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OCR A LEVEL PHYSICS A (H556): QUESTIONS BY TOPIC

Quantum physics (4.5)

A Level Physics A (H556) · Module 4: Electrons, waves and photons

33 questions · 215 marks · Mark schemes included

OCR A Level Physics A (H556), June 2017 – June 2025

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HOW TO USE THIS BOOKLET

Questions run from the lowest mark tariff to the highest, so similar questions sit together.

Click any row below to jump straight to that question.

On every question page, click ANSWER in the top-right corner to jump to its mark scheme.

Diagrams, graphs, tables and data are printed exactly as they appeared in the original papers.

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QUESTIONS

33 questions · 215 marks · lowest tariff first



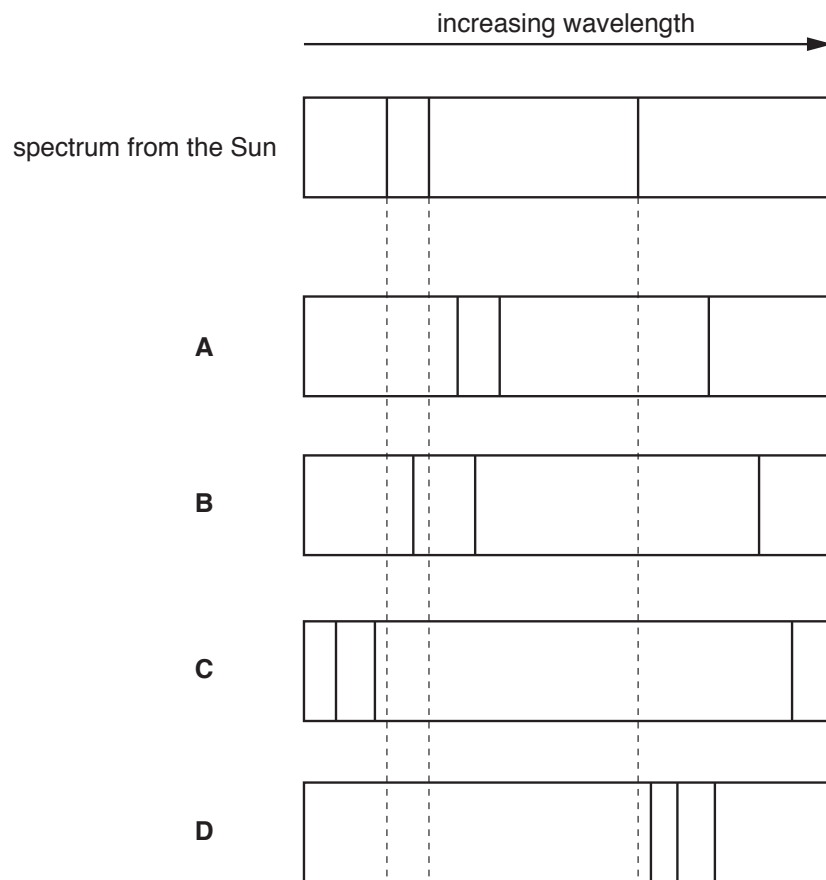
MULTIPLE-CHOICE QUESTIONS

12 questions in this booklet



10 Part of the line spectrum for light from the Sun is shown below.

Which spectrum best shows light from a similar star to the Sun?



Your answer

[1]

- 14** There are four important attenuation mechanisms by which X-ray photons may interact when they pass through matter.

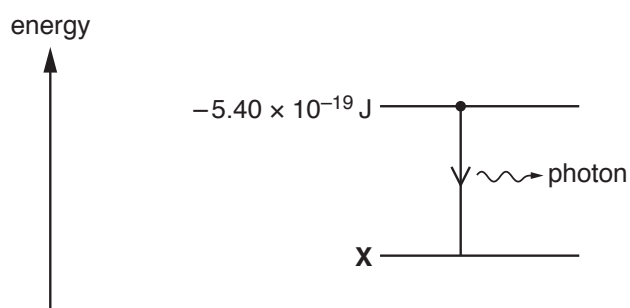
In which mechanism is the X-ray photon scattered with a longer wavelength?

- A** simple scattering
- B** Compton effect
- C** pair production
- D** photoelectric effect

Your answer

[1]

- 8 An electron makes a transition between the two energy levels shown below.



This transition produces a photon of frequency $4.10 \times 10^{14} \text{ Hz}$.

What is the value of the energy level X?

- A $-2.68 \times 10^{-19} \text{ J}$
- B $-2.72 \times 10^{-19} \text{ J}$
- C $-5.40 \times 10^{-19} \text{ J}$
- D $-8.12 \times 10^{-19} \text{ J}$

Your answer

[1]

- 3 An electron has a de Broglie wavelength equal to the wavelength of X-rays.

What is the **best** estimate of the momentum of this electron?

A $10^{-30} \text{ kg m s}^{-1}$

B $10^{-27} \text{ kg m s}^{-1}$

C $10^{-23} \text{ kg m s}^{-1}$

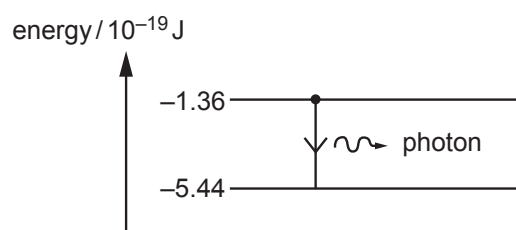
D $10^{-18} \text{ kg m s}^{-1}$

Your answer

[1]



- 6 The diagram below shows two energy levels for the electron in the hydrogen atom.



The electron makes the transition shown by the arrow.

What is the wavelength of the photon emitted?

- A 293 nm
- B 366 nm
- C 488 nm
- D 1460 nm

Your answer

[1]

- 3 Electromagnetic radiation is incident on a metal of work function 2.3 eV .
The maximum kinetic energy (KE) of the photoelectrons is 1.7 eV .

The frequency of this incident electromagnetic radiation is kept the same but its intensity is doubled.

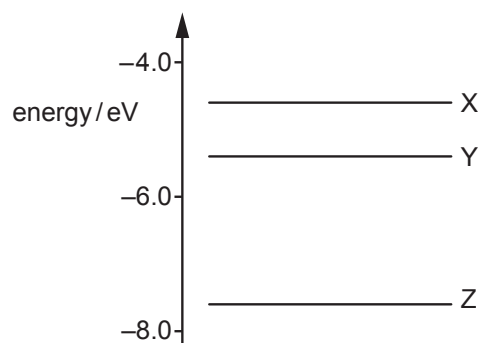
What is the maximum KE of the photoelectrons now?

- A 1.7 eV
- B 2.9 eV
- C 3.4 eV
- D 4.0 eV

Your answer

[1]

12 The diagram shows three energy levels X, Y and Z of an electron within a gas atom.



Which transition is correct when the electron absorbs a photon with the shortest wavelength?

A $Z \rightarrow X$

B $X \rightarrow Z$

C $Y \rightarrow X$

D $X \rightarrow Y$

Your answer

[1]

4 Which of the following statement(s) correctly describe radioactive decay?

- 1 Radioactive decay can be modelled using dice.
- 2 Radioactive decay of nuclei is random.
- 3 Radioactive decay of nuclei is spontaneous.

A Only 1

B Only 2

C 2 and 3

D 1, 2 and 3

Your answer

[1]

- 5 A gamma-ray photon of frequency 6.76×10^{22} Hz creates a particle-antiparticle pair. The particle-antiparticle pair have zero kinetic energy.

What is the mass of the particle?

A 2.49×10^{-28} kg

B 4.98×10^{-28} kg

C 7.47×10^{-20} kg

D 4.48×10^{-11} kg

Your answer

[1]

- 10 A proton of mass $1.67 \times 10^{-27} \text{ kg}$ is travelling at a speed of $2.0 \times 10^5 \text{ m s}^{-1}$.

The table below shows the mass and speed of four particles **A**, **B**, **C** and **D**.

Particle	Mass / kg	Speed / 10^5 m s^{-1}
A	9.11×10^{-30}	5.0
B	8.80×10^{-28}	3.0
C	2.49×10^{-28}	2.0
D	3.34×10^{-27}	1.0

Which particle has the same de Broglie wavelength as the proton?

Your answer

[1]

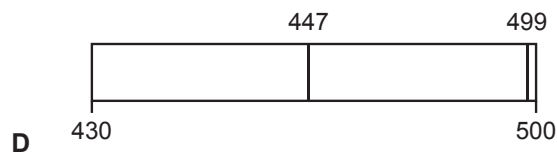
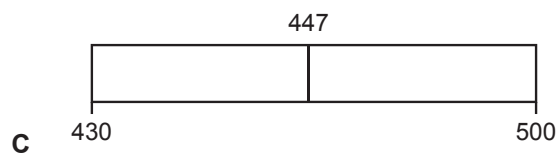
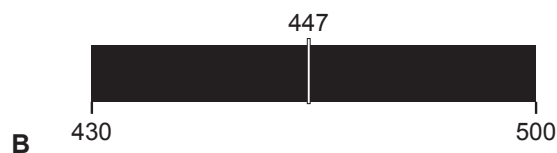
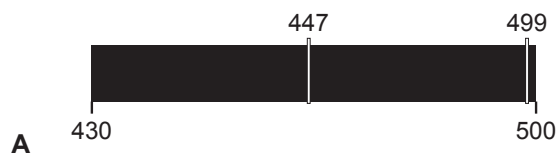
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- 14 Part of the emission spectrum for hydrogen in a laboratory is shown. All wavelengths are given in nm.



Which diagram shows the corresponding part of the absorption spectrum observed from Earth emitted from a galaxy moving away with a velocity of $0.031c$?



Your answer

[1]

15 Which sequence shows the energies below in **increasing** order of magnitude?

- 1 The change in kinetic energy of an electron accelerated through a potential difference of 1 V.
- 2 The kinetic energy of a proton with a velocity of 1000 m s^{-1} .
- 3 The energy of an X-ray photon with a frequency of $3 \times 10^{17} \text{ Hz}$.

A 1 2 3

B 3 1 2

C 2 1 3

D 1 3 2

Your answer

[1]

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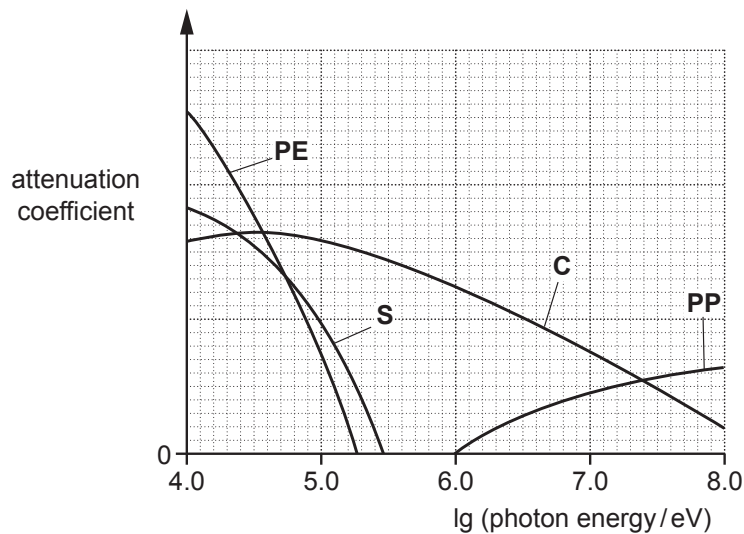
4-MARK QUESTIONS

1 question in this booklet



25 X-ray photons interact with atoms.

The attenuation coefficient against $\lg(\text{photon energy})$ graphs for simple scattering (**S**), photoelectric effect (**PE**), Compton effect (**C**) and pair production (**PP**) are shown below.



- (a) For the X-ray tubes used in hospital, the X-ray photons have energy of about 10^5 eV .

State the attenuation mechanisms for these photons.

.....
 [1]

- (b) With the help of a calculation, explain the minimum photon energy shown on the graph for pair production.

