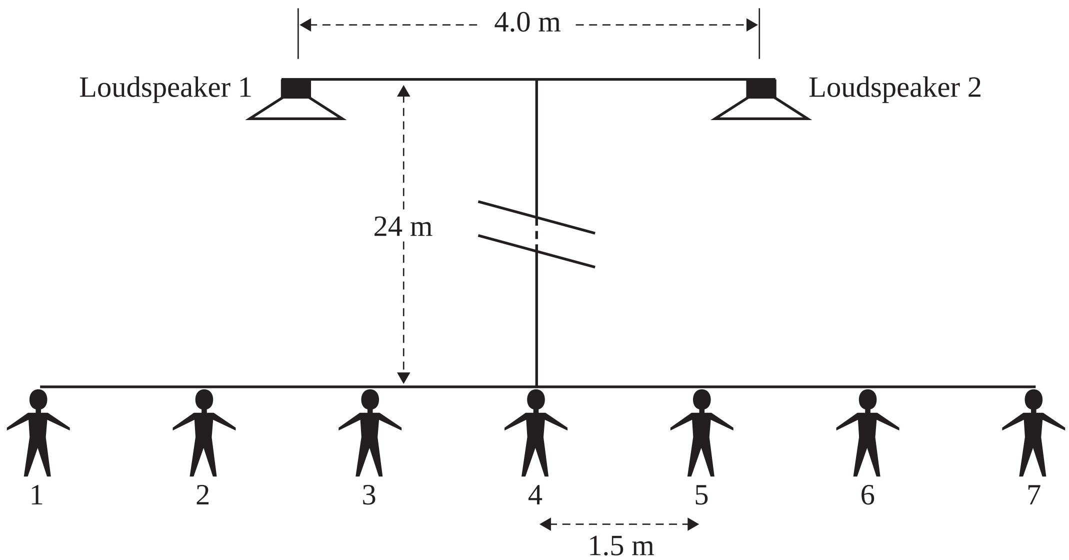


Figure 14

The teacher now connects both loudspeakers.

One student, Elli, predicts that now they will hear a similar sound of double the intensity.

Another student, Sam, disagrees. He says the intensity of the sound will depend on each student's relative distance from each speaker.

b. Evaluate Elli's and Sam's responses. 3 marks

c. Will students 2 and 5 in Figure 14 hear similar or different sound intensities? If you predict that one of these students will hear a higher sound intensity, state which student and justify your prediction. Show your working. 3 marks

16c. Explain the physics of how standing waves are formed on the string. Include a diagram in your response. 3 marks

Question 17 (9 marks)

In an experiment, blue light of frequency 6.25×10^{14} Hz is shone onto the sodium cathode of a photocell. The apparatus is shown in Figure 15.

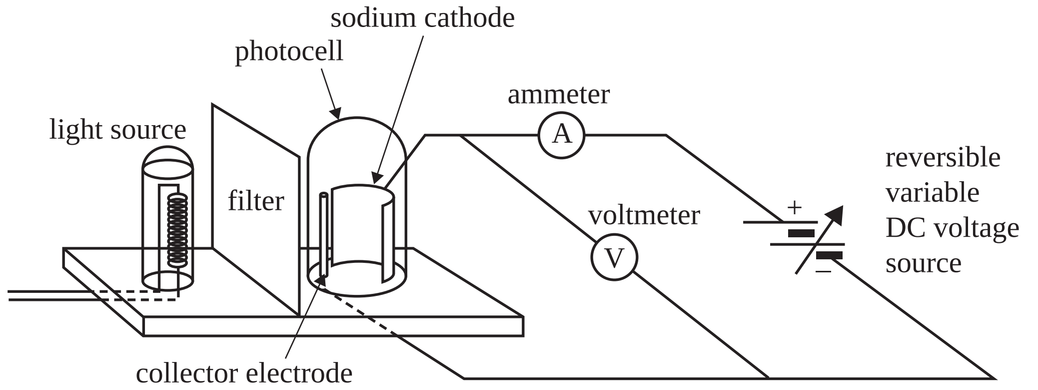


Figure 15

The graph of photoelectric current versus potential difference across the photocell is shown in Figure 16.

