Use the following information to answer Questions 5–9.

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

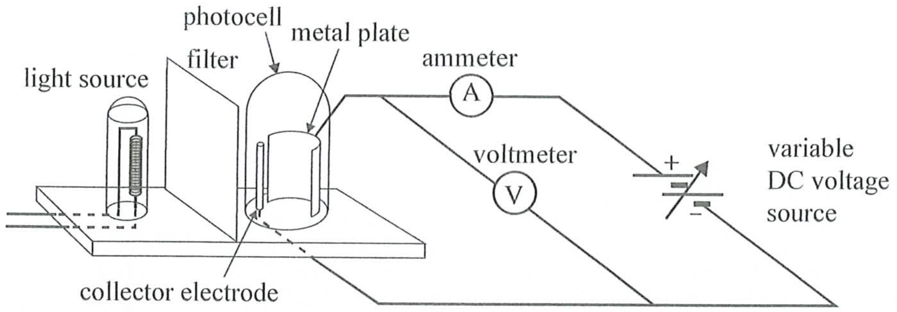


Figure 2

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.

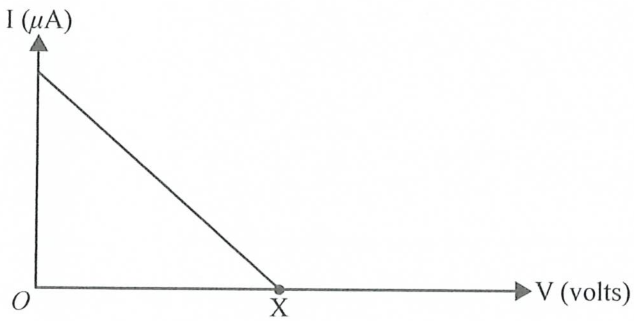


Figure 3

Question 5

Explain why the current drops to zero at point X.

At this point even electrons with maximum kinetic energy are stopped by electric field. So none of the emitted electrons reach collector.

5%.

2 marks

Question 4

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

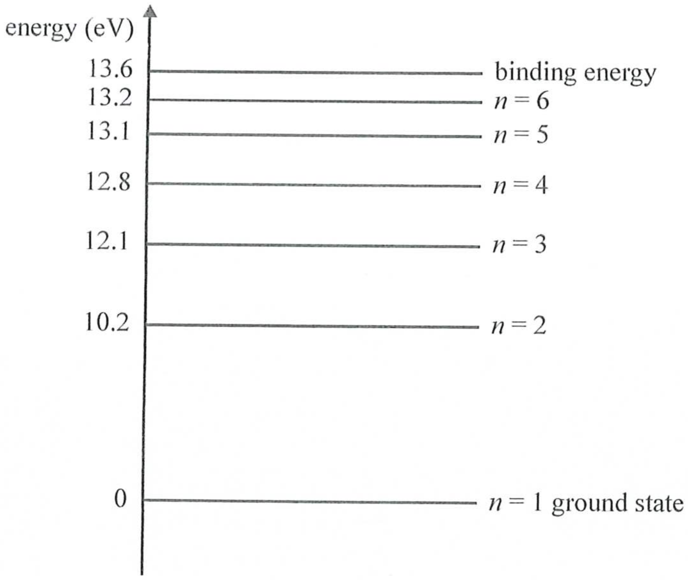


Figure 6

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.

Electron has wave properties with wave length $\lambda = \frac{h}{p}$ (de Broglie wavelength). In order to have stable orbit standing wave must be formed which is possible when circumference equal integer number of wavelength. Only electrons with energies related to these wavelength will form stable levels.

27 %

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.