.....

 [3]

5-MARK QUESTIONS

1 question in this booklet



23 A gamma camera has several important components including a collimator, scintillator and photomultiplier tubes.

(a) Suggest why the collimator needs to be long and narrow.

.....
..... [1]

(b) State the function of the scintillator.

.....
..... [1]

(c) In a single photomultiplier tube, a photon of light produces a $0.32\text{ }\mu\text{A}$ pulse of current for a duration of 1.2 ns .

Calculate the number of electrons responsible for this pulse of current.

number of electrons = ... [2]

(d) State one diagnostic application of a gamma camera.

.....
..... [1]

Question 24 is on the next page



6-MARK QUESTIONS

1 question in this booklet



17* 'Wave-particle duality' refers to the idea that:

- particles, such as electrons, can show behaviour characteristic of waves
- waves, such as visible light, can show behaviour characteristic of particles.

Describe each model.

Describe the experimental evidence that justifies the model.

You do **not** need to describe in detail how the experiments are carried out. [6]

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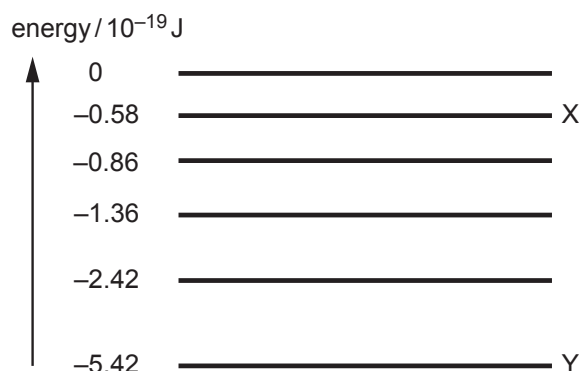
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7-MARK QUESTIONS

1 question in this booklet



- 23** The diagram shows some of the energy levels of the electron in a hydrogen atom.



- (a)** An electron moves from energy level X to energy level Y.

Show that the wavelength of the photon produced is about 410 nm.

[2]

- (b)** The light from the stars in a distant galaxy is analysed on the Earth using a diffraction grating.

Dark lines are observed in the spectrum.

An astronomer concludes that the dark line at a wavelength 432 nm corresponds to the electron transition between X and Y.

- (i)** Explain the origin of the dark lines.

.....

 [2]

- (ii)** Calculate the recession velocity v of the galaxy.

$v = \dots\dots\dots \text{ms}^{-1}$ [2]

- (iii)** State the name of the theory that is supported by evidence from the measurement of the recession velocities of galaxies in the universe.

..... [1]



8-MARK QUESTIONS

3 questions in this booklet



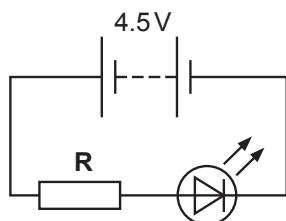
- 17 A light-emitting diode (LED) emits red light when it is positively biased and has a potential difference (p.d.) greater than about 1.8 V.

- (a) The energy of a photon of red light is about 1.8 eV.

Calculate the wavelength λ of this red light.

$\lambda = \dots\dots\dots$ m [3]

- (b) The LED is connected into a circuit, as shown below.

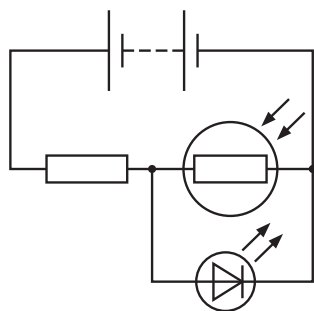


The battery has electromotive force (e.m.f.) 4.5 V and negligible internal resistance.
The resistor **R** has resistance 150 Ω .
Assume the p.d. across the LED is 1.8 V.

Calculate the ratio $\frac{\text{power dissipated by LED}}{\text{power dissipated by resistor}}$.

ratio = $\dots\dots\dots$ [2]

(c) The diagram below shows a circuit designed by a student.



The LED is very close to, and facing the light dependent resistor (LDR).
The circuit is taken into a dark room.

- (i) The student thought that the LED would switch on.
Instead, the LED was found to repeatedly switch on and off.

Explain this behaviour of the LED in this potential divider circuit.

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 [2]

- (ii) Suggest a possible refinement so that the LED switches on permanently when taken into the dark room.

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 [1]

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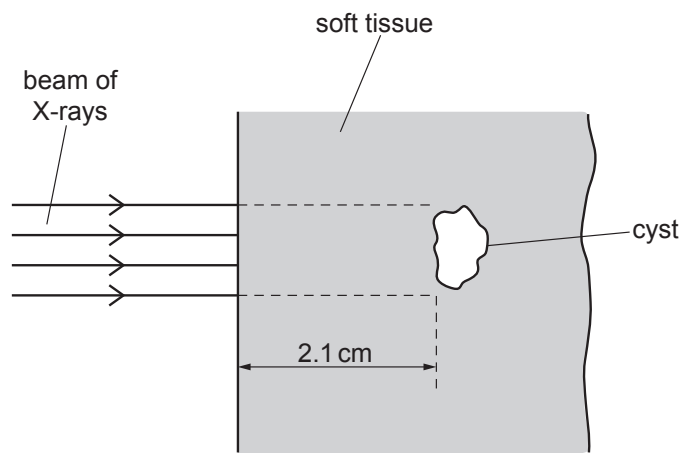
- 21 (a) A high-energy X-ray photon interacts with an electron of an atom through the **Compton effect**.

Describe this effect.

.....

 [2]

- (b) The diagram below shows a beam of X-rays incident normally on some soft tissue.



The attenuation (absorption) constant of the soft tissue is 0.85 cm^{-1} .

The intensity of the beam is $4.6 \times 10^3 \text{ W m}^{-2}$.

There is a small cyst 2.1 cm from the surface of the soft tissue. The cross-sectional area of the cyst normal to the beam is $3.4 \times 10^{-4} \text{ m}^2$.

The beam is switched on for 30 s.

Calculate the X-ray energy incident on the cyst in a period of 30 s.

energy = ... J [4]

- (c) The attenuation coefficients of the cyst and the soft tissues in (b) were similar. This prevented imaging the cyst using a two-dimensional X-ray image.

Name a different X-ray technique that could be used to image the cyst. Explain the advantage of this technique.

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..... [2]



Additional answer space if required

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9-MARK QUESTIONS

4 questions in this booklet



- 5 Hydrogen atoms excited in a discharge tube only emit four different discrete wavelengths of visible photons.

*(a) In a semi-darkened room, a single slit is placed in front of the discharge tube. A student holds a diffraction grating which has 300 lines per millimetre. The student looks through the grating at a 15 cm plastic ruler placed 0.50 m away, as shown in Fig. 5.1. The paths of the different colours of light from the slit to the student's eye are shown in Fig. 5.2.

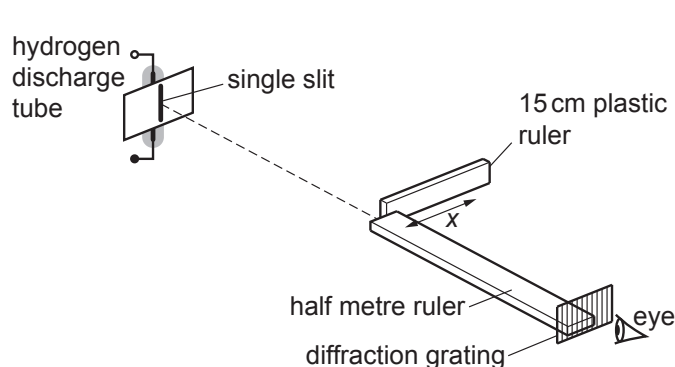


Fig. 5.1 (not to scale)

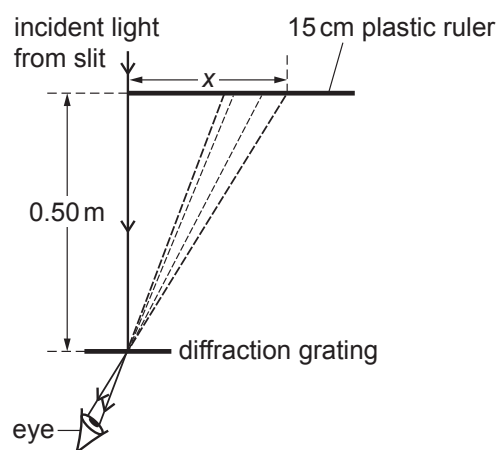


Fig. 5.2 (not to scale)

Four **first** order images of the slit, one at each photon wavelength, are observed as vertical lines against the background of the plastic ruler, as shown in Fig. 5.3.

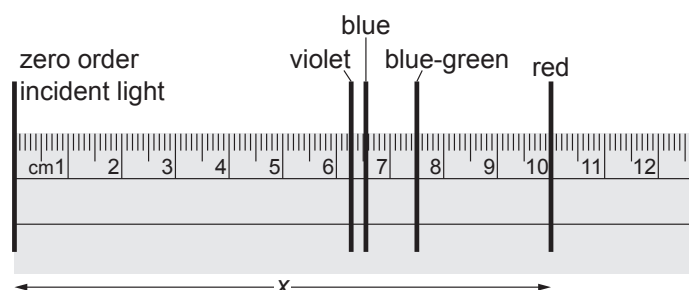


Fig. 5.3

The student decides to determine the wavelength of the photons which form the **red** line observed at $x = 10$ cm on the ruler.

- Describe how the information that has been given can be used to determine the wavelength of the red photons.
- Estimate the percentage uncertainty in the measured value of the wavelength. [6]

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Question 5 continues on page 18

- (b) (i) Show that the energy of a photon of wavelength 486 nm is 4.09×10^{-19} J.

[1]

- (ii) Fig. 5.4 shows some of the energy levels of an electron in a hydrogen atom.

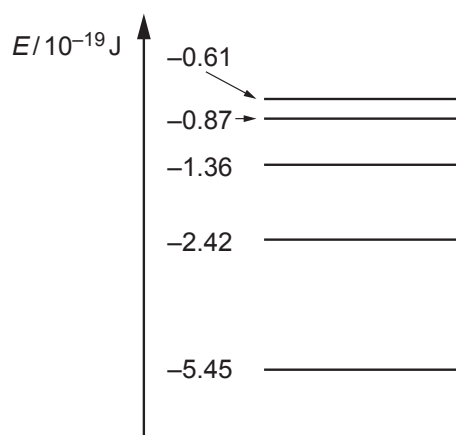


Fig. 5.4 (not to scale)

Draw an arrow on Fig. 5.4 to show an electron transition which would cause the **emission** of a photon of wavelength 486 nm. [2]

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Question 6 begins on page 20



17 (a) Define the **work function** of a metal.

.....
..... [1]

(b) The work function of potassium is 2.3 eV.

- (i) Potassium emits electrons from its surface when blue light is incident on it. Extremely intense red light produces no electrons.

Explain these observations in terms of photons and their energy.

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..... [4]

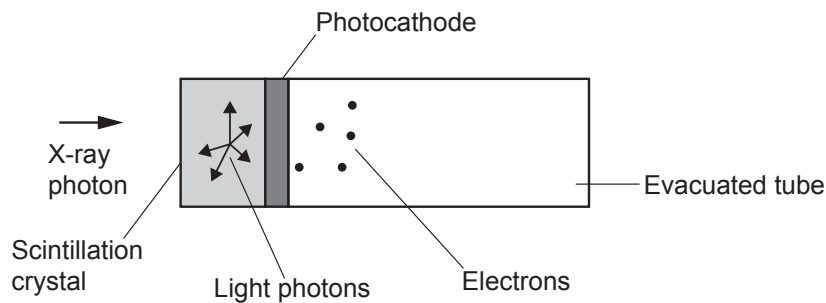
- (ii) Light from a laser is incident on some potassium in a vacuum. Electrons are emitted. The wavelength of the light is 320 nm.