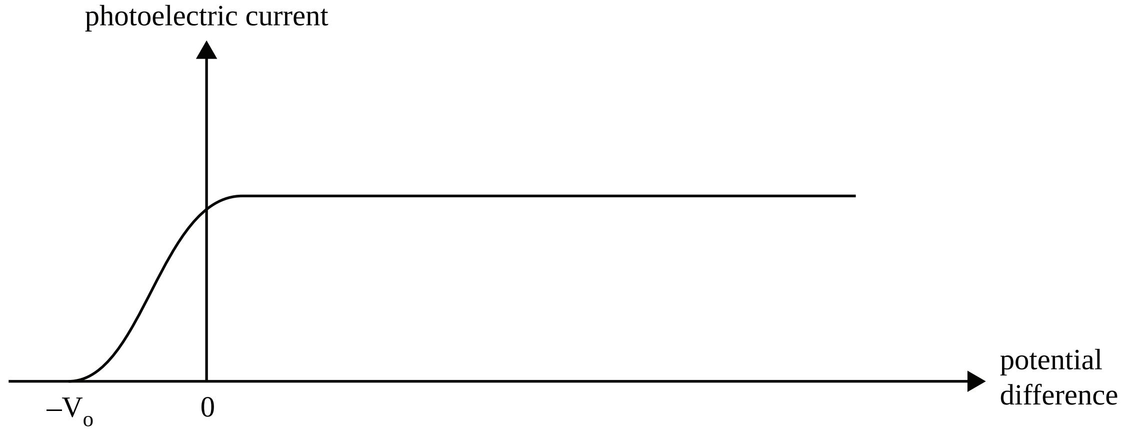


Figure 16

2 marks

b. On the graph of photoelectric current versus potential difference shown in Figure 16, sketch the curve expected if the light is changed to **ultraviolet** with a **higher intensity** than the original blue light. 2 marks

c. The results of photoelectric effect experiments in general provide strong evidence for the particle-like nature of light.
Outline **two** aspects of these results that provide the strong evidence that is not explained by the wave model of light, and explain why. 5 marks

Question 19 (4 marks)

Roger and Mary are discussing diffraction.

Mary says electrons produce a diffraction pattern.

Roger says this is impossible as diffraction is a wave phenomenon and electrons are particles; diffraction can only be observed with waves, as with electromagnetic waves, such as light and X-rays.

Evaluate Mary's and Roger's statements in light of the current understanding of light and matter. Describe **two** experiments that show the difference between Mary's and Roger's views.

END OF QUESTION AND ANSWER BOOK

Question 17 (6 marks)

The results of photoelectric effect experiments provide evidence for the particle-like nature of light.

Outline **one** aspect of the results that would provide this evidence. Your response should explain:

- why a wave model of light cannot satisfactorily explain this aspect of the results
- how the photon theory does explain this aspect of the results.

Question 18 (3 marks)

Explain how the diffraction pattern produced by a stream of electrons passing through a narrow slit can illustrate Heisenberg's uncertainty principle.

END OF QUESTION AND ANSWER BOOK

Question 19 (4 marks)

Figure 19 shows the spectrum of light emitted from a hydrogen vapour lamp.

The spectral line, indicated by the arrow on Figure 19, is in the visible region of the spectrum.

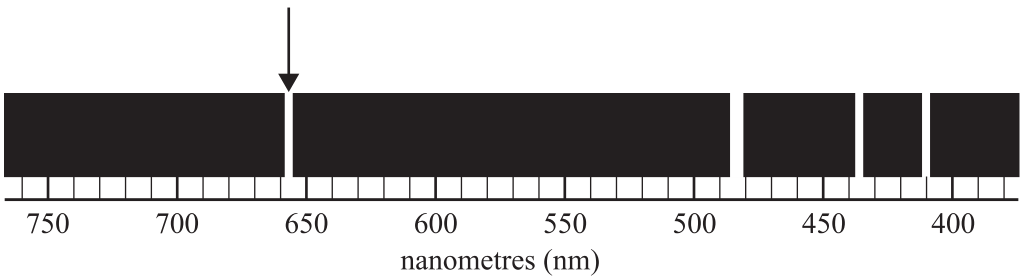


Figure 19

a. The following list gives the four visible colours that are emitted by the hydrogen atom.