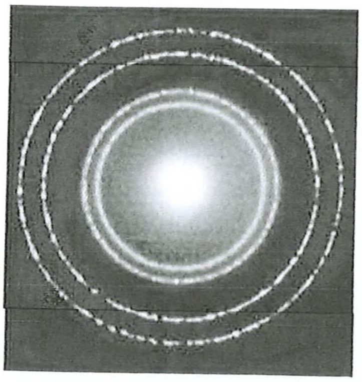


Figure 29

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

26%

Student A is correct. The fringe spacing depends on wavelength (determined by wavelength) which is determined by momentum. $\lambda = \frac{h}{p}$

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.

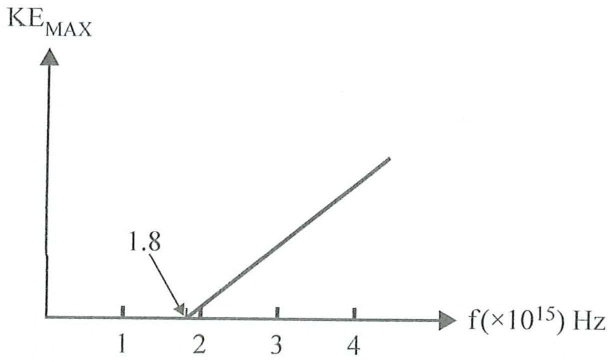


Figure 30

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

According to the particle model of light increasing intensity increase number of photons but will not change energy of each photon. So kinetic energy of electrons will be the same.

7%

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.

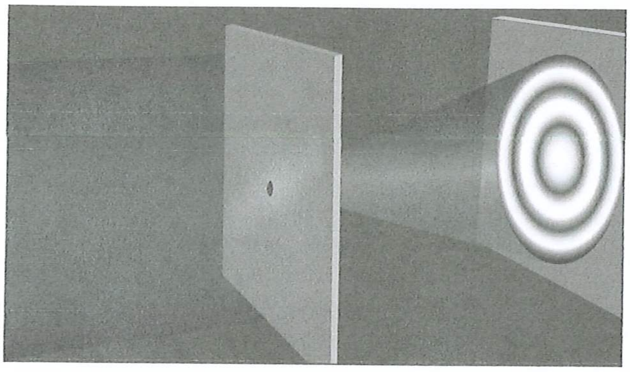


Figure 31

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

55%

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

29%

~~For~~ Amount of diffraction determined by the ratio $\frac{\lambda}{w}$, where λ is a wavelength and w is size of the opening. Increasing w results in less diffraction and so smaller diameter of the rings.

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.

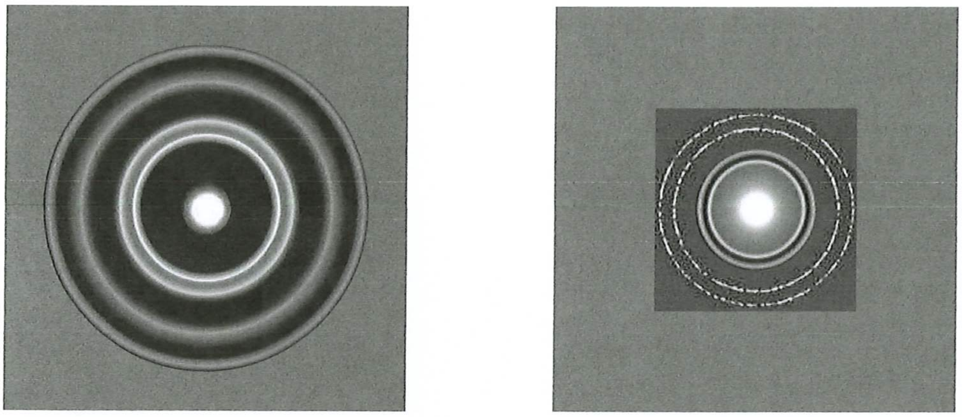


Figure 32
not to scale

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

Diffraction pattern determined by wavelength, 10%.
so different patterns means different wavelength.
Wavelength related to momentum, not to the energy. $\lambda = \frac{h}{p}$

$\lambda_{photon} = \frac{hc}{E}$ $\lambda_{electron} = \frac{h}{\sqrt{2mE}}$

Same energy → different wavelengths

$\lambda_{photon} = \frac{1.99 \times 10^{-25}}{E}$ $\lambda_{electron} = \frac{4.9 \times 10^{-19}}{\sqrt{E}}$

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.

