✓ **Question 16**

When light of a specific frequency strikes a particular metal surface, photoelectrons are emitted.

If the light intensity is increased but the frequency of the light remains the same, which of the following is correct?

	Number of photoelectrons emitted	Maximum kinetic energy of the photoelectrons
A.	remains the same	remains the same
B.	remains the same	increases
(C.)	increases	remains the same
D.	increases	increases

✓ **Question 17**

A metal surface has a work function of 2.0 eV.

The minimum energy of an incoming photon required to eject a photoelectron is

(A.) 3.2×10^{-19} J

B. 1.6×10^{-19} J

C. 8.0×10^{-20} J

D. 4.0×10^{-20} J

$2.0 \times 1.6 \times 10^{-19}$ J

Question 18

A student measures a very small current in a circuit and obtains the result 0.000670 A.

The number of significant figures in the measurement 0.000670 A is

A. 2

B. 3

C. 5

D. 6

Question 19

An independent variable is best described as one that is

A. set by the researcher.

B. not relevant to the experiment.

C. fixed throughout the experiment.

D. not related to any other variables in the experiment.

Question 20

The main reason for repeating an experiment is to

A. reduce random error.

B. reduce systematic error.

C. allow for differences between researchers.

D. allow for variations in controlled variables.

END OF SECTION A
TURN OVER

✓ **Question 12** (3 marks)

Figure 12 shows the energy level diagram for the hydrogen atom.

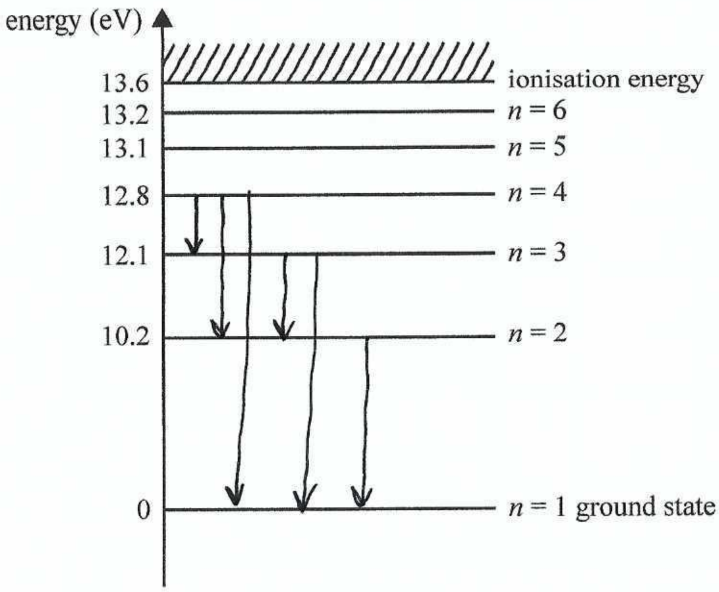


Figure 12

List the possible photon energies following emissions from the $n = 4$ state.

0.7 2.6 12.8 1.9 12.1 10.2 eV

In order 0.7, 1.9, 2.6, 10.2, 12.1, 12.8 eV

✓ **Question 13** (7 marks)

Electrons are accelerated through a potential difference of 4000 V and then pass through a metallic crystal. The resulting diffraction pattern is observed.

a. Calculate the de Broglie wavelength of these electrons. 3 marks

$\lambda = \frac{h}{p}$ $\quad \frac{p^2}{2m} = eV \quad p = \sqrt{2meV}$

$p = \sqrt{2 \times 9.1 \times 10^{-31} \times 1.6 \times 10^{-19} \times 4000}$

$= 3.4 \times 10^{-23}$ Ns

$\lambda = \frac{6.63 \times 10^{-34}}{3.4 \times 10^{-23}} = 1.95 \times 10^{-11}$ m

2×10^{-2} nm

b. A student, Jane, says that X-rays of a suitable wavelength could produce the same diffraction pattern.

Calculate the energy of the X-ray beam required to give a similarly spaced diffraction pattern to the electrons. Show your working. 2 marks

$E_{ph} = pc = 3.4 \times 10^{-23} \times 3 \times 10^{8}$

$= 1.02 \times 10^{-14}$ J

$= \frac{1.02 \times 10^{-14}}{1.6 \times 10^{-19}}$

$= 6.375 \times 10^{4}$ eV

6.4×10^{4} eV

c. Explain how electrons and X-rays can exhibit similar diffraction patterns. 2 marks

Diffraction depends on wavelength.
De Broglie wavelength of electrons = wavelength of X-rays so diffraction pattern is the same.

✓ **Question 16** (6 marks)

Students are investigating the photoelectric effect.

The apparatus used by the students is shown in Figure 13. A light source shines light through a filter that only allows one frequency of light to pass through. This monochromatic light shines onto a metal plate and photoelectrons are emitted. Different filters allow different frequencies to strike the metal plate. For each frequency, the maximum kinetic energy of the emitted photoelectrons is measured by using a stopping voltage.

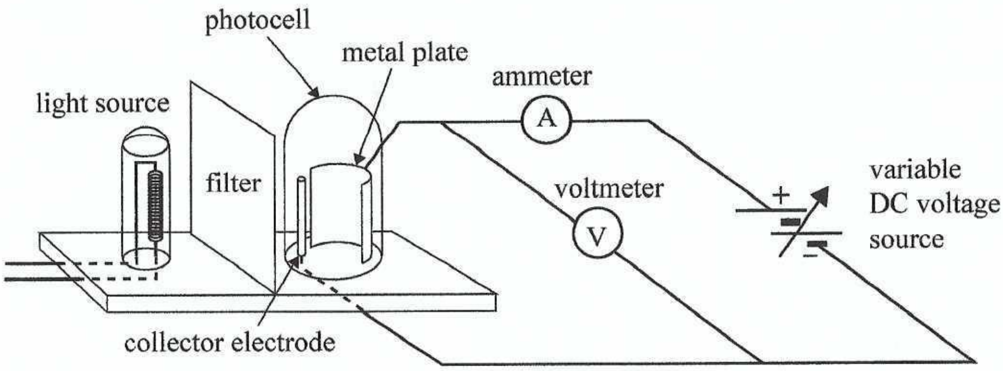


Figure 13

The graph of the data the students collected for the maximum kinetic energy of emitted photoelectrons versus frequency is shown in Figure 14. A line of best fit has been drawn.