Circle the colour that corresponds to the spectral line indicated by the arrow on Figure 19. 1 mark

violet blue-violet blue-green red

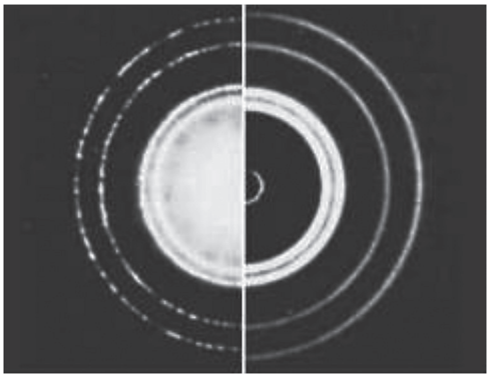
b. Explain why the visible spectrum of light emitted from a hydrogen vapour lamp gives **discrete** spectral lines, as shown in Figure 19. 3 marks

c. The microwaves from the source are polarised.

Explain what is meant by the term ‘polarised’. You may use a diagram in your answer. 2 marks

Question 17 (7 marks)

Students are comparing the diffraction patterns produced by electrons and X-rays, in which the same spacing of bands is observed in the patterns, as shown schematically in Figure 18. Note that both patterns shown are to the same scale.



electrons X-rays

Figure 18

The electron diffraction pattern is produced by 3.0×10^3 eV electrons.

a. Explain why electrons can produce the same spacing of bands in a diffraction pattern as X-rays. 3 marks

Question 18 (5 marks)

The energy level diagram for a hydrogen atom is shown in Figure 19.

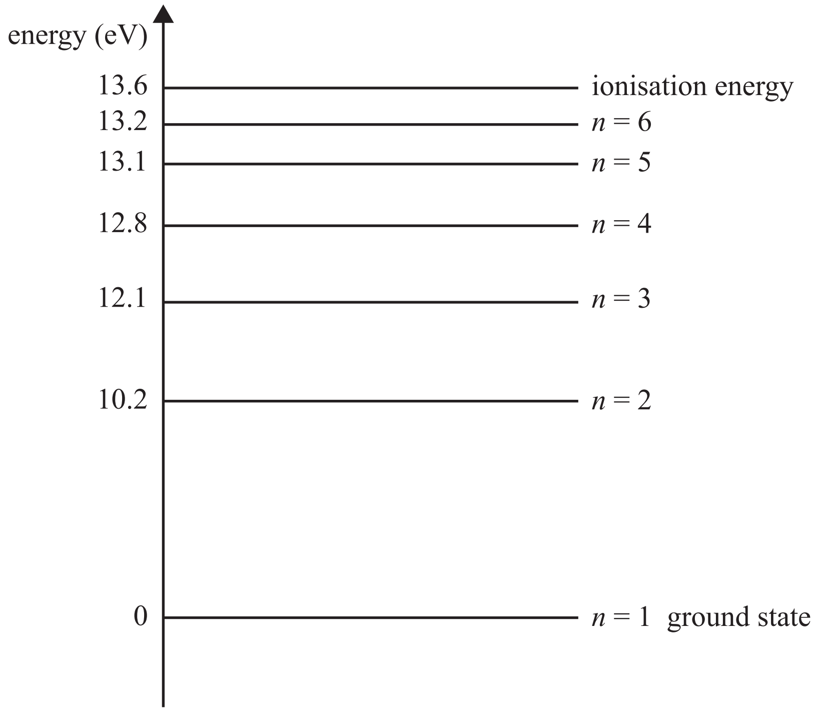


Figure 19

a. A hydrogen atom in the ground state is excited to the $n = 4$ state.