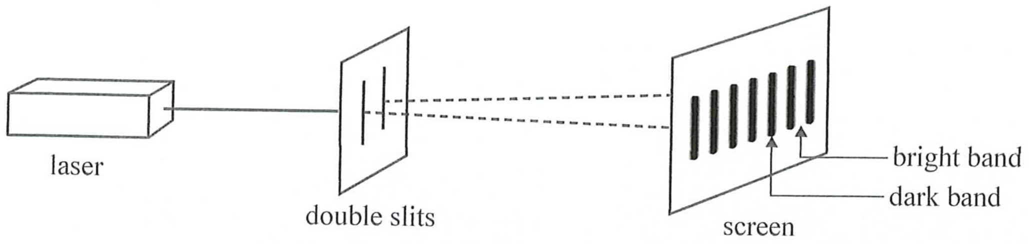


Figure 18

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

Bright band. As the path difference to this point is 0 ther will be constructive interference and so bright band. 38%

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

Photoelectric effect supports particle model of light. Existence of threshold frequency can be explained by particle model and cannot be explained by the wave model.

50%

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

2 marks

Electron diffraction. Diffraction is a wave phenomenon. So electrons behave as a waves with de Broglie wavelength.

23%

Question 21 (5 marks)

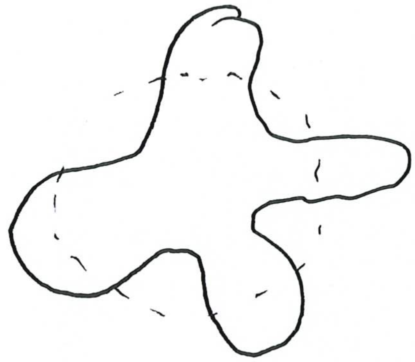
a. Use the model of quantised states of the atom to explain why only certain energy levels are allowed. 3 marks

Electron have wave properties with de Broglie wavelength. Only states of electrons in the atom can exist where standing wave

23%

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

40%



can form with circumference of the orbit equal whole number of wavelength $2\pi r = n\lambda$. Different possible states correspond to different integer values of n.

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.

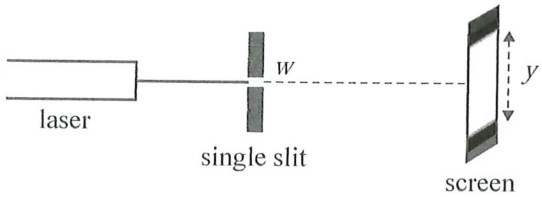


Figure 23

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

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

2 marks

50%

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 $2y$.

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

D

Width of the pattern proportional to $\frac{\lambda}{w}$.

$\Delta x \approx \frac{L\lambda}{w}$

$w \times 2 \therefore \Delta x \div 2$

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).

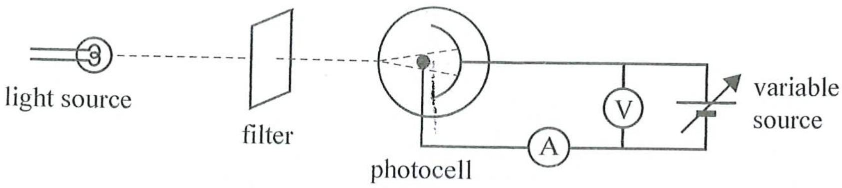


Figure 24

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

Voltage measured is the voltage required to just stop emitted electrons so represent the maximum kinetic energy of photoelectrons 14%.

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

Graph will be the same. This supports the particle model of light. Energy of photons depends on frequency not intensity. Intensity affects number of photons but not their energy. 36%.

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.