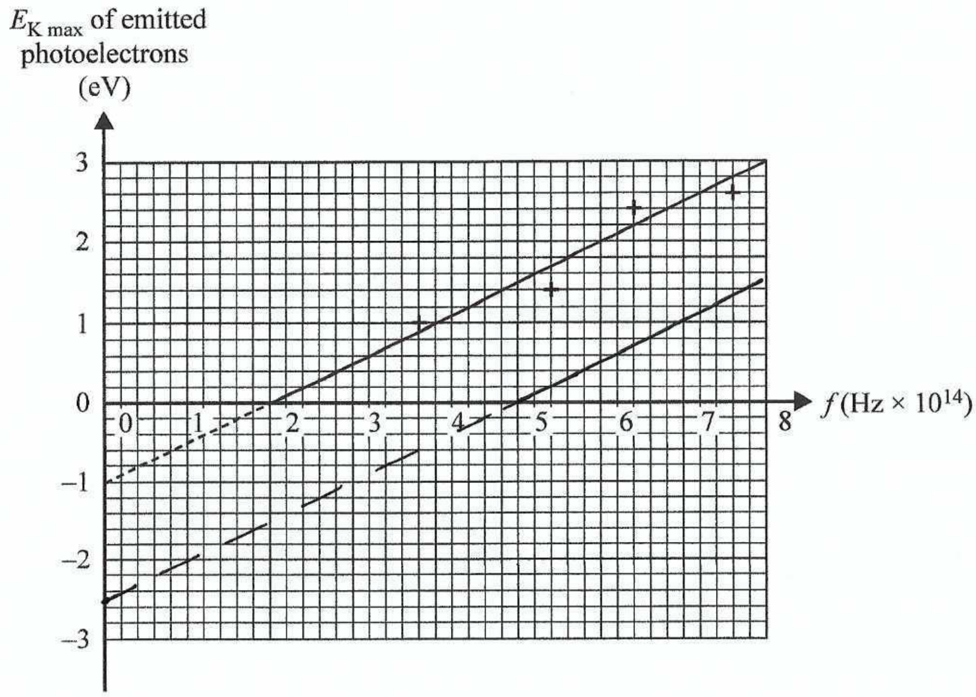


Figure 14

a. Determine the value of Planck's constant, h, that the students would have obtained from this graph. 2 marks

Gradient $h = \frac{3}{6.0 \times 10^{14}} = 5 \times 10^{-15}$

5×10^{-15} eV s

b. Determine the value of the minimum frequency, or cut-off frequency, f_0, that the students would have obtained from this graph. 1 mark

2.0×10^{14} Hz

c. Determine the value of the work function of the metal in the plate that the students would have obtained from this graph. 1 mark

1.0 eV

d. The students replace the photocell with one that has a different metal plate with a work function of 2.5 eV.

On Figure 14, draw in the graph they would now expect. 2 marks

See graph

✓ **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.

Threshold frequency.
According to the wave model there should be no threshold frequency as it associate energy with amplitude so light of any frequency with sufficient intensity will produce photoelectrons.
But results show that only light with frequency above threshold will produce electrons. The particle model of light explain that photons energy proportional to frequency so photons with high enough frequency will have enough energy to produce photoelectrons.

Question 18 (3 marks)

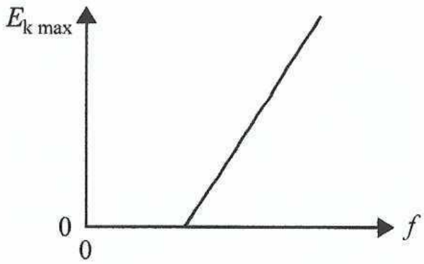
Explain how the diffraction pattern produced by a stream of electrons passing through a narrow slit can illustrate Heisenberg's uncertainty principle.

Heisenberg's uncertainty principle $\Delta x \Delta p \geq \frac{h}{4\pi}$ states that if position is known more precisely, momentum will be known less precisely. When electrons pass through the slit their position is known more precisely so uncertainty in momentum and hence velocity and direction increase. As a result electron paths after the slit spreading out and results in the diffraction pattern.

END OF QUESTION AND ANSWER BOOK

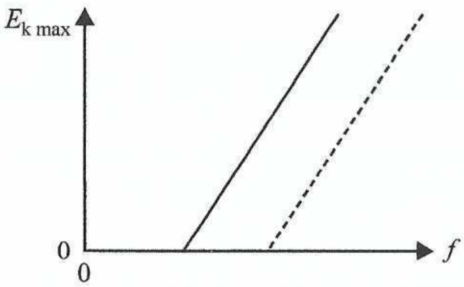
Question 17 70 %

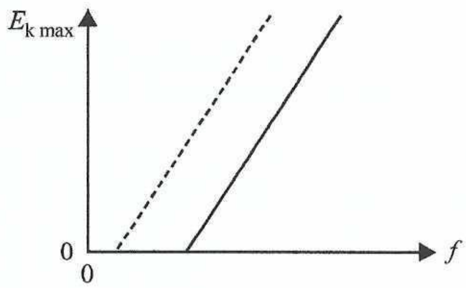
The results of a photoelectric experiment are displayed in the graph below. The graph shows the maximum kinetic energy ($E_{k\ max}$) of photoelectrons versus the frequency (f) of light falling on the metal surface.

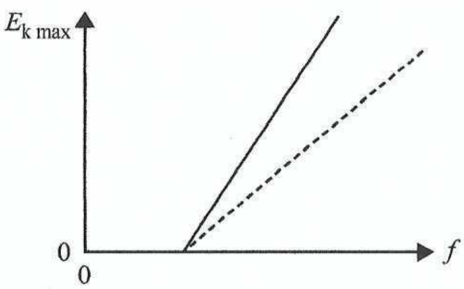


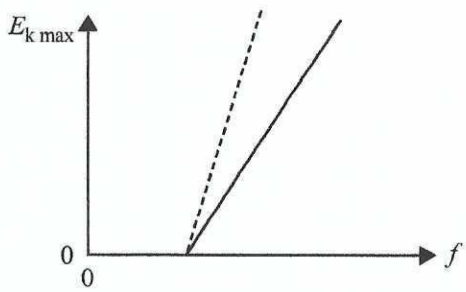
A second experiment is conducted with the original metal surface being replaced by one with a larger work function. The original data is shown with a solid line and the results of the second experiment are shown with a dashed line.

