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.

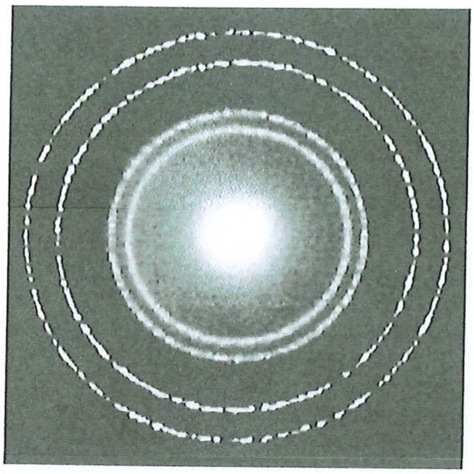


Figure 19

a. Calculate the de Broglie wavelength of the electrons. Show your working. 2 marks

$\lambda = \frac{h}{p} = \frac{6.63 \times 10^{-34}}{4.6 \times 10^{-24}}$ (1)

$= 1.44 \times 10^{-10}$ (1)

$\boxed{1.44 \times 10^{-10} \text{ m}}$

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

A diffraction pattern is a result of the interference which is a wave phenomena (1) So as electron ~~beeing~~ produce such pattern it is an evidence that they have wave preperties

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.

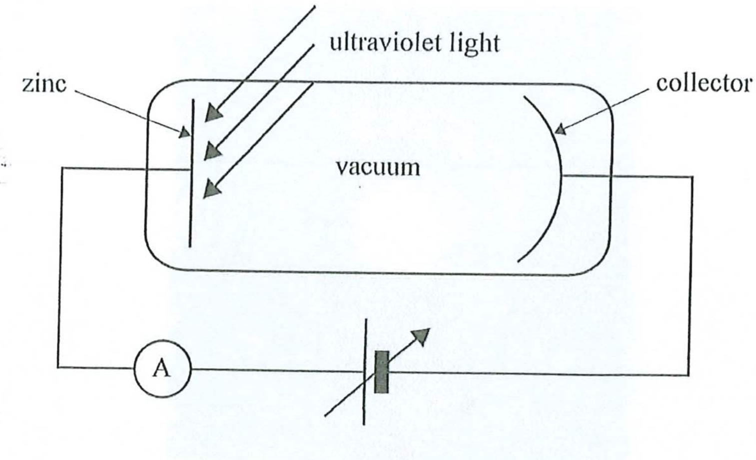


Figure 18

a. The work function of zinc is 4.30 eV.

Calculate the minimum frequency of the ultraviolet light that could eject a photoelectron. 2 marks

$W = hf_0$

$f_0 = \frac{W}{h} = \frac{4.3}{4.14\times10^{-15}}$ (1)

$= 1.04\times10^{15}$ (1)

1.04×10^{15} Hz

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

No (1)

Red light has lower frequency so photons will not have enough energy to ~~produce~~ release electrons (1)

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.

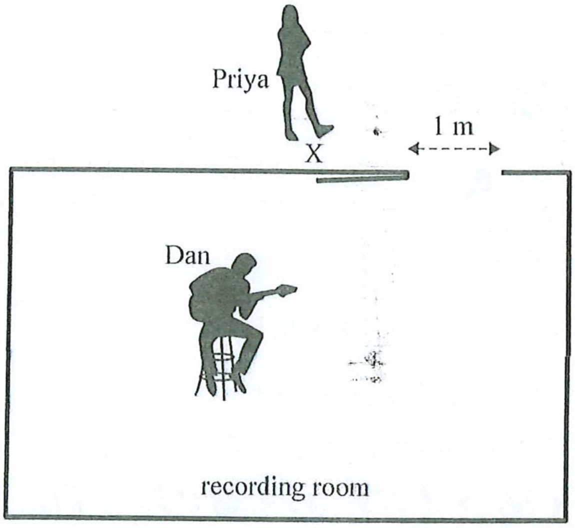


Figure 15

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

Priya will hear low frequencies but not high (1). This is the result of diffraction (spreading out of sound waves when they travel throug the opening) (1). As amount of diffraction is proportional to $\frac{\lambda}{w}$ lower frequencies will spread more. (1)

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.