Calculate the shortest de Broglie wavelength of the emitted electrons.

de Broglie wavelength = ... m [4]

- 19 The diagram shows part of an X-ray telescope which uses a crystal scintillation device to detect low energy X-rays from the stars.

X-rays hit the crystal and cause it to emit visible light photons. These travel to the photocathode in an evacuated tube. The photocathode uses the light photons to produce electrons.



Each X-ray photon detected by the telescope has an energy of 32 keV.

The light photons have a wavelength of 510 nm.

The efficiency of the crystal is 15%.

- (a) Show that each X-ray photon produces about 2000 light photons.

[3]

- (b) The photocathode has a work function of 2.3 eV.

- (i) Explain what is meant by the *work function*.

.....
 [1]

- (ii) Calculate the maximum kinetic energy of the electrons leaving the photocathode.

maximum kinetic energy = ...J [2]

- (iii) 12 X-ray photons are detected every minute.

Use your answer to (a) to calculate the current I leaving the photocathode. Assume that all the photons of light produce photoelectrons.

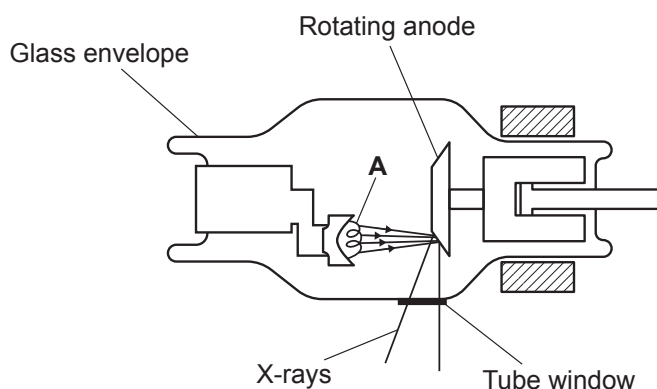
I = ... A [2]

- (iv) State one other assumption you have made to enable you to calculate the current I in (b)(iii).

.....
..... [1]

18 X-rays are used for diagnostic imaging in a hospital.

The diagram shows the structure of an X-ray tube.



(a) Name the component labelled **A** on the diagram.

..... [1]

(b) Suggest why the anode is made to rotate.

..... [1]

(c) X-rays are produced at characteristic wavelengths which depend on the material of the anode.

Describe how the electrons from component **A** are responsible for producing X-rays.

.....
.....
..... [2]

- (d) An electron strikes the anode. The kinetic energy of the electron changes from 150 keV to 60 keV.

Calculate the minimum wavelength, λ , of the X-ray photon emitted by the interaction of the electron with the anode.

$$\lambda = \dots\dots\dots \text{ m [3]}$$

- (e) A radiologist targets a uniform beam of X-rays at a tumour 4.6 cm below the skin of a patient. The beam is at right angles to the surface of the skin.

The intensity of the X-ray beam at the tumour is 30% of the incident intensity.

Calculate the attenuation coefficient, μ , of the tumour tissue in cm^{-1} .

$$\mu = \dots\dots\dots \text{ cm}^{-1} [2]$$

10-MARK QUESTIONS

2 questions in this booklet



- 19 (a) Electromagnetic radiation is incident on a negatively charged zinc plate. Electrons are emitted from the surface of the plate when a weak intensity ultraviolet source is used. Electrons are not emitted at all when an intense visible light from a lamp is used.

Explain these observations.

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..... [4]

- (b) The **maximum** wavelength of the electromagnetic radiation incident on the surface of a metal which causes electrons to be emitted is $2.9 \times 10^{-7} \text{ m}$.

Calculate the maximum kinetic energy of electrons emitted from the surface of the metal when each incident photon has energy of 5.1 eV.

maximum kinetic energy = ... J [3]

- (c) Electromagnetic radiation of constant wavelength is incident on a metal plate. Photoelectrons are emitted from the metal plate. Fig. 19.1 shows an arrangement used to determine the maximum kinetic energy of electrons emitted from a metal plate.

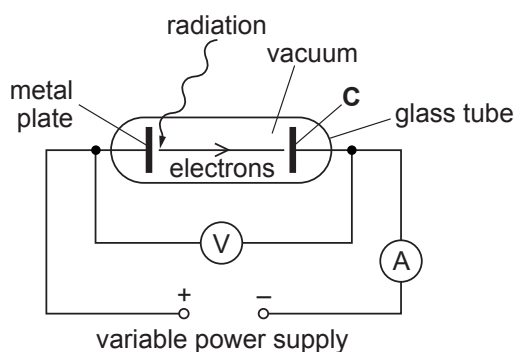


Fig. 19.1

The metal plate and the electrode C are both in a vacuum. The electrode C is connected to the negative terminal of the variable power supply.

Fig. 19.2 shows the variation of current I in the circuit as the potential difference V between the metal plate and C is increased from 0 V to 3.0 V.

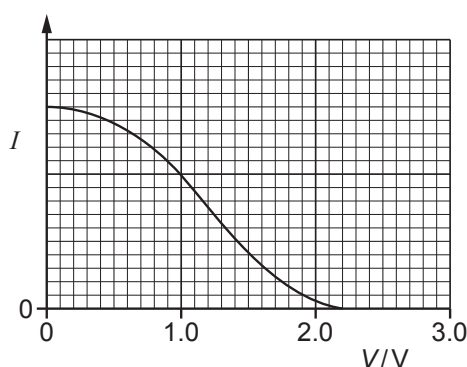


Fig. 19.2

Explain why the current decreases as V increases and describe how you can determine the maximum kinetic energy of the emitted electrons.

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..... [3]

19 Fig. 19.1 shows an electric circuit.

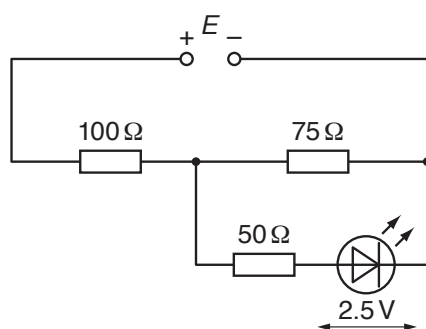


Fig. 19.1

The power supply has electromotive force (e.m.f.) E and negligible internal resistance.

The resistance values of the resistors are shown in Fig. 19.1. The I – V characteristic of the light-emitting diode (LED) is shown in Fig. 19.2.

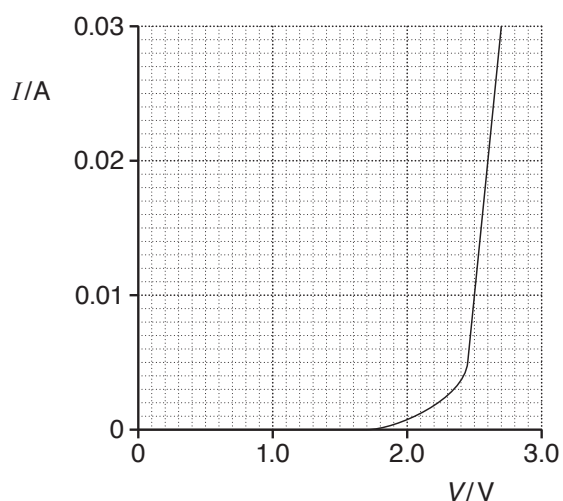


Fig. 19.2

The potential difference (p.d.) across the LED is $2.5\ \text{V}$.

(a) Use Fig. 19.2 to show that the p.d. across the $50\ \Omega$ resistor is $0.50\ \text{V}$.

- (b) Calculate the e.m.f. E of the power supply.

$E = \dots\dots\dots$ V [3]

- (c) The LED emits blue light of wavelength 4.7×10^{-7} m.

- (i) Estimate the number of blue light photons emitted from the LED per second.

number of photons per second = $\dots\dots\dots$ s⁻¹ [3]

- (ii) The light from the LED is incident on a metal of work function 2.3 eV.

Explain, with the help of a calculation, whether or not photoelectrons will be emitted from the surface of the metal.

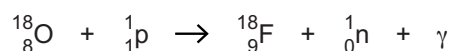
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..... [2]

11-MARK QUESTIONS

4 questions in this booklet



- 25 (a) The nuclear reaction below shows how the isotope of fluorine-18 ($^{18}_9\text{F}$) is made from the isotope of oxygen-18 ($^{18}_8\text{O}$).



The oxygen-18 nucleus is **stationary** and the proton has kinetic energy of $0.25 \times 10^{-11} \text{ J}$. The binding energy of the $^{18}_8\text{O}$ nucleus is $2.24 \times 10^{-11} \text{ J}$ and the binding energy of the $^{18}_9\text{F}$ nucleus is $2.20 \times 10^{-11} \text{ J}$. The proton and the neutron have zero binding energy.

- (i) Explain why a high-speed proton is necessary to trigger the nuclear reaction shown above.

.....

 [2]

- (ii) Estimate the minimum wavelength λ of the gamma ray photon (γ).

$\lambda = \dots\dots\dots \text{ m}$ [3]

- (iii) Fluorine-18 is a positron emitter.
 Name a medical imaging technique that uses fluorine-18 and state one benefit of the technique.

.....

 [2]

(b) Describe how the components of a computerised axial tomography (CAT) scanner can produce high-quality images of the internal structures of a patient.

[4]

- 6 Fig. 6.1 shows a single photomultiplier tube and its internal components. The tube can detect gamma photons in high-energy physics experiments.

A single gamma photon incident on the scintillator crystal generates many photons of blue light. These visible light photons travel to the photocathode where they are converted into photoelectrons. The number of electrons is then multiplied in the photomultiplier tube with the help of electrodes called dynodes. A short pulse of electric current is produced at the output end of the photomultiplier tube.

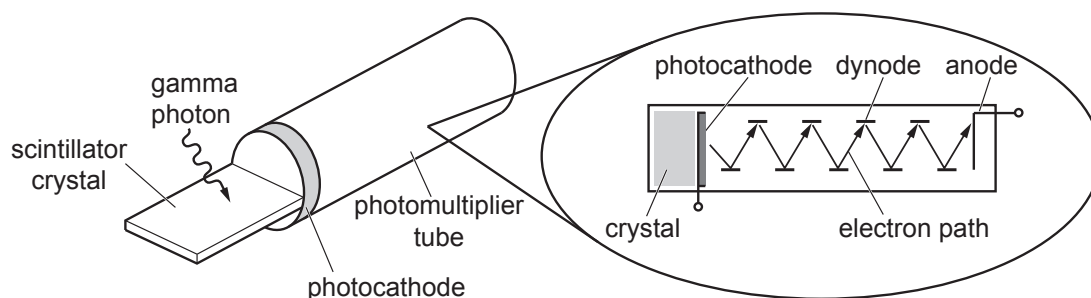


Fig. 6.1

- (a) Fig. 6.2 shows a section through the scintillator crystal in air.

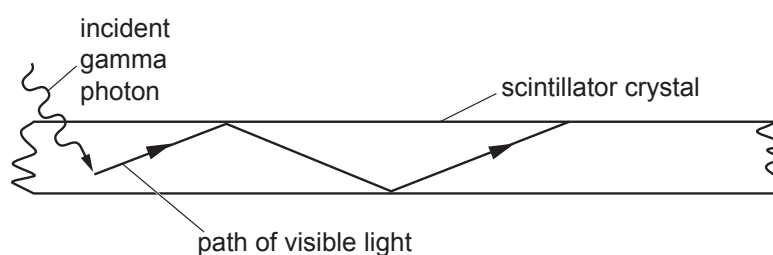


Fig. 6.2

- (i) The refractive index of the scintillator crystal for visible light is 1.69. The refractive index of air is 1.00. Calculate the critical angle C for this crystal.

$$C = \dots\dots\dots^\circ \quad [2]$$

- (ii) Explain why the visible light inside the scintillator crystal follows the path shown in Fig. 6.2.

.....

.....

.....

..... [2]

- (b) A high energy gamma photon passing through the scintillator crystal converts some of its energy into visible light photons of mean wavelength 450 nm.