Which one of the following graphs shows the results from the second experiment?

A.


B.


C.


D.


Question 18

The experimental uncertainty in a measurement of any particular quantity is **best** described as

A. a quantitative estimate of the doubt associated with the measurement.

B. the degree of confidence a scientist has in their experimental technique.

C. the difference between the measurement and the true value of the quantity.

D. the result of one measurement; repeated measurements can eliminate uncertainty.

√**Question 17** (7 marks)

To investigate the photoelectric effect, Sai and Kym set up an experiment.

The apparatus is shown in Figure 17.

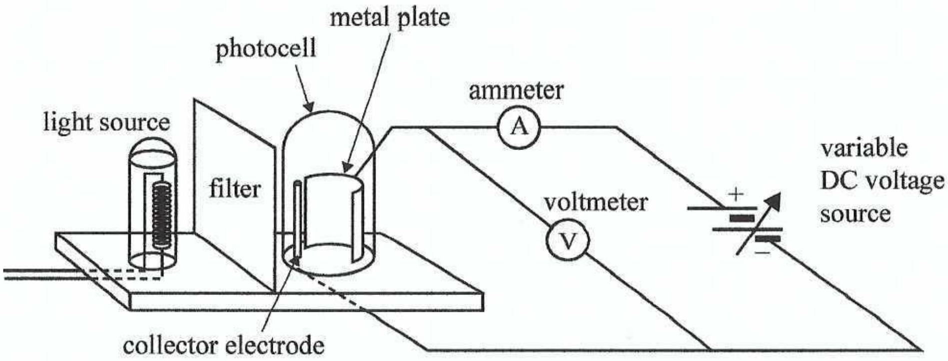
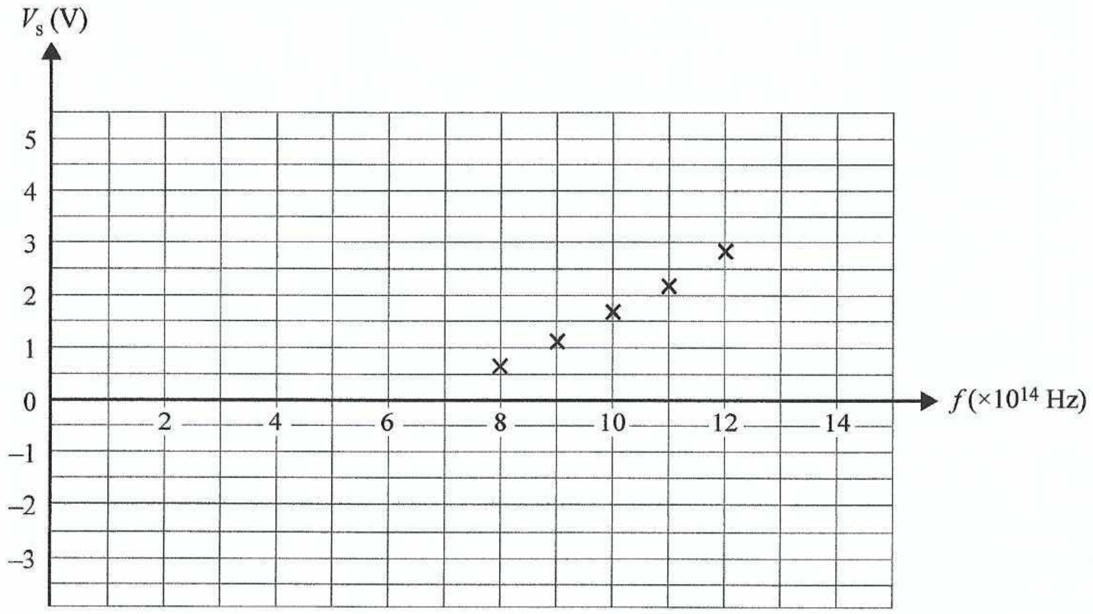


Figure 17

With the light source on and a filter in place, Sai and Kym measure the maximum kinetic energy of emitted photoelectrons by gradually changing the collector voltage until the current measured by the ammeter just falls to zero.

They record this voltage (the stopping voltage) for each frequency of the incident light and plot their results in a graph of stopping voltage, V_s, versus frequency, $f\,(\times 10^{14}$ Hz), of the incident light, as shown below.



With 6.0×10^{14} Hz light, the ammeter always shows zero. Sai wants to repeat the experiment for this frequency with a much brighter light source and wants to expose the metal to the light for much longer. Kym says photoelectrons will never be ejected with this frequency of light.

a. **i.** Who is correct – Sai or Kym? Write the name in the box provided below. 1 mark

Kym

ii. What explanation might Sai give to support her opinion that by waiting longer and using a brighter light source, photoelectrons could be ejected from the metal with light of a frequency of 6.0×10^{14} Hz? 2 marks

Increasing brightness increases delivered energy. Increasing time lead to electrons over time gain sufficient energy.

b. Use the graph to calculate Planck's constant. Show your working. 2 marks

Planck's constant = gradient of the graph.

$h = (5-6) \times 10^{-15}$ eVs

$h = \frac{2.8 - 0.6}{(12-8) \times 10^{14}} = 5.5$ eVs

5.5 eV s

c. Determine the work function of the metal from the graph. Give your reasoning. 2 marks

W = −y intercept

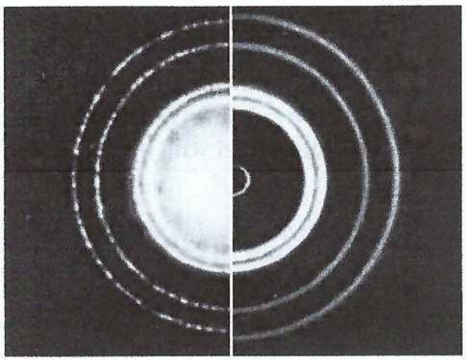
W = 3 − 4 eV

3.5 eV

Question 18 (5 marks)

The diffraction patterns for X-rays and electrons through thin polycrystalline aluminium foil have been combined in the diagram in Figure 18, which shows an electron diffraction pattern on the left and an X-ray diffraction pattern on the right. The images are to the same scale.