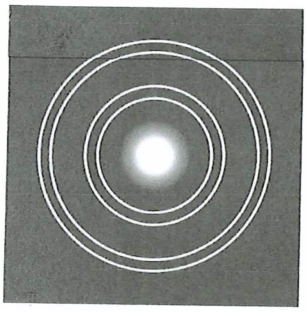


Figure 19

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

$\lambda_e = \frac{h}{mv}$ $v \uparrow \longrightarrow \lambda_e \downarrow$

54%

END OF QUESTION AND ANSWER BOOK

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.

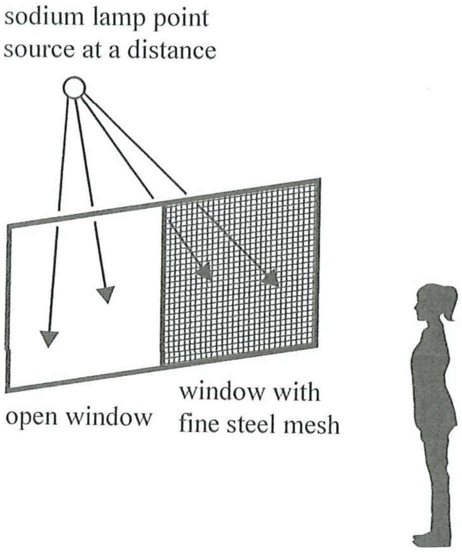


Figure 18

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

63%

Gaps in the mesh should be similar size to wavelength

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

32%

Diffraction pattern depends on ratio $\frac{\lambda}{w}$. $\frac{\lambda}{w}$ is very small as width of the window is big

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

The experiment show interference pattern which is a wave property. 55%

Not in the new (2024 study design)

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

34%

$n = \frac{c}{v}$ If $n\uparrow$, $v\downarrow$

$v = \lambda f$ If $v\downarrow$, $\lambda\downarrow$ (f = const)

$\Delta x = \frac{\lambda L}{d}$ If $\lambda\downarrow$ $\Delta x\downarrow$

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.

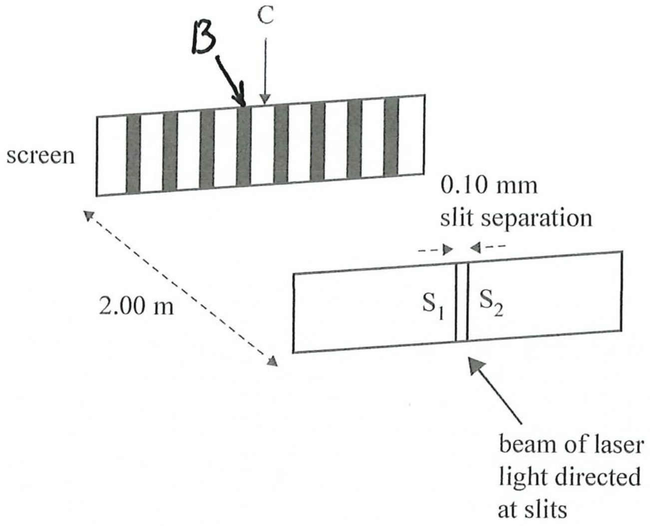


Figure 10

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

20%

Path difference to point C equal zero. Path difference to point B (see diagram) equal $\frac{\lambda}{2}$. So at C constructive and at B destructive interference take place.

Question 17 (3 marks)

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

Photons with energies equal differences between energy levels of electrons in the atoms will be absorbed and electrons will be excited to higher energy levels. Therfore these photons will be missing from the spectrum.

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.

The interference pattern produced by electrons passing through 2 narrow slits can not be explained by classical physics which predicts that electrons will produce only 2 lines on the screen as electrons will travel in straight lines. But electrons diffract as they have wave properties.

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.