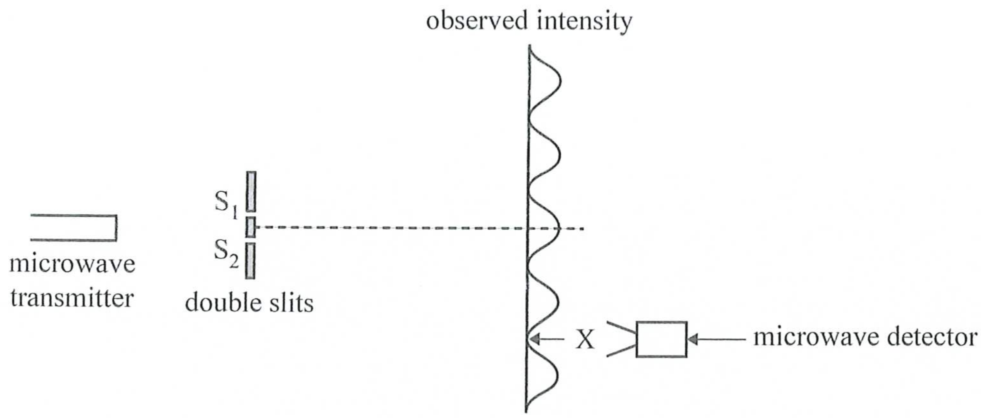


Figure 26

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

Young's experiment demonstrated interference which is a wave phenomena so it supports wave model of light.

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.

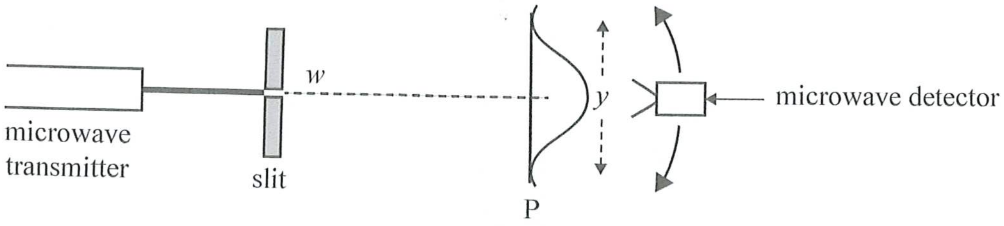


Figure 27

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

$y \propto \frac{\lambda}{w}$ so increase of wavelength results in the increase of the width of the pattern.

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).

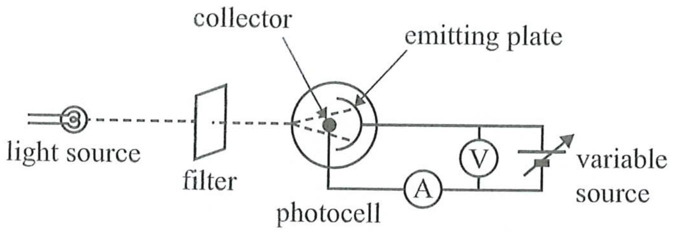


Figure 28

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.