The X-rays have a photon energy of 8000 eV.



electrons X-rays

Figure 18

a. Calculate the wavelength of the electrons in nanometres. Show your working. 2 marks

$E = \frac{hc}{\lambda}$

$\lambda = \frac{hc}{E} = \frac{4.14 \times 10^{-15} \times 3 \times 10^{8}}{8000}$

$= 1.55 \times 10^{-10}$ m

0.155 nm

b. Calculate the kinetic energy of the electrons in joules. Show your working. 3 marks

$E = \frac{p^2}{2M}$ $p = \frac{h}{\lambda} = \frac{6.63 \times 10^{-34}}{1.55 \times 10^{-10}} = 4.277 \times 10^{-24}$

$E = \frac{(4.277 \times 10^{-24})^2}{2 \times 9.1 \times 10^{-31}} = 1.0 \times 10^{-17}$ J

1.0×10^{-17} J

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.

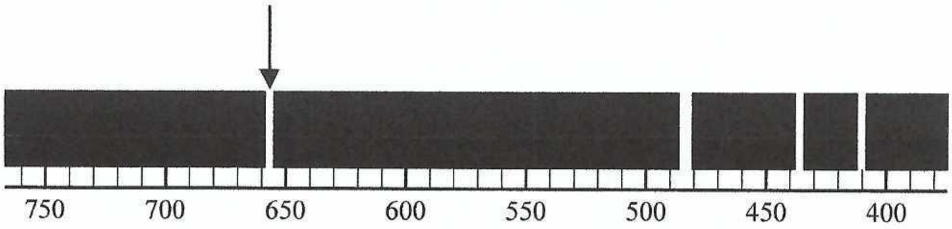


Figure 19

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

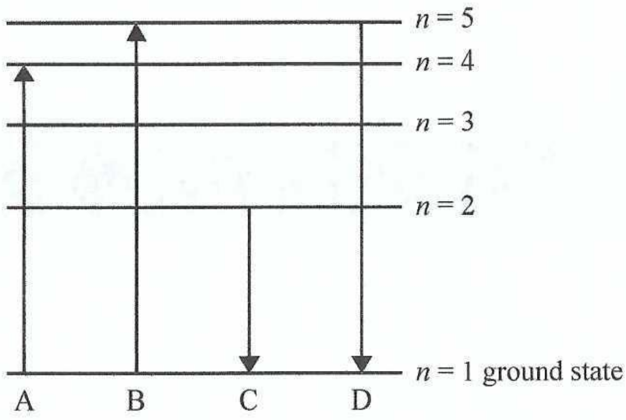
violet blue-violet blue-green red

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

Electrons can have only discrete energies in the atom.
(Orbit at discrete energy levels)
Photons are emitted when electrons transition between these levels.
Transitions result in discrete photon energies

✓**Question 19**

Part of the energy-level diagram for an unknown atom is shown below.

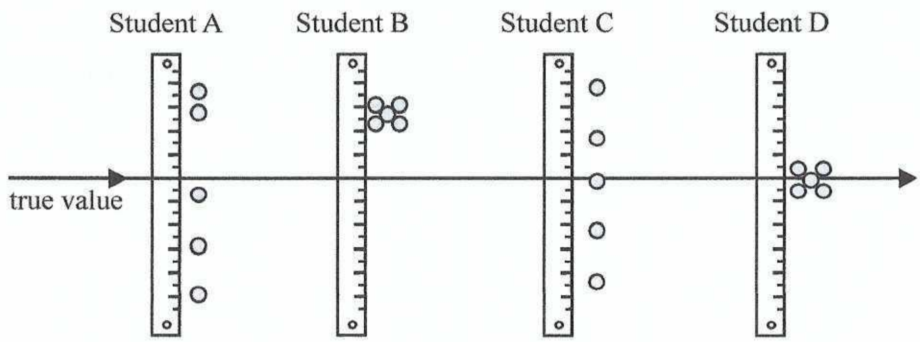


Which one of the arrows shows a change of energy level corresponding to the absorption of a photon of highest frequency?

A. A
B. B
C. C
D. D

Question 20

Four students measure the length of a piece of string. Each student takes five measurements and displays the results as five dots, as shown in the diagram below. The true value is also shown in the diagram.



Which student produced a set of precise but inaccurate results?

A. Student A
B. Student B
C. Student C
D. Student D

END OF SECTION A
TURN OVER

✓ **Question 11** (6 marks)

Kym and Roger conduct an experiment to observe an electron diffraction pattern. 5000 eV electrons are projected through a diffracting grid and the resulting pattern is observed on a screen.

Kym and Roger want to calculate the wavelength of X-rays that would produce a similarly spaced diffraction pattern.

Kym says that they will need X-rays of 5000 eV.

Roger says that X-rays of a different energy will be needed.

a. Explain why Roger is correct. 2 marks

Diffraction depends on wavelength. To have same diffraction pattern electrons and X-rays must have same wavelength and so the

b. Showing each of the steps involved in your working, calculate the energy of X-rays that would be required to produce the similarly spaced diffraction pattern. 4 marks

$E_e = 5000 \times 1.6 \times 10^{-19} = 8.0 \times 10^{-16}$ J

$p = \sqrt{2mE} = \sqrt{2 \times 9.1 \times 10^{-31} \times 8 \times 10^{-16}} = 3.8 \times 10^{-23}$ Ns

$E_{ph} = pc = 3.8 \times 10^{-23} \times 3 \times 10^{8} = 1.14 \times 10^{-14}$ J

$E_{ph} = \frac{1.14 \times 10^{-14}}{1.6 \times 10^{-19}} = 7.125 \times 10^{4}$ eV

7.1×10^{4} eV

✓**Question 15** (6 marks)

Figure 14 shows the energy-level diagram for a hydrogen atom.