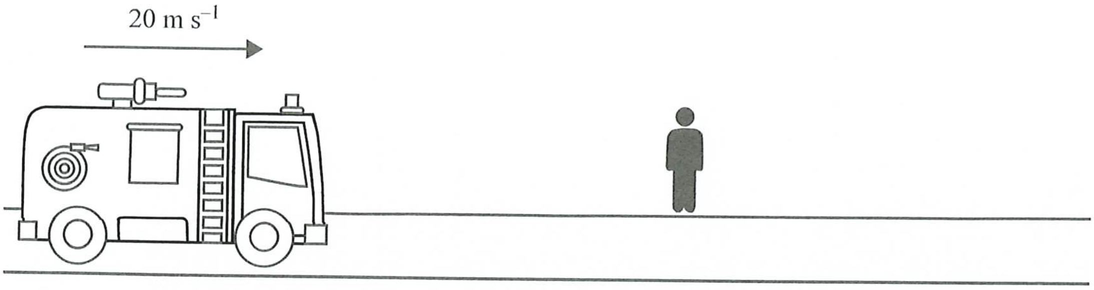
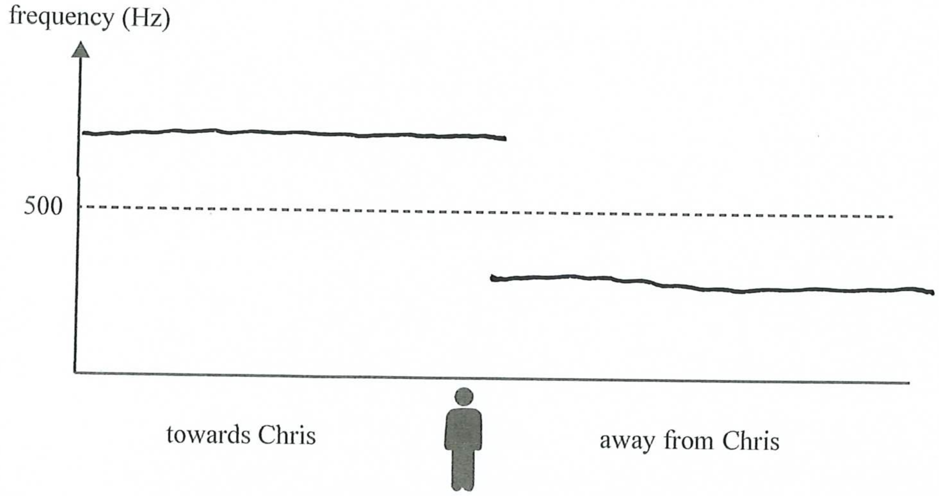


Figure 14

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

12 %



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

1 mark

Doppler effect

81%

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

2 marks

17 %

Electrons in helium can have only discrete energies. (1m) Discrete wavelengths (energies) in helium spectrum correspond to the differences between those discrete energy Levels.

Question 18 (5 marks)

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

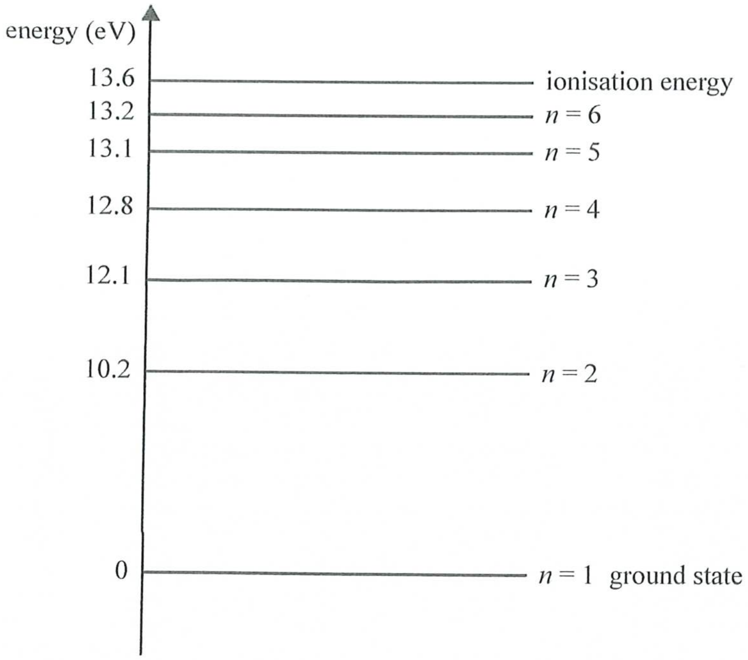


Figure 19

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

Absorbing photon ~~of~~ with energy 12.8eV 54%

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.