Explain how the hydrogen atom could be excited to the $n = 4$ state in one step. 2 marks

c. Explain why only certain wavelengths and, therefore, certain energies are present in the helium spectrum. 2 marks

Question 14 (3 marks)

A distant fire truck travelling at 20 m s^{-1} to a fire has its siren emitting sound at a constant frequency of 500 Hz.

Chris is standing on the edge of the road. Assume that the fire truck is travelling directly towards him as it approaches and directly away from him as it goes past. The arrangement is shown in Figure 14.

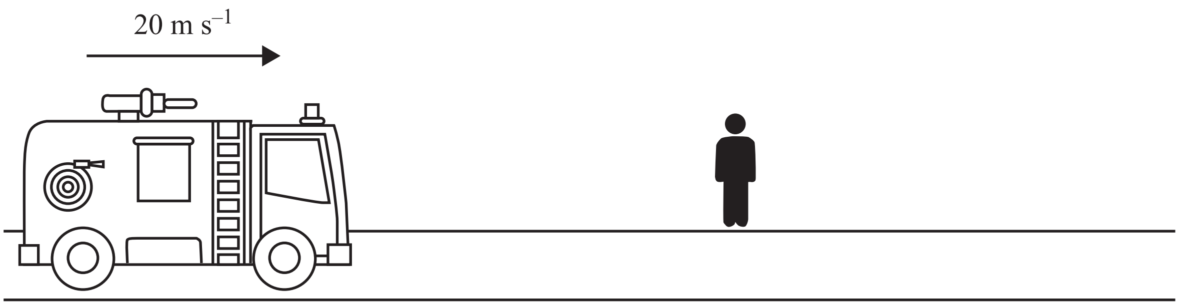
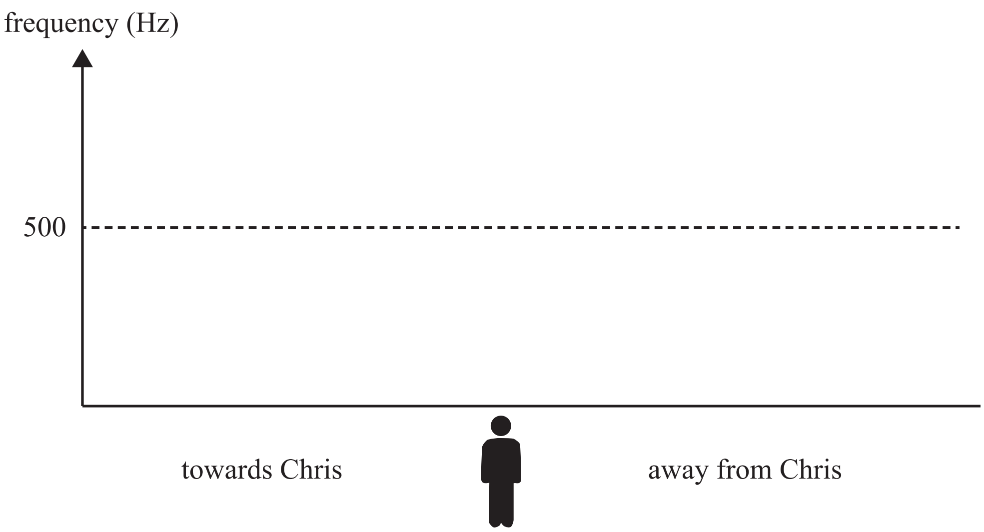


Figure 14

a. On the diagram below, sketch the frequency that Chris will hear as the truck moves towards him and then moves away from him. The 500 Hz siren signal is shown as a dotted line for reference. No calculations are required. 2 marks



b. Name the physics principle involved in Chris's experience. 1 mark

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Question 17 (3 marks)

Describe how absorption line spectra are produced and describe their relationship to electron transitions within atoms.

Question 18 (3 marks)

Provide an example of an instance in which classical laws of physics cannot describe motion at very small scales and explain why they cannot.

Question 12 (8 marks)

Students conduct an experiment in a Physics laboratory using a laser light source, two narrow slits and a screen, as shown in Figure 10.