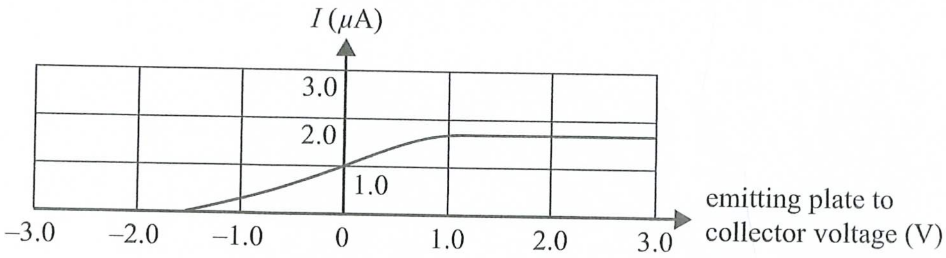


Figure 29

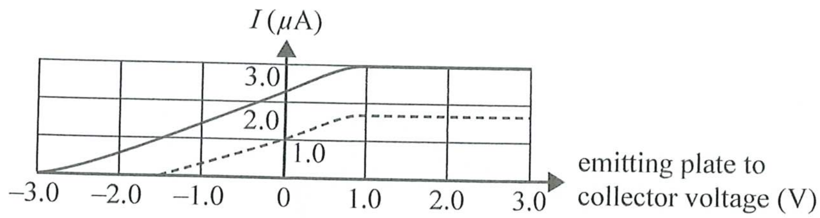
d. Explain why the graph in Figure 29 is a flat, straight line beyond V = +1.0 V. 2 marks

At that voltage all emitted electrons reach collector. Increase of voltage doesn't change the number of the ~~ent~~ electrons reaching collector so current stays the same.

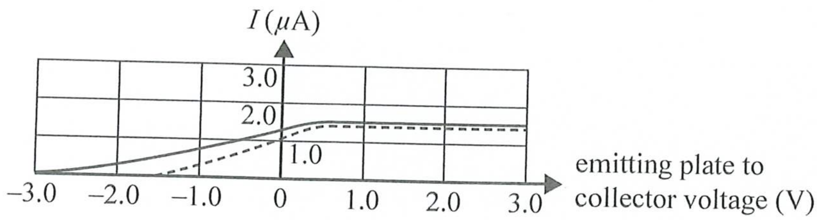
e. The students double the intensity of the light, keeping the frequency the same, and plot the results on a graph, with the original current shown as a dashed line.

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

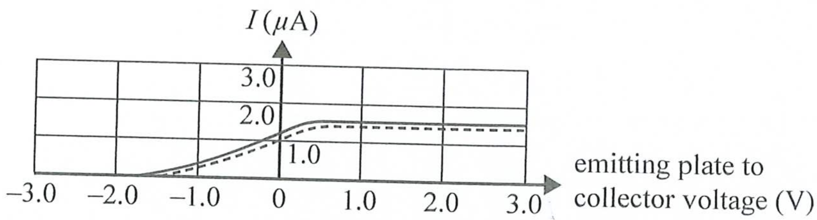
A.



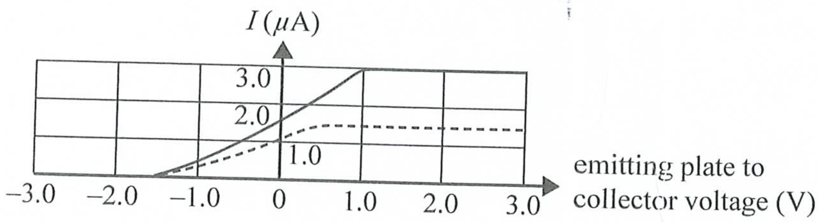
B.



C.



D.



D

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

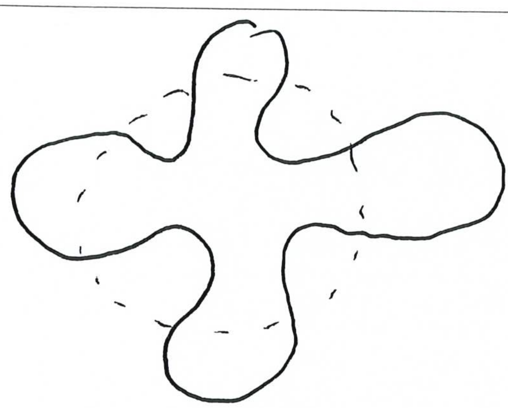
Increase in current without change in stopping voltage supports particle model of light. The particle model predicts that increase in intensity results in the increase of number of photons ~~and~~ but not their energy. So current (number of electrons) will increase but stopping voltage (maximum kinetic energy of electrons) not.

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.

Electrons exhibit a wave properties. They form standing waves in orbits with circumference equal to a whole number of wavelength. So only certain discrete energy states can exist.



END OF SECTION A
TURN OVER