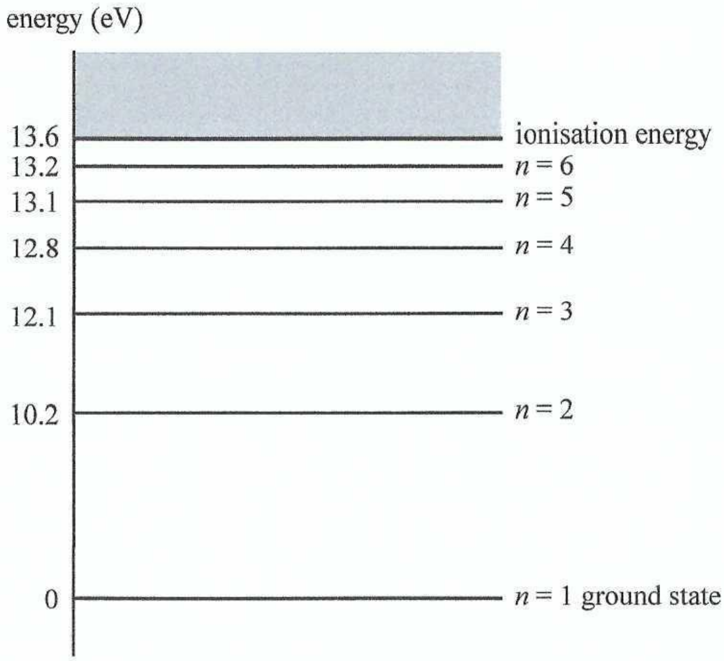


Figure 14

a. The hydrogen atom is excited from the ground state to a higher energy level. Subsequently, it makes a transition from this higher energy level to the $n = 3$ energy level, emitting a photon of wavelength 1242 nm.

What was the number, n, of the energy level before the photon was emitted? Show your working. 3 marks

$\Delta E = \frac{hc}{\lambda} = \frac{4.14 \times 10^{-15} \times 3 \times 10^{8}}{1242 \times 10^{-9}} = 1.0 \text{ eV}$

$12.1 + 1 = 13.1 \text{ eV} \rightarrow n = 5$

$n =$ 5

b. The quantised states of the electron of the hydrogen atom provide evidence of the wave–particle duality of the electron.

Describe how an electron in an allowed state is modelled to provide this evidence. You may include a diagram.

3 marks

Electrons can behave as a waves with wavelength equal to the deBroglie wavelength. Only energy levels which can exist are energy levels ~~w~~ for which standing waves can form. $C = 2\pi r = n\lambda$, where n is a natural number.

✓**Question 16** (8 marks)

April sets up the apparatus shown in Figure 15 to investigate the photoelectric effect. She can change the frequency of the light incident on the metal plate by changing the filter and she can change the type of metal of which the plate is made.

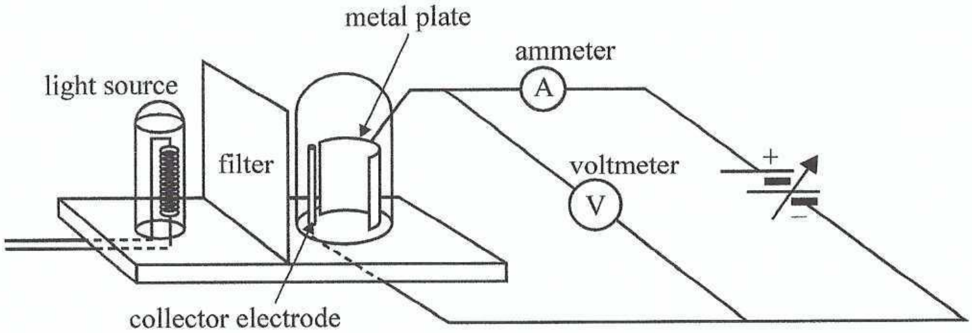


Figure 15

a. For her first experiment, April chooses a filter that gives light of frequency 7.13×10^{14} Hz and a metal plate made of caesium with a work function of 1.95 eV.

April adjusts the voltage of the collector electrode so that the current becomes smaller and smaller.

When the ammeter, A, reaches zero, April records the voltage shown on the voltmeter, V.

Use calculations to determine this voltage. 3 marks

$V = hf - W$

$= 4.14 \times 10^{-15} \times 7.13 \times 10^{14} - 1.95$

$= 2.95 - 1.95$

$= 1$

1.0 V

b. For her second experiment, April uses a metal plate made of zinc. Zinc has a threshold frequency for emission of photoelectrons of 1.04×10^{15} Hz. Photoelectrons are emitted.

Calculate the maximum wavelength, in nanometres, of the light for photoelectrons to be emitted from the zinc plate. Show your working. 2 marks

$\lambda = \frac{c}{f_0} = \frac{3 \times 10^8}{1.04 \times 10^{15}} = 2.88 \times 10^{-7}$ m

288 nm

c. For her third experiment, April changes the metal plate from the zinc plate used in the second experiment to a plate made of platinum. Platinum has a threshold frequency of 1.53×10^{15} Hz. April uses light of frequency 7.13×10^{14} Hz but does not make any other changes. Photoelectrons are not emitted.

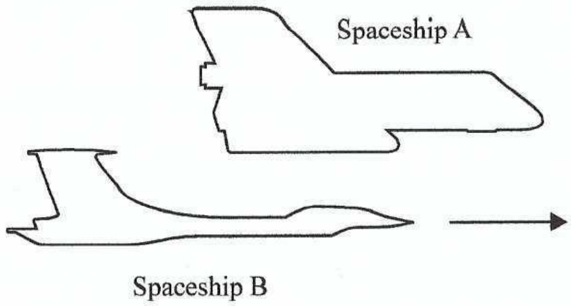
April observes for a longer time and then increases the intensity of the light beam but still finds that photoelectrons are not emitted.

Explain how April's observations support the particle model of light but do not support the wave model of light in explaining the photoelectric effect. 3 marks

Particle model predicts threshold frequency below which light doesn't have enough energy to release photoelectrons regardless of intensity. The wave model predicts that ~~phot~~ electrons can accumulate energy over time and eventually get enough energy to left metal. The particle model predicts that energy of photon depends on frequency and One electron can absorbe 1 photon.