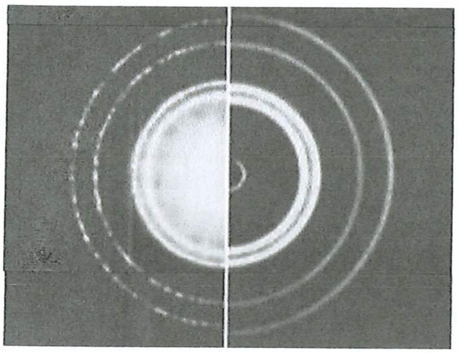


Figure 18

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

Electrons have wave properties with de Broglie wavelength. Diffraction pattern depends on wavelength. Same spacing means that electrons and X-rays have same wavelength.

22%

14

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

41%

Light is transverse wave. Polarised light has oscillations of electric field only in one plane and magnetic in one plane perpendicular to the plane in which electric field oscillates.

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.

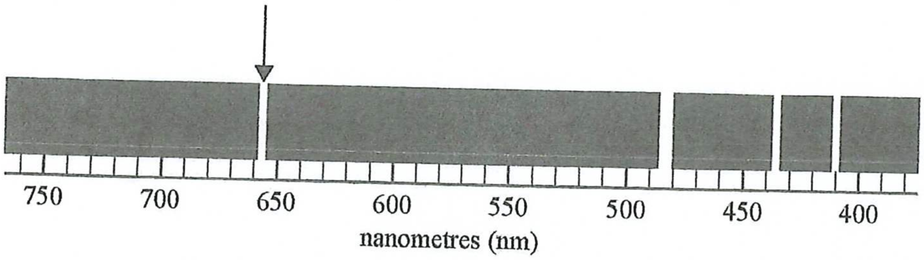


Figure 19

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

64%

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

11%

Electrons orbit nucleus at discrete energy levels (~~shells~~) (1m) Photons are emitted when electrons transition between these levels (1m). Transitions result in descrete photon energies and so discrete spectral lines (1m)

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.

Existence of the threshold frequency. According to the wave model there should be no threshold frequency as energy of light depends on intensity (amplitude) of the wave and so light with any frequency should produce photo electrons. But the results show that only the light with frequency above threshold can produce photoelectrons. According to the particle model energy of photons proportional to their frequency. $E = hf$ Only photons with enough energy will produce photoelectrons.

$hf \geq W$

Question 18 (3 marks) Not in the new study design (2024)

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

$\Delta x \Delta p \geq \frac{h}{4\pi}$

There more precisely position of the particle is known the less precisely its momentum is known. When electron pass through the slit uncertainty in its position is small so uncertainty in the momentum is big and so its direction. As a result electrons paths after the slit is spread out and results in the diffraction pattern.

END OF QUESTION AND ANSWER BOOK

Question 19 (4 marks) 10 %.

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.

Mary is correct. Roger is incorrect. Electrons have wave properties with de Broglie wavelength. If electrons pass through a crystal they will produce a diffraction pattern like X-rays passed through the cristal. If electrons will pass through a single or double slit they will produce an interference pattern.

END OF QUESTION AND ANSWER BOOK

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

40%

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

16%

- Existence of a threshold frequency.

The wave model predicts that light of any frequency will produce photoelectrons as energy of light determined by amplitude (intensity). But experiment showed that light with frequency below threshold frequency will not produce photoelectrons regardless of intensity.

- Stopping voltage is independent from intensity but depend on frequency. The wave model predict that increase of intensity will increase amount of energy delivered to electrons so more electrons will be emitted and with greater kinetic energy so higher stopping voltage will be required. But experiment showed that increase of intensity increases the photocurrent but not affecting stopping voltage.

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.