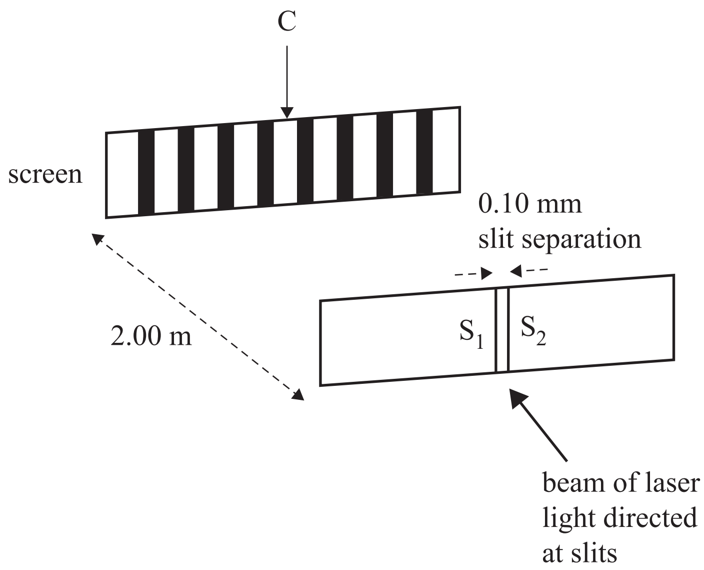

Figure 10

Point C is at the centre of the pattern of light and dark bands on the screen. The slit separation is 0.10 mm and the distance between the two slits and the screen is 2.00 m.

a. The band at point C is a bright band.

Explain why the band at point C is bright and why there is a dark band to the left of the centre. 2 marks

The experiment performed by the students is often described as Young's double-slit experiment.

b. Explain how this experiment gave support to those who argued that light has a wave-like nature. 2 marks

d. The students decide to safely immerse the entire apparatus in a liquid. The refractive index of the liquid is unknown but it is greater than the refractive index of air. Using the same laser light, they notice that the spacing of the bands changes.

Describe the change observed in the spacing of the bands and explain why this change occurred. 2 marks

Question 16 (3 marks)

A small sodium lamp, emitting light of wavelength 589 nm, is viewed at night through two windows from across a street. The glass of one window has a fine steel mesh covering it and the other window is open, as shown in Figure 18. Assume that the sodium lamp is a point source at a distance.

A Physics student is surprised to see a pattern formed by the light passing through the steel mesh but no pattern for the light passing through the open window. She takes a photograph of the observed pattern to show her teacher, who assures her that it is a diffraction pattern.

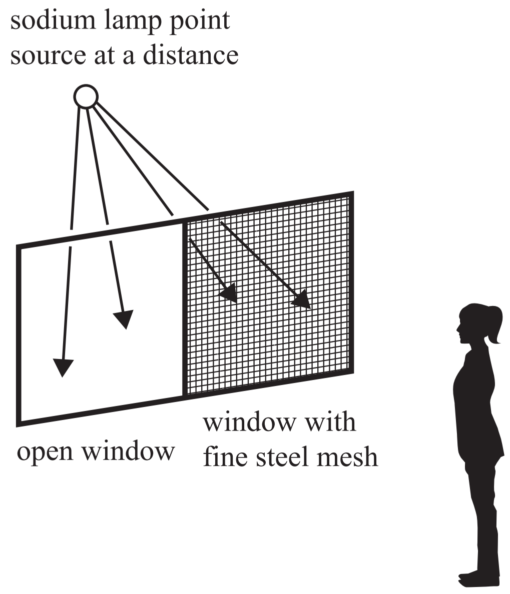

Figure 18

a. State the condition that the fine steel mesh must satisfy for a diffraction pattern to form. 1 mark

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b. Explain why the condition stated in **part a.** does not apply to the open window. 2 marks

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Question 17 (7 marks)

A materials scientist is studying the diffraction of electrons through a thin metal foil. She uses electrons with an energy of 10.0 keV. The resulting diffraction pattern is shown in Figure 19.