Question 13

Joanna is an observer in Spaceship A, watching Spaceship B fly past at a relative speed of $0.943c$ ($\gamma = 3.00$). She measures the length of Spaceship B from her frame of reference to be 150 m.



Which one of the following is closest to the proper length of Spaceship B?

A. 50 m
B. 150 m
C. 450 m
D. 900 m

Question 14 84%

Electrons of mass 9.1×10^{-31} kg are accelerated in an electron gun to a speed of 1.0×10^{7} m s^{-1}.

The best estimate of the de Broglie wavelength of these electrons is

A. 4.5×10^{-6} m
B. 7.3×10^{-8} m
C. 7.3×10^{-11} m
D. 4.5×10^{-12} m

$\lambda = \frac{h}{mv}$

Question 15 40%

Electrons pass through a fine metal grid, forming a diffraction pattern.

If the speed of the electrons was doubled using the same metal grid, what would be the effect on the fringe spacing?

A. The fringe spacing would increase.
B. The fringe spacing would decrease.
C. The fringe spacing would not change.
D. The fringe spacing cannot be determined from the information given.

$v\uparrow \rightarrow p\uparrow \rightarrow \lambda\downarrow \rightarrow \Delta x\downarrow$

Question 16 77%

Students are conducting a photoelectric effect experiment. They shine light of known frequency onto a metal and measure the maximum kinetic energy of the emitted photoelectrons.

The students increase the intensity of the incident light.

The effect of this increase would most likely be

A. lower maximum kinetic energy of the emitted photoelectrons.

B. higher maximum kinetic energy of the emitted photoelectrons.

C. fewer emitted photoelectrons but of higher maximum kinetic energy.

D. more emitted photoelectrons but of the same maximum kinetic energy.

Question 17

Which one of the following is true when incandescent light is compared to laser light?

A. Laser light has a very wide spectrum; incandescent light has a very narrow spectrum.

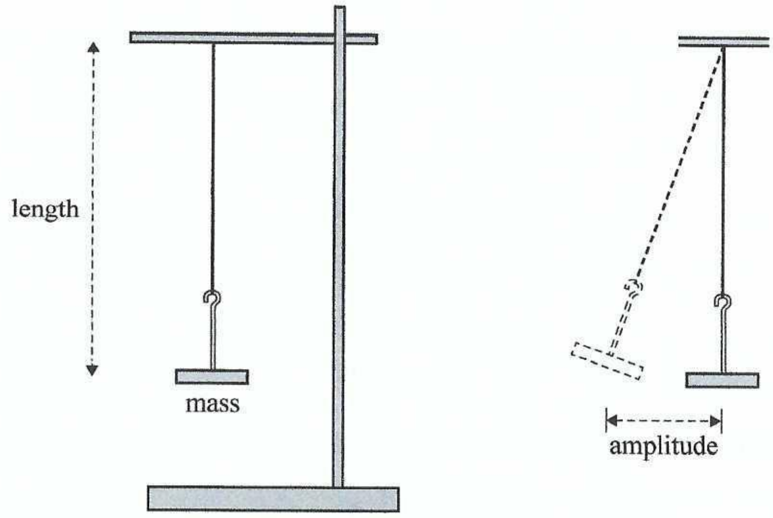
B. Both laser light and incandescent light have a very narrow spectrum.

C. Laser light is incoherent; incandescent light is coherent.

D. Laser light is coherent; incandescent light is incoherent.

Use the following information to answer Questions 18 and 19.

As part of an experimental investigation, Physics students use a pendulum, as shown below, to indirectly measure the magnitude of Earth's gravitational field at their location.



The students use a constant mass and a constant amplitude of swing, changing only the length of the pendulum and then measuring the time for five oscillations. They obtain four different time readings for four different lengths of the pendulum.

By using the relationship

$$T = 2\pi\sqrt{\frac{l}{g}}$$

where T is the period and l is the length of the pendulum, the students obtain four values for the magnitude of Earth's gravitational field.

✓**Question 16** (6 marks)

Students are studying the photoelectric effect using the apparatus shown in Figure 15.

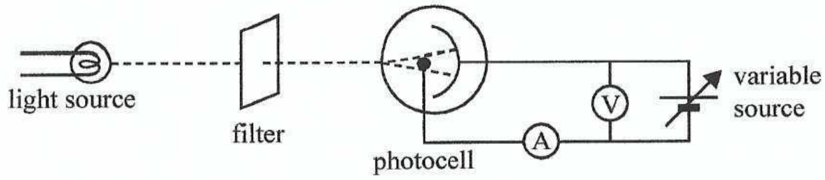


Figure 15

Figure 16 shows the results the students obtained for the maximum kinetic energy ($E_{k\ max}$) of the emitted photoelectrons versus the frequency of the incoming light.

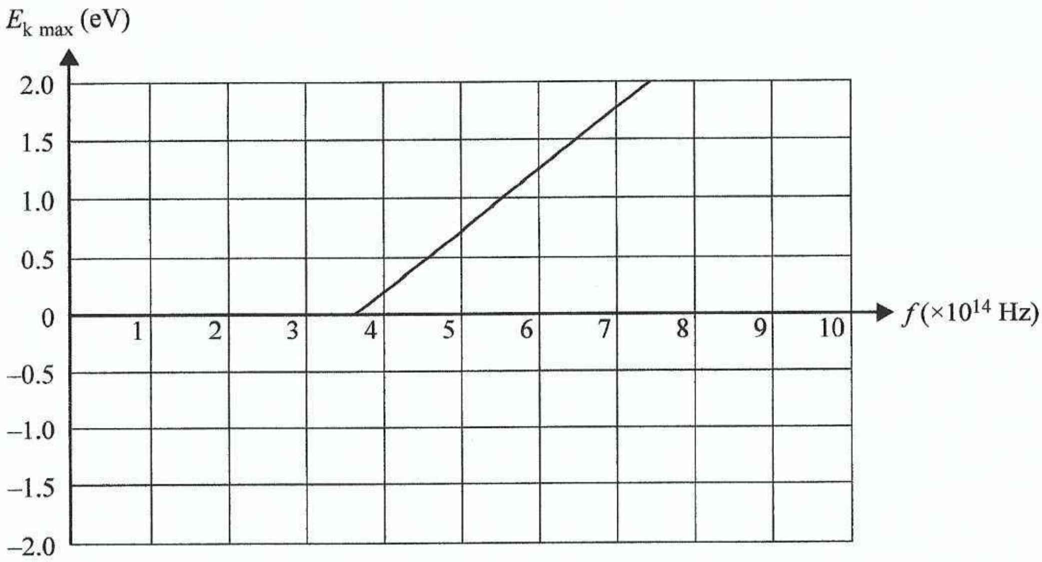


Figure 16

a. Using only data from the graph, determine the values the students would have obtained for — 38%

i. Planck's constant, *h*. Include a unit in your answer — 2 marks

h - gradient $h = \frac{2}{3.8 \times 10^{14}} = 5.3 \times 10^{-15}$

(5 - 5.6)