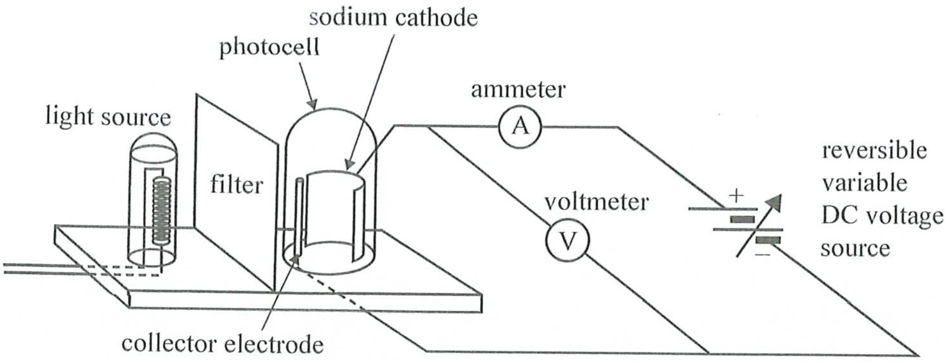


Figure 15

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

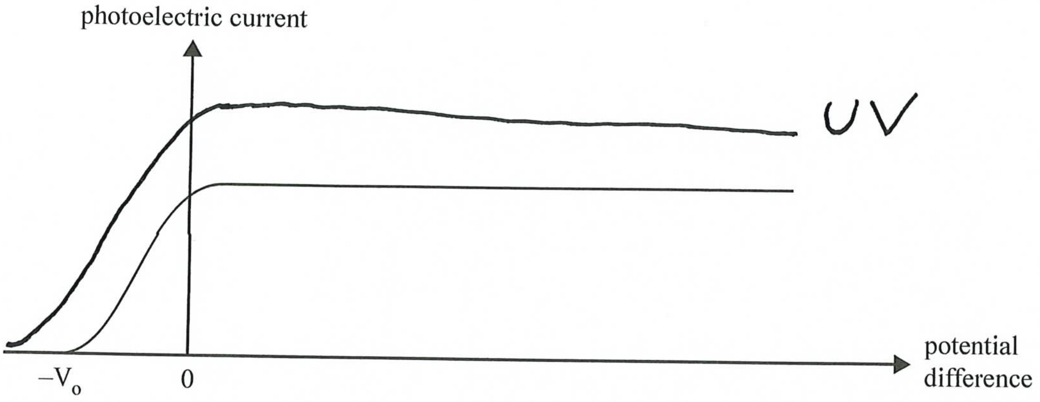


Figure 16

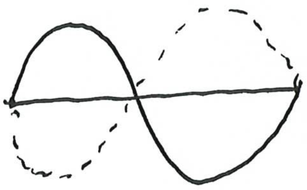
2 marks

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

3 marks

21%

2 identical waves are travelling in opposite direction and reflect at the ends.
The superposition of 2 ~~wave~~ waves take place producing interference pattern.



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

Sam is correct, Elli incorrect. 22%

Addition of the second speaker will produce interference pattern.

The intensity that a student hears will depend on the path difference from each speaker

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

$\Delta x = \frac{\lambda L}{d} = \frac{0.5 \times 24}{4} = 3\ m$ 14%

So distance between antinodes (constructive interference and so higher sound intensity) is 3m. Student 2 is 3m away from the centre so will hear higher intensity. Student 5 is 1.5m away ~~so~~ from the centre so will be at a node and hear a low intensity

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.

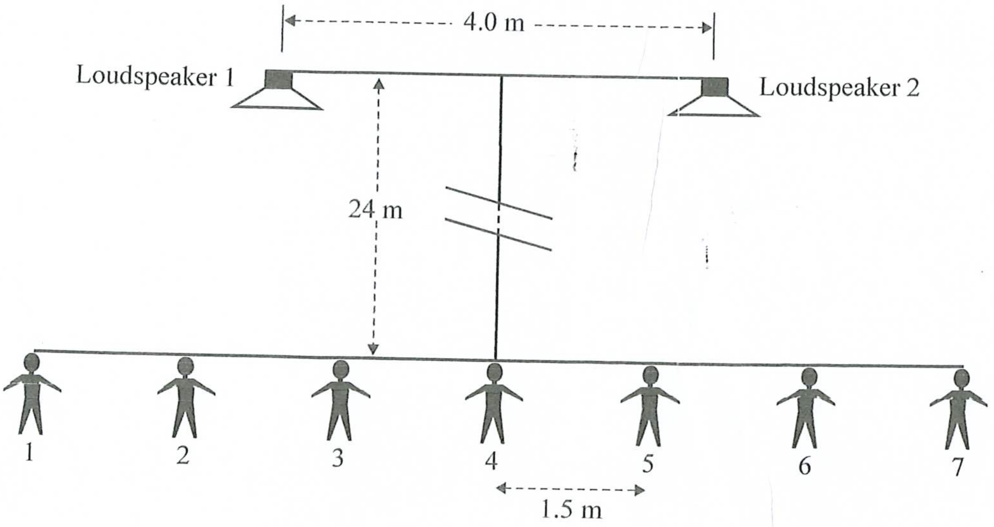


Figure 14

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.