Show that the energy of a single photon of wavelength 450 nm is less than 3 eV.

[3]

- (c) The photocathode is coated with potassium which has a work function of 2.3 eV. Each emitted photoelectron is accelerated by a potential difference of 100 V between the photocathode and a metal plate, called the first dynode.

- (i) Show that the maximum kinetic energy of an emitted electron at the photocathode is very small compared to its kinetic energy of 100 eV at the first dynode.

[1]

- (ii) 2000 photoelectrons are released from the photocathode. Each photoelectron has enough energy to release four electrons from the first dynode at the collision. These four electrons are then accelerated to the next dynode where the process is repeated. There are 9 dynodes in the photomultiplier tube. The total number of electrons collected at the anode for each photoelectron is 4^9 .

The pulse of electrons at the anode lasts for a time of 2.5×10^{-9} s.

Calculate the average current due to this pulse.

average current = ... A [3]



- 19 (a) The Planck constant h is an important fundamental constant in quantum physics.

Determine the S.I. base units for h .

base units = ... [2]

- (b) A researcher is investigating the de Broglie wavelength of charged particles.

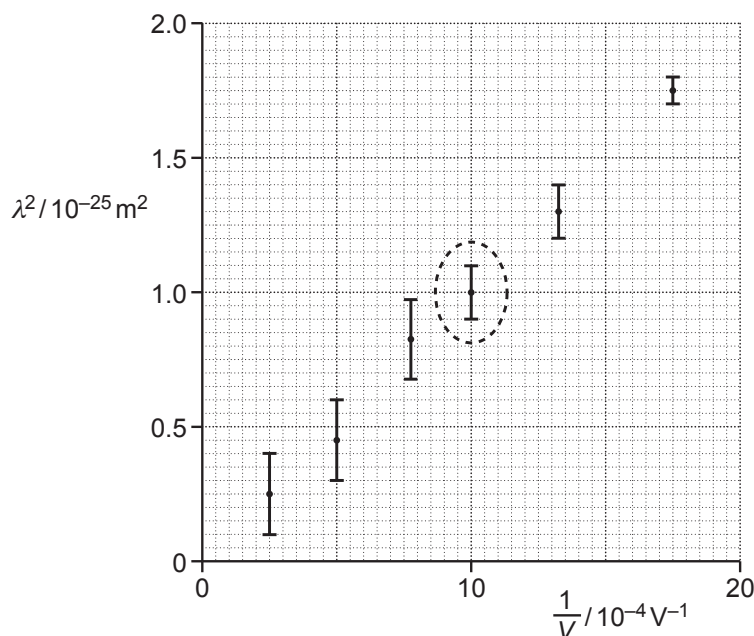
The charged particles are accelerated through a potential difference V . The de Broglie wavelength λ of these particles is then determined by the researcher.

Each particle has mass m and charge q .

- (i) Show that the de Broglie wavelength λ is given by the expression $\lambda^2 = \frac{h^2}{2mq} \times \frac{1}{V}$.

[2]

- (ii) The researcher plots data points on a λ^2 against $\frac{1}{V}$ grid, as shown below.



- 1 Calculate the percentage uncertainty in λ for the data point circled on the grid.

percentage uncertainty = ... % [2]

- 2 Draw a straight line of best fit through the data points. [1]

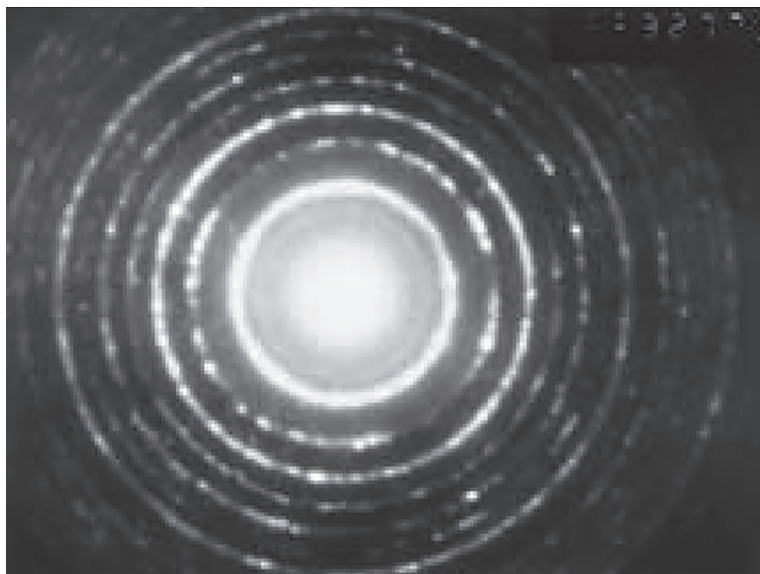
- 3 The charge q on the particle is $2e$, where e is the elementary charge.

Use your best fit straight line to show that the mass m of the particle is about 10^{-26} kg.

[4]



- 19 The picture shows an electron diffraction pattern produced by graphite in a cathode-ray tube.



- (a) Describe the experiment that produces this pattern. Draw a labelled diagram of the apparatus to help you.

.....

.....

.....

.....

..... [4]

- (b) Explain why light and dark circles as shown in the picture are produced, stating what this evidence provides about electron behaviour.

.....

.....

.....

.....

..... [3]

(c) A potential difference (p.d.) 5 kV is used to accelerate the electrons.

(i) Calculate the work done W on the electrons.

$W = \dots\dots\dots$ J [1]

(ii) Calculate the de Broglie wavelength λ of the accelerated electrons.

$\lambda = \dots\dots\dots$ m [2]

(iii) Suggest a value for the spacing between the graphite atoms.
Justify your answer.

.....
.....
..... [1]

14-MARK QUESTIONS

3 questions in this booklet



- 21 (a) Fig. 21.1 shows some of the energy levels of electrons in hydrogen gas atoms. The energy levels are labelled **A**, **B**, **C** and **D**.

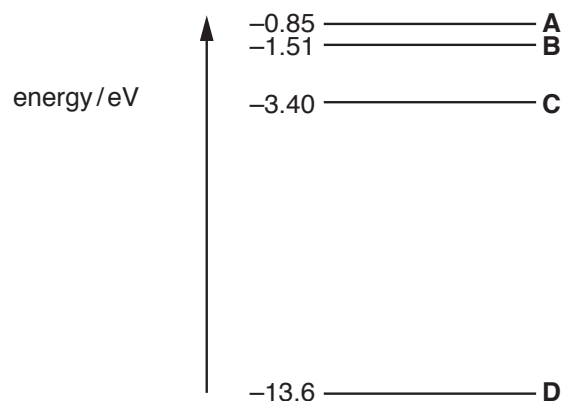


Fig. 21.1 (not to scale)

- (i) Explain why the energy levels are negative.

.....
 [1]

- (ii) An electron makes a transition (jump) from level **C** to level **A**.

- 1 Calculate the energy gained by this electron.

energy = ... eV [1]

- 2 Calculate the wavelength in nm of the photon absorbed by this electron.

wavelength = ... nm [3]

- (b) Light from a distant galaxy is passed through a diffraction grating. Fig. 21.2 shows the part of the spectrum of light that shows a strong hydrogen-alpha emission line.

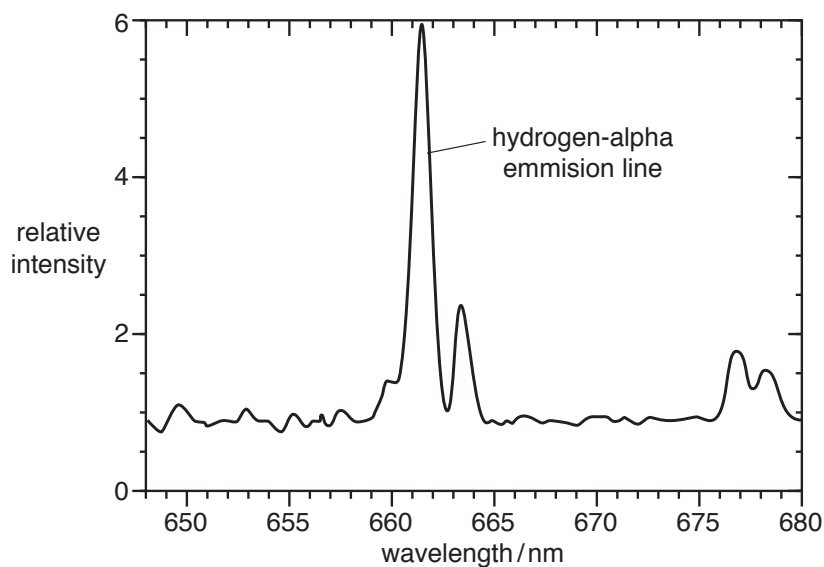


Fig. 21.2

- (i) State how an emission line is produced.

.....
 [1]

- (ii) State an adjustment that could be made to the experimental arrangement that would space the emission lines more widely.

.....
 [1]

- (iii) In the laboratory, the wavelength of the hydrogen-alpha emission line is 656.3 nm. Use Fig. 21.2 to determine the recession velocity of the galaxy.

recession velocity = ... ms^{-1} [3]

- (iv) Suggest why hydrogen spectral lines play an important role in determining red shift of galaxies.

.....
..... [1]

- (c) Light from a similar star is viewed in a galaxy **further** away. The star is part of a pair of stars which orbit a common centre of mass.

Describe and explain how the equivalent spectrum might appear.

.....
.....
.....
.....
.....
.....
..... [3]

- 20 (a) An approximate value of the Planck constant h can be determined in the laboratory using light-emitting diodes (LEDs). An LED suddenly starts to conduct and emit monochromatic light when the potential difference across an LED exceeds a minimum value V_0 . The potential difference V_0 and the wavelength λ of the emitted light are related by the equation

$$V_0 = \left(\frac{hc}{e} \right) \times \frac{1}{\lambda}$$

where e is the elementary charge and c is the speed of light in a vacuum.

Fig. 20.1 shows some data points plotted by a student on a V_0 against $\frac{1}{\lambda}$ graph for five different LEDs.

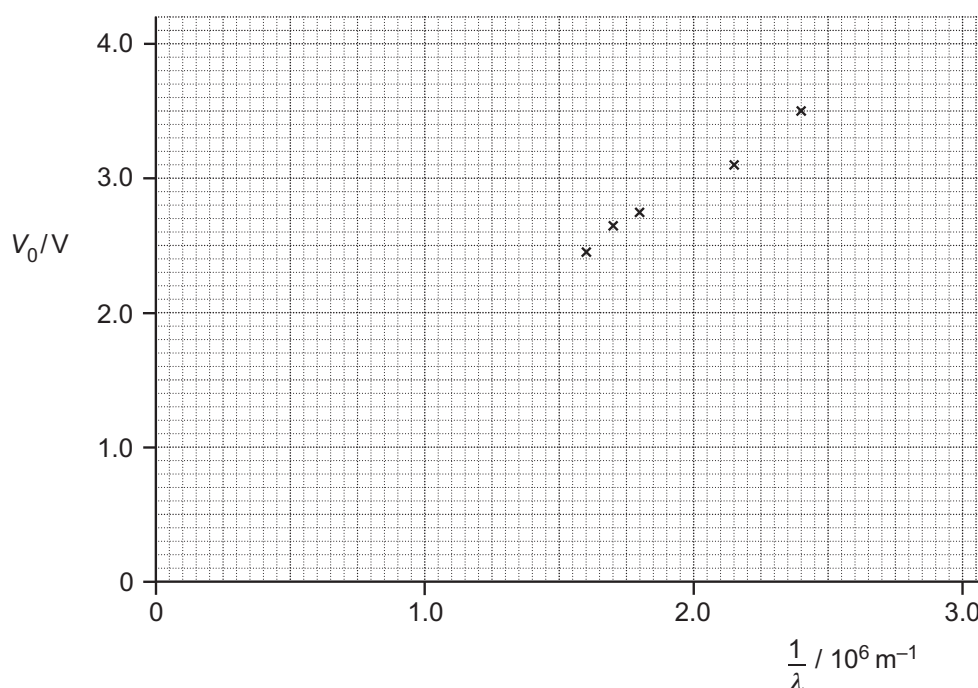


Fig. 20.1

The potential difference across each LED was measured using a digital voltmeter with divisions $\pm 0.01 \text{ V}$. The values for the wavelengths are accurate and were provided by the manufacturer of the LEDs.