5.3×10^{-15} eV s

ii. the maximum wavelength of light that would cause the emission of photoelectrons 1 mark

$\lambda = \frac{c}{f_0} = \frac{3\times10^8}{3.7\times10^{14}} = 0.81\times10^{-6} = 8.1\times10^{-7}$ m 44%

810 nm

(790 – 833)

iii. the work function of the metal of the photocell. 1 mark

Read from the graph 56%

1.9 eV

(1.8 – 2.0)

b. The work function for the original metal used in the photocell is ϕ.

On Figure 17, draw the line that would be obtained if a different metal, with a work function of $\frac{1}{2}\phi$, were used in the photocell. The original graph is shown as a dashed line. 2 marks

69%

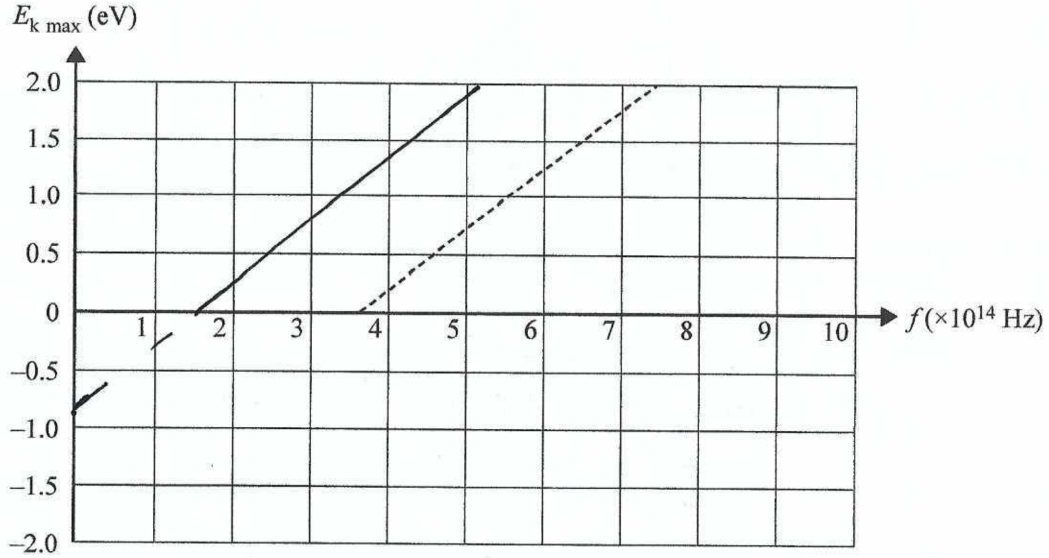
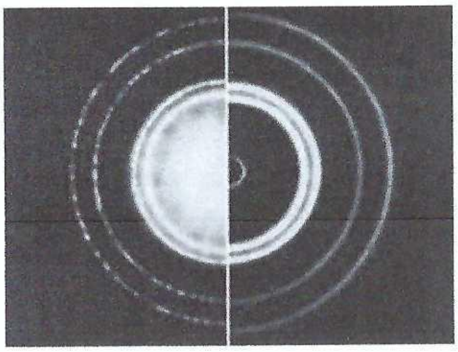


Figure 17

✓**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.

22 %

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

Electrons can behave as waves with deBroglie wavelength

Spacing in diffraction pattern depends on wavelength.

Electrons have same wavelength as X-rays.

23 %

b. Calculate the frequency of X-rays that would produce the same spacing of bands in a diffraction pattern as for the electrons. Show your working. 4 marks

$E_{el} = 3 \times 10^3 \times 1.6 \times 10^{-19} = 4.8 \times 10^{-16}$ J

$p = \sqrt{2mE} = \sqrt{2 \times 9.1 \times 10^{-31} \times 4.8 \times 10^{-16}} = 2.96 \times 10^{-23}$ Ns

$f = \frac{c}{\lambda}$ $\lambda = \frac{h}{p}$

$f = \frac{pc}{h} = \frac{2.96 \times 10^{-23} \times 3 \times 10^8}{6.63 \times 10^{-34}} = 1.34 \times 10^{19}$

1.34×10^{19} Hz

Question 18 (5 marks)

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

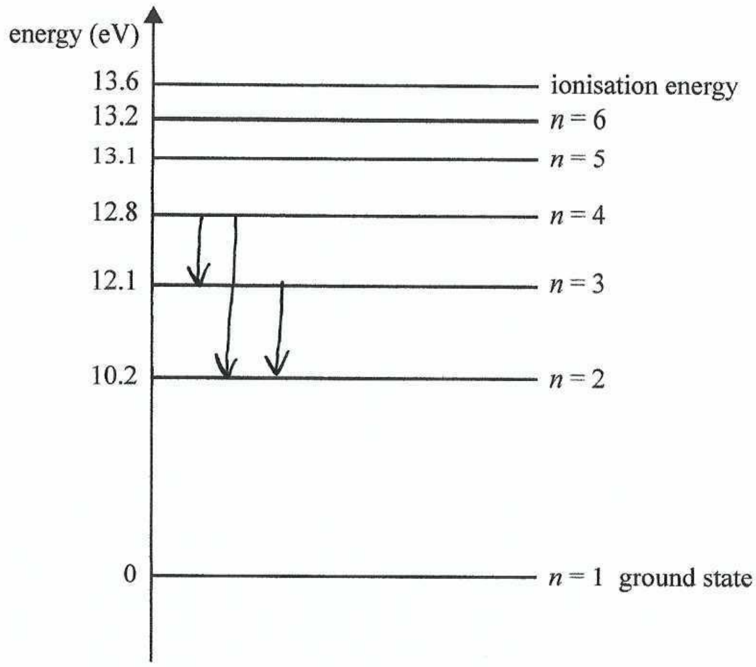


Figure 19

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

54%

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

Absorb photon with energy of 12.8 eV

b. List the possible photon energies that could be emitted as the atom goes from the $n = 4$ state to the $n = 2$ state.