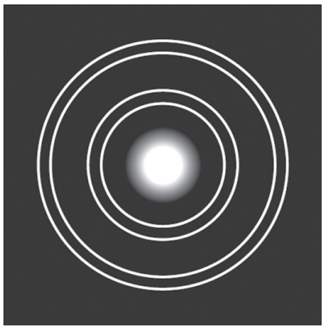

Figure 19

nm

b. The materials scientist then increases the energy of the electrons by a small amount and hence their speed by a small amount.

Explain what effect this would have on the de Broglie wavelength of the electrons. Justify your answer. 3 marks

END OF QUESTION AND ANSWER BOOK

Question 16 (3 marks)

Priya and Dan are playing music in a soundproof recording room. Priya leaves the room while Dan is still playing. She notices that when she is standing at point X with the door open, as shown in Figure 15, she can still hear the music. The music is not only softer, but some of the frequencies also seem to be relatively much softer. The door to the recording room is 1 m wide.

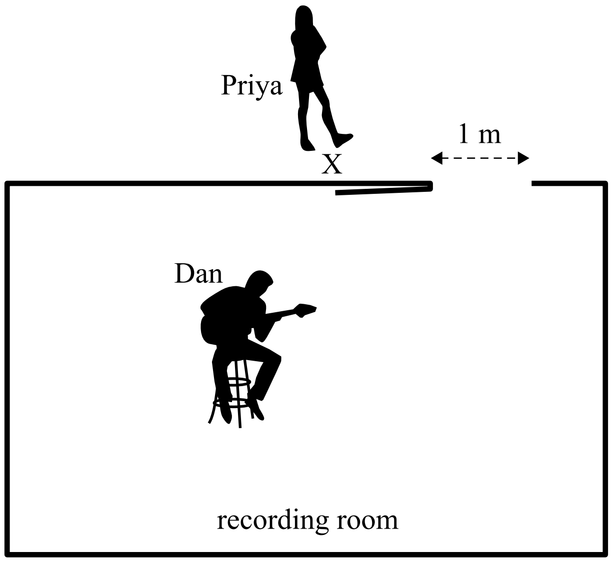

Figure 15

Outline in what way the music sounds different to Priya and explain why.

Question 19 (4 marks)

In an experiment on the photoelectric effect, Sam shines ultraviolet light onto a zinc plate and ejects photoelectrons, as shown in Figure 18.

b. Sam wants to produce a greater photocurrent – that is, to emit more photoelectrons. He considers using a much brighter red light instead of the original ultraviolet light source used in **part a.**

Is Sam's idea likely to produce a greater photocurrent? Explain your answer. 2 marks

Question 20 (5 marks)

A beam of electrons, each with a momentum 4.60×10^{-24} kg m s^{-1}, is passed through a salt crystal to produce a diffraction pattern, as shown in Figure 19.

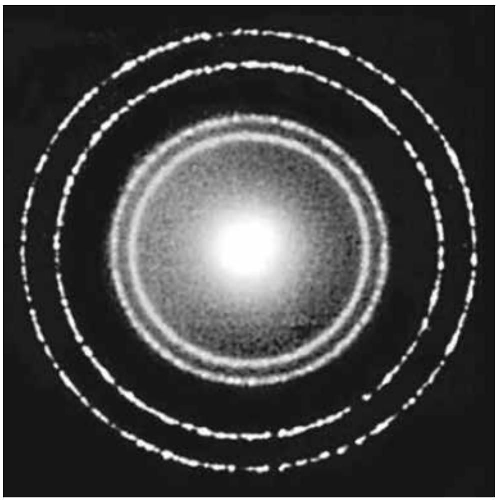

Figure 19

a

b. Explain why electron diffraction patterns from salt crystals provide evidence for the wavelike nature of matter. 3 marks

Question 21 (3 marks)

The energy levels of the hydrogen atom are discrete (quantised) and there are no levels between them.

Explain, in terms of the properties of the electron in the hydrogen atom, why only certain energy levels are allowed.

END OF QUESTION AND ANSWER BOOK