The value of V_0 was determined by directly observing the state of the LED in the **brightly** lit laboratory.

- (i) Draw the straight line of best fit on Fig 20.1 and determine the gradient of the line.

- (ii) Use your answer in (i) and the equation on page 20 to determine a value for h to 2 significant figures. Show your working.

$h =$ Js [3]

- (iii) Calculate the percentage difference between your value in (ii) and the accepted value of the Planck constant.

difference = ... % [1]

- (iv) Identify the two types of errors shown by the data in Fig. 20.1 and suggest how you could have refined the experiment to reduce or eliminate these errors.

.....

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.....

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.....

.....

..... [4]

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Question 21 is on page 24
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19 The diagram below shows two parallel plates, **E** and **C**, in an evacuated glass tube.

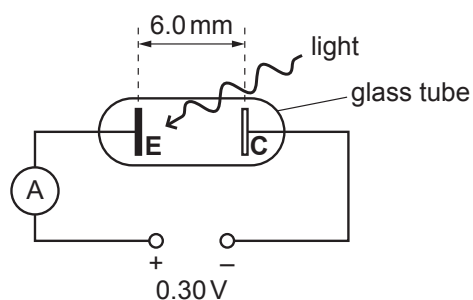


Plate **E** is made from potassium, which is sensitive to light. Plate **C** is not sensitive to light.

The separation between the plates is 6.0 mm and the potential difference between the plates is 0.30 V.

Light of frequency 6.3×10^{14} Hz is incident on plate **E**. The photoelectrons emitted from this plate have **maximum** kinetic energy 0.30 eV (4.8×10^{-20} J). The photoelectrons are repelled by the negative plate **C**. The ammeter reading is zero because these photoelectrons reach plate **C** with zero kinetic energy.

(a) Calculate the work function of potassium in eV.

work function = ... eV [3]

(b) This question is about a photoelectron emitted perpendicular to plate **E** and with an initial kinetic energy of 4.8×10^{-20} J.

(i) Show that the magnitude of deceleration of this photoelectron is $8.8 \times 10^{12} \text{ ms}^{-2}$.

[3]

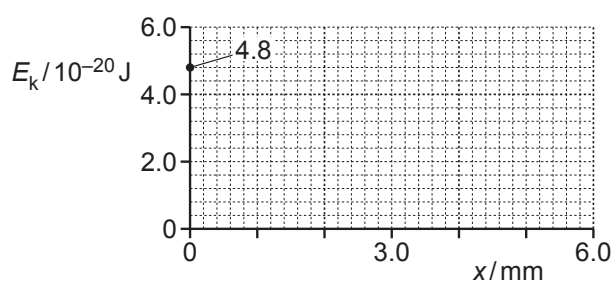
- (ii) Show that the initial speed of the photoelectron is about $3 \times 10^5 \text{ m s}^{-1}$.

[2]

- (iii) Calculate the time t taken by the photoelectron to travel from plate E to plate C.

$t = \dots\dots\dots \text{ s}$ [2]

- (iv) Using the axes shown below, sketch a graph of kinetic energy E_k against distance x from plate E.



[2]

- (c) Explain, in terms of photons, what happens to the ammeter reading when light of frequency greater than $6.3 \times 10^{14} \text{ Hz}$ is now incident on plate E.

.....

 [2]

15-MARK QUESTIONS

1 question in this booklet



- 2 $^{60}_{27}\text{Co}$ is produced by irradiating the stable isotope $^{59}_{27}\text{Co}$ with neutrons.

Each nucleus of $^{60}_{27}\text{Co}$ then decays into a nucleus of nickel (Ni) by the emission of a low energy beta-minus particle, one other particle and two gamma photons.

- (a) Complete the nuclear equations for these two processes.



- (b) Students want to carry out an investigation into gamma photon absorption using a source of $^{60}_{27}\text{Co}$.

They add sheets of lead between the source **S** and a radiation detector **T**, to give a total thickness d of lead. **S** and **T** remain in fixed positions, as shown in Fig. 2.1.

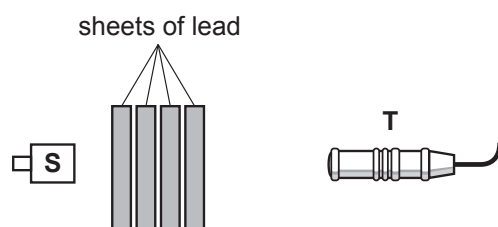


Fig. 2.1

- (i) The $^{60}_{27}\text{Co}$ source emits beta radiation as well as gamma radiation.

Explain why this would not affect the experiment.

.....
 [1]

Question 2 continues on page 6

- (ii) The students record the number N of gamma photons detected by **T** in 10 minutes for each different thickness d of lead. The background count is negligible.

The results are shown in a table. The table includes values of $\ln N$, including the absolute uncertainties.

N	d/mm	$\ln N$
4300 ± 440	0	8.37 ± 0.10
2500 ± 250	10	7.82 ± 0.10
1400 ± 150	20	7.24 ± 0.11
800 ± 90	30	6.68 ± 0.11
500 ± 60	40	6.21 ± 0.12
300 ± 40	50	

N and d are related by the equation $N = N_0 e^{-\mu d}$ where N_0 and μ are constants.

1. The students decide to plot a graph of $\ln N$ against d .

Show that this should give a straight line with gradient $= -\mu$ and y -intercept $= \ln N_0$.

[1]

2. Complete the missing value of $\ln N$ in the table, including the absolute uncertainty.

Show your calculation of the absolute uncertainty in the space below.

[2]

3. In Fig. 2.2, five of the data points have been plotted, including error bars for $\ln N$.
- Plot the missing data point and error bar.
 - Draw a straight line of best fit and one of worst fit.

[2]

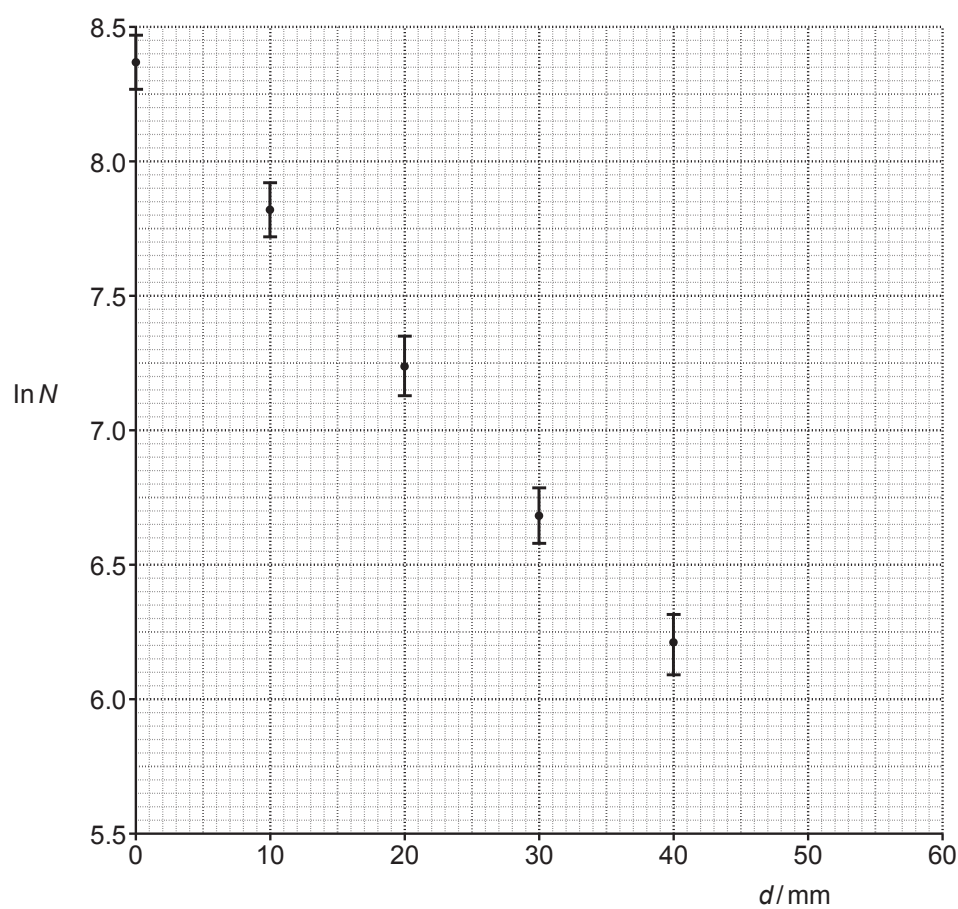


Fig. 2.2

Question 2 continues on page 8

4. Use Fig. 2.2 to determine the value of μ in m^{-1} , including the absolute uncertainty.

$$\mu = \dots\dots\dots \pm \dots\dots\dots \text{m}^{-1} \text{ [4]}$$

5. Determine the thickness, $d_{1/2}$, of lead which halves the number of gamma photons reaching T.

$$d_{1/2} = \dots\dots\dots \text{m} \text{ [2]}$$

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Question 3 begins on page 10.



MARK SCHEMES

official OCR mark schemes



10	B		1	
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14	B		1	
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8	D		1	
---	---	--	---	--



3	C		1	
---	---	--	---	--



6 —	C —	1 .	
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3	A	1	
---	---	---	--



12	A	1	
----	---	---	--



4	D	1	
---	---	---	--



5	A		1	
---	---	--	---	--



10	D		1	
----	---	--	---	--



14	C	1	
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15	C	1	
	Total	15	

9

SECTION B

General rule: For substitution into an equation, allow any subject - unless stated otherwise in the guidance

Question	Answer	Mark	Guidance
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25	(a)		All except pair production / PP	B1	Allow PE, S and C
	(b)		(energy =) $9.11 \times 10^{-31} \times (3.0 \times 10^8)^2$ (energy =) $2 \times 9.11 \times 10^{-31} \times (3.0 \times 10^8)^2 / 1.60 \times 10^{-19}$ $\lg 1.0(2) \times 10^6 = 6$ (as on graph) OR (energy =) 1.0×10^6 (eV) or $\lg 1.0 \times 10^6 = 6$ (from graph) (energy =) 1.6×10^{-13} J and evidence of mc^2 $2 \times 9.11 \times 10^{-31} \times (3.0 \times 10^8)^2 \approx 1.6 \times 10^{-13}$	B1 B1 B1 B1 B1 B1	Note this is 8.2×10^{-14} (J) Note this is $1.0(2) \times 10^6$ eV Note this can be shown in a variety of ways
			Total	4	



23	(a)	Allows only those gamma rays / waves / photons travelling along axis (of the collimator) to get through (and reach scintillator)	B1	Allow less fuzzy / clear image Allow all the gamma rays / waves / photons are parallel / in the same direction (to each other) Allow <u>absorbs</u> those gamma rays / waves / photons not parallel (to the axis of collimator) Allow so the photons are travelling perpendicular to the scintillator Do not allow the gamma rays are travelling vertically, unless it is clear the collimator is also vertical
	(b)	Turn gamma (photons) into (many photons of) light	B1	Ignore reference to rays / waves Ignore reference to flash
	(c)	number of electrons = $\frac{0.32 \times 10^{-6} \times 1.2 \times 10^{-9}}{e}$ number of electrons = 2400	C1 A1	Ignore any POT error for C1 mark
	(d)	Any sensible <u>diagnostic</u> suggestion, e.g. <u>detection</u> of cancer / scans of (named) organ / scans of tissue / bone scans / observing functionality of (named) organ	B1	Not medical <u>treatment</u> e.g. radiotherapy Not body scan Ignore PET scanner Do not allow CAT scan
		Total	5	

17		Level 3 (5–6 marks) Clear description of both models with experimental evidence for both clearly described There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.	Indicative points may include: Description Particles as waves: Shows wave properties such as interference, diffraction, ‘standing waves’ (e.g. in atoms) (de Broglie) wavelength = h/p with some discussion Not localised in space like a particle Waves as particles: Light consists of photons Photon as quantum of electromagnetic energy, energy = hf Only whole quanta emitted, not continuous energy Evidence / Justification Particles as waves: Evidence: electron diffraction The fact the evidence can only be explained using the concept of a wave or is not possible in the particle model e.g. • Passed through (e.g.) graphite • Where atomic separation is similar to wavelength • Changing accelerating voltage changes the wavelength and hence the interference pattern • Rings occur due to constructive and destructive interference • Pattern still observed if intensity is very low => even few / single electron shows diffraction pattern => ‘one electron’ behaves like a wave
		Level 2 (3–4 marks) Clear description of both models OR experimental evidence for both models OR clear description of one model and experimental evidence on one model OR some description of both models and some experimental evidence of both models There is a line of reasoning presented with some structure. The information presented is in the most part relevant and supported by some evidence.	
		Level 1 (1–2 marks) Limited description of one model OR limited experimental evidence for one model There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.	
		0 marks No response or no response worthy of credit.	