61%

3 marks

2.6 eV 1.9 eV 0.7 eV

Question 15 (4 marks)

The metal surface in a photoelectric cell is exposed to light of a single frequency and intensity in the apparatus shown in Figure 14.

The voltage of the battery can be varied in value and reversed in direction.

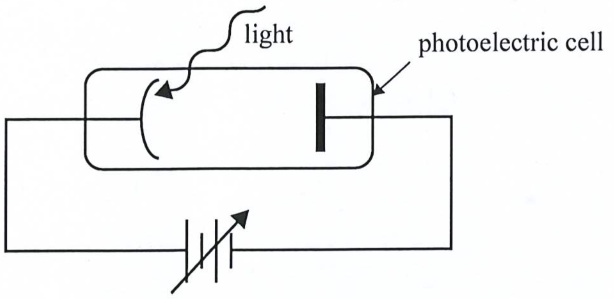


Figure 14

a. A graph of photocurrent versus voltage for one particular experiment is shown in Figure 15.

On Figure 15, draw the trace that would result for another experiment using light of the same frequency but with triple the intensity.

2 marks

52 %

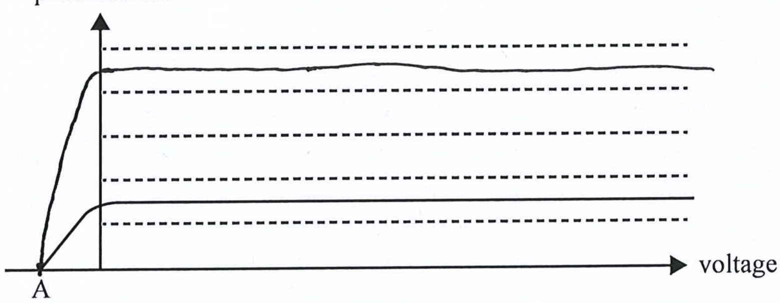


Figure 15

b. What is a name given to the point labelled A on Figure 15?

1 mark

70 %

Stopping voltage

c. Why does the photocurrent fall to zero at the point labelled A on Figure 15?

1 mark

32 %

Stopping voltage is big enough to turn back even the electrons with highest kinetic energy

Question 16 (5 marks)

A beam of electrons travelling at 1.72×10^5 m s^{-1} illuminates a crystal, producing a diffraction pattern as shown in Figure 16. Take the mass of an electron to be 9.1×10^{-31} kg. Ignore relativistic effects.

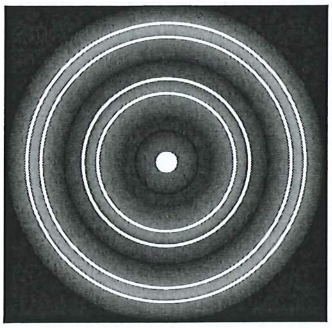


Figure 16

a. Calculate the kinetic energy of one of the electrons. Show your working. 2 marks

51 %

$E_K = \frac{mv^2}{2}$

$= \frac{9.1 \times 10^{-31} \times (1.72 \times 10^5)^2}{2} = 1.35 \times 10^{-20}$ J

$\frac{1.35 \times 10^{-20}}{1.6 \times 10^{-19}} = 0.08$ eV

0.08 eV

b. The electron beam is now replaced by an X-ray beam. The resulting diffraction pattern has the same spacing as that produced by the electron beam.

Calculate the energy of one X-ray photon. Show your working. 3 marks

32 %

$\lambda_x = \lambda_e \quad p_x = p_e \quad p_e = 9.1 \times 10^{-31} \times 1.72 \times 10^5$

$= 1.565 \times 10^{-25}$ kg m s^{-2}

$E_x = pc = 1.565 \times 10^{-25} \times 3 \times 10^8 = 4.7 \times 10^{-17}$ J

$\frac{4.7 \times 10^{-17}}{1.6 \times 10^{-19}} = 293$

293 eV

Question 17 (5 marks)

Figure 17 shows the emission spectrum for helium gas.

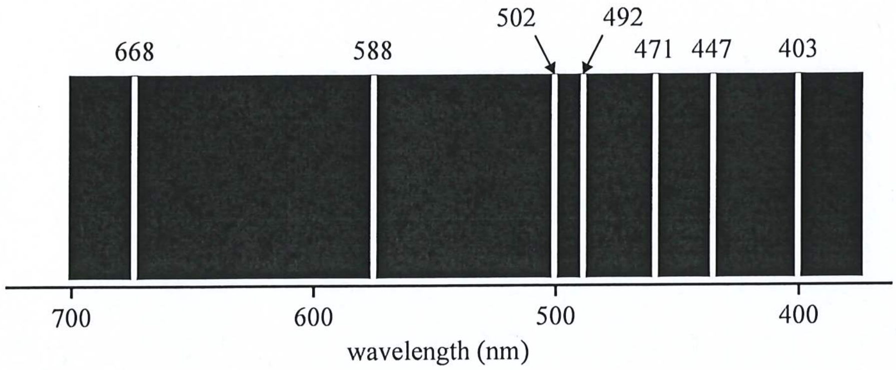


Figure 17

a. Which spectral line indicates the photon with the lowest energy? 1 mark

668 nm

Longest wavelength ~ lowest energy 60%.

b. Calculate the frequency of the photon emitted at the 588 nm line. Show your working. 2 marks

59%

$f = \frac{c}{\lambda} = \frac{3 \times 10^8}{588 \times 10^{-9}}$

5.1×10^{14} Hz

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

2 marks

Electron exist only in discrete energy levels (1m) 17%.
When electron transition between these energy Levels happen only discrete amounts of energy are emitted. (1m)