Question		Answer	Guidance
			Waves as particles: Evidence: photoelectric effect / LED threshold voltage / emission absorption spectra / discharge of electroscope The fact the evidence can only be explained using particle concept or is not possible under the wave model e.g. • zero (photoelectric) emission below threshold frequency • zero light of LED below threshold pd • gold foil falls when incident light is above a particular frequency • discrete frequencies of emission due to discrete energy levels • increasing intensity below threshold has no effect => not a continuous energy transfer that we would see with waves

23	a		Difference in energy level = 4.84×10^{-19} (J) $\lambda = hc/4.84 \times 10^{-19}$ and 4.11×10^{-7} (m) seen	M1 A1	Accept (-.58 - (-5.42)) for 4.84 Accept $E = hf$ to find f , followed by $\lambda = c/f = 4.11 \times 10^{-7}$ (m) seen Allow 4.104×10^{-7} (m) seen
	b	i	Dark lines are absorption lines / idea of photon absorption / idea of electrons absorbing energy / idea of electrons making transition to higher energy level (i.e. excitation) Caused by light passing through (cooler) stellar atmosphere or Earth's atmosphere	B1 B1	 Allow (cooler) gases/hydrogen (gas)
		ii	$\Delta \lambda / \lambda = 22/410$ or $21/411$ $v = 0.054c = 1.6(1) \times 10^7$ (m s ⁻¹)	C1 A1	NB 21/411 gives 1.5×10^7 (m s ⁻¹) Any evidence of use of 432 as denominator of $\Delta \lambda / \lambda$ is XP zero marks
		iii	Big Bang / Expanding universe i.e. Hubble's Law / dark matter or dark energy / AW	B1	ignore redshift ignore Doppler
			TOTAL	7	



17	(a)	$(E =) 1.8 \times 1.6 \times 10^{-19} \text{ or } 2.88 \times 10^{-19} \text{ (J)}$ $1.8 \times 1.6 \times 10^{-19} = \frac{6.63 \times 10^{-34} \times 3.0 \times 10^8}{\lambda}$ $\lambda = 6.9 \times 10^{-7} \text{ (m)}$	C1 C1 A1	
	(b)	$(V_R =) 2.7 \text{ (V) or (current =) } 0.018 \text{ (A)}$ $(\text{ratio} = \frac{0.018 \times 1.8}{0.018 \times 2.7})$ ratio = 0.67	C1 A1	Note the mark can be scored on circuit diagram Note values of powers are: 0.0324 W and 0.0486 W Allow 2/3; Not 0.66 (rounding error)
	(c) (i)	In darkness LDR has more resistance / p.d. across LDR is large or In light LDR has less resistance / p.d. across LDR is small Clear idea that when the LED is on, this will force the p.d. across LED / LDR to decrease, forcing the LED to switch off (ORA) (The cycle of LED switching on and off is repeated)	B1 B1	Note the explanation must be in terms of p.d. / potential divider. Ignore current
	(ii)	A sensible suggestion, e.g. Point the LED away from the LDR / increase distance (between LED and LDR) / insert a card between (LED and LDR)	B1	
		Total	8	

21	(a)	Electron removed / ejected (from atom) <u>Photon</u> (scattered with) increased wavelength / lower frequency / lower energy	B1 B1	Needs a comparative statement
	(b)	(intensity $I = I_0 e^{-\mu x}$) $= 4.6 \times 10^3 \times e^{-0.85 \times 2.1}$ Either: (power =) $4.6 \times 10^3 \times e^{-0.85 \times 2.1} \times 3.4 \times 10^{-4}$ Or (energy per unit area =) $4.6 \times 10^3 \times e^{-0.85 \times 2.1} \times 30$ energy = $4.6 \times 10^3 \times e^{-0.85 \times 2.1} \times 3.4 \times 10^{-4} \times 30$ energy = 7.9 (J)	C1 C1 C1 A1	intensity = 772 (W m ⁻²) power = 0.262 (W) energy per unit area = 23160 J m ⁻² energy at surface = 47 (J) 2 marks
	(c)	CAT (CT) scan Any <u>one</u> from • A CAT scan will give 3D image • A CAT scan gives better contrast	M1 A1	Insufficient: more detail / clearer image
		Total	8	

17	(a)	eV or J $\rightarrow$ [kg m ² s ⁻²] in base units by any method base units = kg m ² s ⁻¹	C1 A1	Allow kg (m s ⁻¹) ² Allow base units in any order
	*(b)	Level 3 (5–6 marks) Clear description of method and analysis of data <i>There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.</i> Level 2 (3–4 marks) Some description of method and analysis of data or Clear description or Clear analysis <i>There is a line of reasoning presented with some structure. The information presented is in the most part relevant and supported by some evidence.</i> Level 1 (1–2 marks) Limited description or Limited analysis <i>There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.</i> 0 marks <i>No response or no response worthy of credit.</i>	B1× 6	Indicative scientific points may include: Description • Circuit with LED connected to a variable supply (and series /current limiting resistor) / or use of variable resistor • p.d. across LED increased until LED emits light • Voltmeter (across LED) used to measure V • Use a range of LEDs • λ determined using diffraction grating / spectrometer / double-slit / use $n\lambda = d \sin \theta$ / $\lambda = ax/D$ OR λ determined from manufacturer's data / known wavelength • Darkroom used / tube placed over LED used to establish switching of LED / switch-on identified from finite ammeter reading Analysis of data • Plot of V against λ^{-1} / eV against λ^{-1} / eV against c/λ • Line of best-fit drawn through the points • Straight line (through origin) • Correct gradient for described graph hc/e or hc or h • Correct arrangement for determination of h $h = (\text{gradient} \times e) / c$ or $h = \text{gradient} / c$ (allow numerical values for e and/or c)
		Total	8	

5	(a)	Level 3 (5 - 6 marks) Clear procedure or correct determination of wavelength, plus reasonable estimation of uncertainty in λ or $(\sin) \theta$ <i>There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.</i> Level 2 (3 – 4 marks) Description of procedure or correct determination of λ, but no estimation of uncertainty or Clear estimation of uncertainty in wavelength but limited description of procedure and/or determination of λ or $(\sin) \theta$ or Some description of procedure, an attempt to determine the wavelength, and an attempt to estimate uncertainty in some of the measurements (e.g. in x) <i>There is a line of reasoning presented with some structure. The information presented is in the most part relevant and supported by some evidence.</i> Level 1 (1 – 2 marks) A limited selection from the scientific points worthy of credit. <i>There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.</i> 0 marks <i>No response or no response worthy of credit.</i>	B1 x 6	Use level of response annotations in RM Assessor, e.g. L2 for 4 marks, L2^ for 3 marks, etc. <u>L1 maximum for any answers which use formula $\lambda = ax/D$</u> Indicative scientific points may include: Procedure • use formula $n\lambda = d\sin\theta$ • $n = 1$ since first order spectrum • find d using number of lines/mm = 300 mm^{-1} • find θ using distance of grating from plastic ruler = 0.50 m and $x = 0.10 \text{ m}$ (not protractor) Determination of wavelength • calculate d ($= 10^{-3}/300$) = $3.3 \times 10^{-6} \text{ m}$ • use $x = 0.10 \text{ m}$ and distance to grating = 0.50 m to calculate $\tan \theta$ ($= 0.2$) • $\theta = 11.3^\circ$ • $\sin \theta = 0.196$ • alternatively, calculate hypotenuse of triangle (using Pythagoras's theorem) = 0.51 m, giving $\sin \theta$ ($= 0.10/2600^{1/2}$) = 0.196 • allow use of small angle rule ($\sin \theta \approx \tan \theta \approx \theta = 0.2$) • calculate λ ($= 0.196 \times 10^{-3}/300$) = 650 nm Estimation of uncertainty • negligible uncertainty in d (and n) • uncertainty in $\sin \theta$ is found using uncertainty in distance measurements • uncertainty in each distance measurement is $\pm 1.0 \text{ mm}$ or $\pm 0.5 \text{ mm}$ or $\pm 2.0 \text{ mm}$ • maximum % uncertainty in $\tan \theta / \theta / \sin \theta = 3\%$ • so % uncertainty in $\lambda = \%$ uncertainty in $\sin \theta = 3\%$
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H556/03

Mark Scheme

June 2019

Question			Answer	Marks	Guidance
5	(b)	(i)	$E = (hc/\lambda) = 6.63 \times 10^{-34} \times 3(.00) \times 10^8 / 486 \times 10^{-9}$ $E = 4.09 \times 10^{-19} \text{ (J)}$	M1 A0	This is a 'show that' question so the mark is for giving the full substitution of values leading to an answer correct to 3 SF
		(ii)	(vertical) arrow pointing downwards from -1.36 to -5.45	B1 B1	
			Total	9	



H556/03

Mark Scheme

June 2019

Question	Answer	Marks	Guidance
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17	(a)		The <u>minimum</u> energy needed to remove an electron (from the surface of a metal)	B1	Allow work done for energy Allow photoelectron for electron
	(b)	(i)	energy of blue light / photon of blue light > 2.3 eV / work function or energy of red light / photon of red light < 2.3 eV / work function Energy of photon is independent of intensity (energy of photon given by equation) $E = hf$ / $E = hc/\lambda$ One photon interacts with one electron	B1 B1 B1 B1	Not blue light has frequency > threshold frequency Or red light has frequency < threshold frequency Allow intensity linked to <u>rate</u> of photons / <u>rate</u> of electrons emitted per second Allow E proportional f / E proportional to $1/\lambda$
		(ii)	$(\phi =) 2.3 \times 1.6 \times 10^{-19}$ or $(E =) \frac{6.63 \times 10^{-34} \times 3.0 \times 10^8}{320 \times 10^{-9}}$ $(KE_{\max} =) \frac{6.63 \times 10^{-34} \times 3.0 \times 10^8}{320 \times 10^{-9}} - 2.3 \times 1.6 \times 10^{-19}$ $(v =) \sqrt{\frac{2 \times 2.5356 \times 10^{-19}}{9.11 \times 10^{-31}}}$ $(\text{wavelength} =) \frac{6.63 \times 10^{-34}}{9.11 \times 10^{-31} \times 7.46 \times 10^5}$ wavelength = 9.8×10^{-10} (m)	C1 C1 C1 A1	$\phi = 3.68 \times 10^{-19}$ (J); $E = 6.2156 \times 10^{-19}$ (J) $KE_{\max} = 2.5356 \times 10^{-19}$ (J) $v = 7.46 \times 10^5$ (m s ⁻¹)
			Total	9	



19	(a)		Calculation in eV: $E_{\text{light photon}} = hc/\lambda = 6.63 \times 10^{-34} \times 3.0 \times 10^8 / 510 \times 10^{-9}$ $= 3.90 \times 10^{-19} \text{ (J)}$ $E_{\text{light photon}} = 3.9 \times 10^{-19} / 1.6 \times 10^{-19}$ $= 2.44 \text{ (eV)}$ Number of photons = $(E_{\text{x-ray photon}}/E_{\text{light photon}}) \times \text{efficiency}$ $= (32\,000 / 2.44) \times 0.15$ $= 1969$	C1 Calculation in J: $E_{\text{light photon}} = hc/\lambda = 6.63 \times 10^{-34} \times 3.0 \times 10^8 / 510 \times 10^{-9}$ $= 3.90 \times 10^{-19} \text{ (J)}$ C1 $E_{\text{x-ray photon}} = 32 \times 10^3 \times 1.6 \times 10^{-19}$ $= 5.12 \times 10^{-15} \text{ (J)}$ Number of photons = $(E_{\text{x-ray photon}}/E_{\text{light photon}}) \times \text{efficiency}$ $= (5.12 \times 10^{-15} / 3.90 \times 10^{-19}) \times 0.15$ C1 $= 1969$ A0 Answer to at least 3sf Allow use of 2.4eV for energy of light photon to give 2000 in either method
	(b)	(i)	(The work function is) the minimum energy required to release an electron (from the surface of a metal)	B1 Allow minimum work done for minimum energy Do not allow idea of energy needed to release multiple electrons Do not allow release of electron from atom Do not allow idea of ionisation energy
		(ii)	$\phi = 2.3 \times 1.6 \times 10^{-19} \text{ (= } 3.68 \times 10^{-19} \text{ J)}$ $KE_{\text{max}} = (3.90 - 3.68) \times 10^{-19} = 2.2 \times 10^{-20} \text{ (J)}$	C1 Or $\phi = 2.44 - 2.3 \text{ (= } 0.14 \text{ eV)}$ A1 $KE_{\text{max}} = 0.14 \times 1.6 \times 10^{-19} = 2.2 \times 10^{-20} \text{ (J)}$ Answer to at least 2sf Allow use of 2.4 eV to give $1.6 \times 10^{-20} \text{ (J)}$ ecf light photon energy from (a)

Question			Answer	Mark	Guidance
		(iii)	$I \left(= \frac{Q}{t} \right) = \frac{12 \times 1969 \times 1.6 \times 10^{-19}}{60}$ $= 6.3 \times 10^{-17} \text{ (A)}$	C1 A1	Allow full credit for use of 2000 Answer to at least 2sf (6.30) Allow use of $N = 2000$ to give $I = 6.4 \times 10^{-17} \text{ (A)}$ Allow ecf on N from (a)
		(iv)	One from: One to one interaction between (light) photon and electron That there are no secondary electrons That the current is continuous / X-rays arrive at a constant rate within the minute (or 1 every 5s) All the electrons leave the photocathode	B1	

18	(a)	Heater / cathode / filament	B1	ALLOW filament lamp IGNORE Thermionic
18	(b)	Cooling / preventing melting (of anode)	B1	NOT just 'so the same spot isn't hit all the time'
18	(c)	Electrons (in anode) are removed from (inner) energy level (by collision) (Outer) electron (in anode) falls to lower energy level (emitting characteristic X-ray photon)	B1 B1	Alternative answer: Electrons decelerate on collision with anode (X-rays / photons are produced) because of change in <u>kinetic</u> energy (of electrons)
18	(d)	Photon energy, $(E) = 90 \times 10^3 \times 1.6 \times 10^{-19}$ (= 1.44×10^{-14} J) $\lambda = hc/E = \frac{6.63 \times 10^{-34} \times 3 \times 10^8}{1.44 \times 10^{-14}}$ = 1.4×10^{-11} (m)	C1 C1 A1	ALLOW calculation of conversion of 150 keV (2.4×10^{-14}) or 60 keV (9.6×10^{-15}) for this mark only No conversion to J or conversion using wrong physics (e.g. division by 1.6×10^{-19}) to J is XP Use of $\lambda = h/p$ and $E = mc^2$ is XP Correct to at least 2 significant figures

Question		Answer	Mark	Guidance
18	(e)	$(I = I_0 e^{-\mu x} \text{ to give}) 0.3 = e^{-(\mu \times 4.6)}$	C1	ALLOW $3.3 = e^{(\mu \times 4.6)}$ Expect to see both 0.3 and 4.6 correctly substituted into equation
		$\mu (= -\ln(0.3) / 4.6) = 0.26 \text{ (cm}^{-1}\text{)}$	A1	Correct to at least 2 significant figures (0.262 cm ⁻¹) Negative final answer (- 0.26) loses second mark

19	(a)	Photon(s) mentioned One-to-one interaction between photons and electrons Energy of photon is independent of intensity / intensity is to do with <u>rate</u> (of photons / photoelectric emission) / photon energy depends on frequency / energy of photon depends on wavelength / photon energy $\propto$ frequency / photon energy $\propto 1/\lambda$ energy of uv photon(s) > work function (of zinc) / frequency of uv > threshold frequency	B1 B1 B1 B1	Allow 'photon absorbed by an electron' Allow: collide etc. for interaction Allow $E = hf$ or $E = hc/\lambda$ Allow energy of light photon(s) < work function (of zinc) / frequency of light < threshold frequency Allow $\geq$ instead of > here Not $f > f_0$
	(b)	$\phi = \frac{6.63 \times 10^{-34} \times 3.0 \times 10^8}{2.9 \times 10^{-7}}$ or 6.86×10^{-19} (J) $E = 5.1 \times 1.60 \times 10^{-19}$ or 8.16×10^{-19} (J) max kinetic energy = $(8.16 - 6.86) \times 10^{-19}$ max kinetic energy = 1.3×10^{-19} (J)	C1 C1 A1	Note: Using 5.1 and not 8.16×10^{-19} cannot score this mark or the next mark Allow 2 marks for 0.81 eV
	(c)	Any <u>three</u> from: The electrons are repelled by C / electrons travel against the electric field (AW) The electrons are emitted with a 'range' of speed / velocity / kinetic energy (AW) As V increases the slow(er) electrons do not reach C and hence I decreases maximum KE in the range 2.1 <u>eV</u> to 2.2 <u>eV</u> or 3.36×10^{-19} <u>J</u> to 3.52×10^{-19} <u>J</u>	B1×3	Note 'range' can be implied by 'highest' or 'lowest' Allow 'find p.d. when current is (just) zero, and then $KE = e \times V$'
		Total	10	

19	(a)		current = 0.01 (A) p.d. = 0.01×50 (= 0.50 V)	M1 A1	
	(b)		$(V_{75} =) \mathbf{0.5 + 2.5}$ (V) or $(R_{LED} =) \mathbf{250}$ (Ω) or $(R_p =) \mathbf{60}$ (Ω) $(I_{100} =) \mathbf{0.05}$ (A) $(E = 3.0 + 0.05 \times 100)$ $E = 8.0$ (V)	C1 C1 A1	Allow other correct methods Note there is no ECF from (a) Allow 1 SF for the p.d. of 3 (V) There is no ECF here from wrong physics (XP) from the parallel network Allow 1 SF answer of 8
	(c)	(i)	$(P =) 0.01 \times 2.5$ or $0.01^2 \times 250$ or $2.5^2/250$ or 0.025 (W) $(E_{\text{photon}} =) \frac{6.63 \times 10^{-34} \times 3.0 \times 10^8}{4.7 \times 10^{-7}}$ or 4.23×10^{-19} (J) (number per second = $\frac{0.025}{4.23 \times 10^{-19}}$) number per second = 5.9×10^{16} (s ⁻¹)	C1 C1 A1	Allow 4.0×10^{-19} (J); which is 2.5 eV Note using 4.0×10^{-19} (J) gives 6.25×10^{16} (s ⁻¹)
		(ii)	$(E_{\text{photon}} =) 2.64$ (eV) or $(\phi =) 3.68 \times 10^{-19}$ (J) or $(f_0 =) 5.55 \times 10^{14}$ (Hz) or $(\lambda_0 =) 5.40 \times 10^{-7}$ (m) Photoelectrons are emitted and $2.6(4) > 2.3$ or $4.23 \times 10^{-19} > 3.68 \times 10^{-19}$ or 6.38×10^{14} (Hz) $> 5.55 \times 10^{14}$ (Hz) or 4.7×10^{-7} (m) $< 5.40 \times 10^{-7}$ (m)	M1 A1	Possible ECF from (i) Allow 2.6 (eV) or 3.7×10^{-19} (J) Allow 2.5 (eV) as the energy of the photon Note the conclusion must be consistent with (i) Allow $hf > \phi$ Note this can be implied by calculating the KE of the emitted electron
			Total	10	

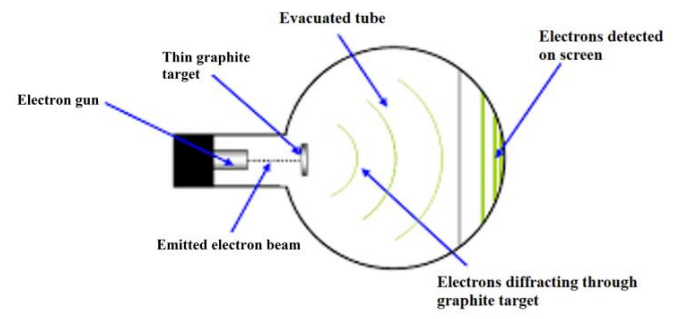
25	(a)	(i)	Proton is repelled (by nucleus) (High-speed) proton can get close to (oxygen) nucleus	B1 B1	Allow 'proton can experience the strong (nuclear) force' Not 'collide / hit nucleus'
		(ii)	$E = [0.25 - (2.24 - 2.20)] \times 10^{-11} \text{ (J)}$ or $0.21 \times 10^{-11} \text{ (J)}$ $\lambda = \frac{6.63 \times 10^{-34} \times 3.00 \times 10^8}{0.21 \times 10^{-11}}$ (Any subject) $\lambda = 9.5 \times 10^{-14} \text{ (m)}$	C1 C1 A1	Allow 2 marks for 6.9×10^{-14} ; $E = 0.29 \times 10^{-11}$ used Allow 1 mark for a value correctly calculated based on any other incorrect value for E (e.g. $8(.0) \times 10^{-14}$ for $E = 0.25 \times 10^{-11}$ and $5(.0) \times 10^{-13}$ for $E = 0.04 \times 10^{-11}$)
		(iii)	Used in PET (scans) Any one from: Used to diagnose function of organ / brain / body Detection of cancer / tumour Non-invasive / no surgery / no infection 3D (image)	M1 A1	
	(b)		X-ray (tube) moves around the patient A thin (fan-shaped X-ray) beam is used (Images / scans of) cross-sections through the patient are taken Any one from: • A three-dimensional image is produced • (Soft) tissues can be identified	B1 B1 B1 B1	Allow 'X-rays passed through different angles.' Allow 'slice(s)' Allow 'good contrast image'
			Total	11	



Question	Answer	Mark	Comments	
6	(a) (i)	$\sin C = 1/n = 1/1.69 (= 0.592)$ $C = 36^\circ$	C1 A1	
	(ii)	<u>Total internal reflection</u> occurs because the <u>angle of incidence</u> (at the surface) is greater than the <u>critical angle/ 36°</u>	B1 B1	allow because <u>i</u> > <u>C</u>
	(b)	$E = (hc/\lambda) = 6.63 \times 10^{-34} \times 3.0 \times 10^8 / 450 \times 10^{-9}$ $E = 4.42 \times 10^{-19}$ (J) energy = 2.76 (eV)	C1 C1 A1	N.B. the answer here must be 2 SF or more
	(c) (i)	$2.76 - 2.3 = 0.46$ eV (so only 0.5% of energy/AW)	B1	allow $2.8 - 2.3 = 0.5$ eV and $3.0 - 2.3 = 0.7$ eV possible ecf from (b)
	(ii)	$n = 2000 \times 4^9 (= 5.24 \times 10^8)$ $Q = ne = 8.4 \times 10^{-11}$ (C) $I = 8.4 \times 10^{-11} / 2.5 \times 10^{-9}$ average current = 0.034 (A)	C1 C1 A1	allow ecf for wrong n allow 34 m(A); answer is 1.7×10^{-5} A if 2000 omitted (2/3)
		Total	11	



19	(a)		$h \rightarrow \text{J s} \quad / \quad h \rightarrow \text{N m s} \quad / \quad \text{J} \rightarrow \text{kg m}^2 \text{s}^{-2}$ base unit = $\text{kg m}^2 \text{s}^{-1}$	C1 A1	
	(b)	(i)	$Vq = \frac{1}{2} mv^2$ and $\lambda = \frac{h}{mv}$ Clear algebra leading to $\lambda^2 = \frac{h^2}{2mq} \times \frac{1}{V}$	M1 A1	Allow p for mv Allow e for q in (b)(i) – this is to be treated as a ‘slip’
		(ii)1	(% uncertainty in λ^2) 10% (% uncertainty in λ) 5%	C1 A1	Note 10 (%) on answer line will score the C1 mark
		(ii)2	Straight line of best fit passes through all error bars	B1	
		(ii)3	gradient = $1.0 (\times 10^{-22})$ $\frac{h^2}{2mq} = \text{gradient}$ $\frac{(6.63 \times 10^{-34})^2}{2 \times m \times 3.2 \times 10^{-19}} = \text{gradient}$ $m = 6.9 \times 10^{-27} \text{ (kg)}$ (hence about 10^{-26} kg)	C1 C1 C1 A1	Ignore POT for this mark; Allow $\pm 0.20 (\times 10^{-22})$ Possible ECF for incorrect value of gradient Note check for AE (condone rounding error here) and answer must be about 10^{-26} (kg) for any incorrect gradient value for this A1 mark Special case: $1.37 \times 10^{-26} \text{ kg}$ scores 3 marks for $q = 1.6 \times 10^{-19} \text{ C}$ because answer is about 10^{-26} kg
			Total	11	

19	(a)	Any four from: In an evacuated tube (Electrons released by) thermionic emission / (low voltage supply causes) emission of electrons from cathode/filament/electron gun Electrons accelerated towards anode / electrons accelerated through (high) pd / electric field Diffacted through a graphite (target) / graphite is thin Electrons detected on a (phosphor) screen / electrons produce visible light on impact with screen	4xB1	ALLOW marking points as labels on the diagram or as the answer lines. 
	(b)	(Provides evidence of) wave nature of electrons Light circles caused by constructive interference / waves arriving in phase Dark circles caused by destructive interference / waves arriving in antiphase	B1 B1 B1	ALLOW out of phase by 180° / π NOT just out of phase
	(c)	(i)	Work done = $1.60 \times 10^{-19} \times 5 \times 10^3 = 8.0 \times 10^{-16}$ (J)	A1 ALLOW correct answer to 1 significant figure

21	(a)	(i)	<u>electron</u> bound to nucleus / represents energy <u>electron</u> must gain to leave the atom / total energy of <u>electron</u> in atom is less than that of a free electron	B1	Allow ionisation level defined as zero as AW for 'represents electron must gain energy to leave atom / move up energy level' Allow potentials for attractive forces are negative.
		(ii)1	energy = 2.55 (eV)	B1	Ignore sign
		(ii)2	energy = $2.55 \times 1.60 \times 10^{-19}$ (J) $\lambda = \frac{6.63 \times 10^{-34} \times 3.0 \times 10^8}{2.55 \times 1.60 \times 10^{-19}}$ (Allow any subject) wavelength = 4.9×10^{-7} (m) wavelength = 490 (nm)	C1 C1 A1	Possible ECF from (ii)1 Note: wavelength = 488 (nm) to 3 sf
	(b)	(i)	<u>Electron(s)</u> makes a transition to a lower (energy) level / loses energy and emitting a photon(s) / EM radiation	B1	
		(ii)	Reduce grating separation / increase distance between grating and screen	B1	Allow 'use finer grating' or 'use grating with more lines mm^{-1} ' Not 'smaller slit size'
		(iii)	wavelength (of peak) = 661.5 nm $v = 3.0 \times 10^8 \times (661.5 - 656.3) / 656.3$ recession velocity = 2.4×10^6 (m s ⁻¹)	C1 C1 A1	Allow: between 661 and 662 nm Note: check divided by 656.3 nm Range of acceptable answers. 2.1(5)-2.6(1) x 10 ⁶
		(iv)	(Relative) abundance of hydrogen (AW)	B1	Allow 'Hydrogen commonly found in stars' (AW)
	(c)		Less intense Galaxy is moving faster and therefore greater / longer wavelength (AW) Periodic shift in wavelength (if plane of orbit is in line of sight) (ORA)	B1 B1 B1	Allow 'greater red shift' / 'greater Doppler shift' / 'to the right' for longer wavelength Allow argument referring to splitting of line because of relative velocities of two component stars. Not idea of blue shift.
			Total	14	



20	(a)	(i)	A straight line with non-zero V_0 intercept gradient = 1.3×10^{-6}	B1 B1	Ignore spread of data points on either side of the line Allow Intercept > 0 and < 1.0 V Allow $(1.10 \text{ to } 1.60) \times 10^{-6}$; no need to check calculation
		(ii)	gradient = $\frac{hc}{e}$ (Any subject) $h = \frac{1.3 \times 10^{-6} \times 1.60 \times 10^{-19}}{3.00 \times 10^8}$ (Any subject) $h = 6.9 \times 10^{-34}$ (J s)	C1 C1 A1	Possible ECF from (i) Note the answer must be given 2 SF only
		(iii)	difference = $\frac{6.9 \times 10^{-34} - 6.6(3) \times 10^{-34}}{6.6(3) \times 10^{-34}} \times 100 \%$ difference = 4.1 %	B1	Possible ECF from (ii) Ignore sign Not division by value from (ii) Allow 1 SF answer
		(iv)	Random (error) / data points are spread about line Systematic (error) / line does not pass through origin Take (many) repeat readings (of V_0) and average Conduct the experiment in a darkroom / use (black) tube over the LED to view when it is lit / use a (digital) voltmeter with no zero error	B1 B1 B1 B1	Allow other sensible suggestion Not faulty voltmeter

Question		Answer	Marks	Guidance
	(b)	Any one from: Energy of visible light photon < work function (of zinc) (frequency of) visible (light/photon) < threshold frequency Any one from: Energy of UV photon > work function (of zinc) (frequency of) UV (radiation/photon) > threshold frequency Any two from: • Collapse of leaf linked to removal of electrons • One-to-one interaction of photon and (surface) electron • Photon energy is independent of intensity / Intensity linked to rate of photons (incident on the zinc plate)	B1 B1 B1 × 2	Allow f for frequency, λ for wavelength and ϕ for work function throughout Allow 'overcome' / 'met' / 'reached' when describing > or < Allow photons Not f_0 for threshold frequency Allow equivalent statement with wavelength Allow = instead of > or < throughout for UV Allow equivalent statement with wavelength Ignore stem / plate / leaf / electroscope becoming positive
		Total	14	

19	(a)		$(hf = \phi + KE_{\max}) = 6.63 \times 10^{-34} \times 6.3 \times 10^{14} = \phi + 4.8 \times 10^{-20}$ $\phi = 3.6969 \times 10^{-19} \text{ (J)}$ $\phi = 2.3 \text{ (eV)}$	C1 OR (in eV) $hf = 6.63 \times 10^{-34} \times 6.3 \times 10^{14} / 1.6 \times 10^{-19}$ C1 $\phi = 2.6 - 0.30 \text{ (eV)}$ A1 $\phi = 2.3 \text{ (eV)}$
	(b)	(i)	$a = \frac{VQ}{dm}$ OR $a = \frac{EQ}{m}$ OR $KE = \frac{1}{2}mv^2$ and $v^2 = u^2 + 2as$ OR $KE = F \times d$ and $F = m \times a$ $a = \frac{0.30 \times 1.6 \times 10^{-19}}{6.0 \times 10^{-3} \times 9.11 \times 10^{-31}} \quad / \quad a = \frac{50 \times 1.6 \times 10^{-19}}{9.11 \times 10^{-31}} \quad /$ (Use of $KE = \frac{1}{2}mv^2$) $= 4.8 \times 10^{-20} = \frac{1}{2} \times 9.11 \times 10^{-31} \times v^2$ and (use of $v^2 = u^2 + 2as$) $v^2 = (1.05 \times 10^{11}) = 2 \times a \times 6 \times 10^{-3} (\pm 0^2)$ / (Use of $KE = F \times d$) $= 4.8 \times 10^{-20} = F \times 6 \times 10^{-3}$ and (use of $F = m \times a$) $F = (8.0 \times 10^{-18}) = 9.11 \times 10^{-31} \times a$ $a = 8.78 \dots \times 10^{12} \text{ (m s}^{-2}\text{)}$	C1 Allow u and v interchangeably throughout Allow calculation of $E = (0.30 / 6 \times 10^{-3}) = 50 \text{ (V m}^{-1}\text{)}$ or $v = 3.2 \times 10^5 \text{ (m s}^{-1}\text{)}$ or $v^2 = 1.05 \times 10^{11} \text{ (m s}^{-1}\text{)}^2$ or $F = 8.0 \times 10^{-18} \text{ (N)}$ for C1 mark M1 Substitution mark – in any arrangement. Expect full substitutions including numerical value of m_e if appropriate Method 1: direct calculation of a Method 2: using $KE = \frac{1}{2}mv^2$ and $v^2 = u^2 + 2as$ Method 3: using $KE = F \times d$ and $F = m \times a$ A1 Note must be more than 2 SF (not paper SF penalty) Ignore negative sign
		(ii)	(Use of $KE = \frac{1}{2}mv^2$) $= 4.8 \times 10^{-20} = \frac{1}{2} \times m \times v^2$ OR $(u^2 = v^2 - 2as) = 0^2 - [2 \times (-) 8.8 \times 10^{12} \times s]$ Full substitution leading to $v = 3.2 \dots \times 10^5 \text{ (m s}^{-1}\text{)}$	C1 Allow u and v interchangeably A1 Numerical value of m_e must be used if using KE method Note must be more than 1 SF (not paper SF penalty) Note 3.25 is acceptable for A1, but not 3.3

Question			Answer	Marks	Guidance
		(iii)	$t = \frac{3.2 \times 10^5}{8.8 \times 10^{12}}$ $t = 3.6 \times 10^{-8} \text{ (s)}$	C1 A1	Allow correct full substitution into any suvat equation Allow 3×10^5 for v Ignore signs of substituted values Expect values between 3.4×10^{-8} and 3.8×10^{-8} (s) No ecf from (b)(i) or (b)(ii)
		(iv)	Any line with negative slope starting from 0, 4.8×10^{-20} A straight line finishing at 6.0,0	M1 A1	$\frac{1}{2}$ square tolerance. ALLOW a curve with negative gradient. ALLOW a region of zero gradient, but not whole line $\frac{1}{2}$ square tolerance on axis intercepted
	(c)		Energy of photon increases (max) kinetic energy / speed (of electrons) increases / (some) electrons (now) reach C and there is a current or reading (on ammeter)	B1 B1	Do not allow increased <u>kinetic</u> energy of photons Do not allow explanation in terms of increased number of emitted electrons (per second) Allow photoelectrons for electrons
			Total	14	

2	(a)		superscripts 1,60,0 subscripts 0,28,-1 $\bar{\nu}_{(e)}$ (nu-bar)	B1 B1 B1	recognisable correct symbol required If superscripts and subscripts included, both must be 0
	(b)	(i)	Beta radiation would not penetrate/ would be absorbed by the lead	B1	Not gamma radiation would be stopped Ignore reference to alpha radiation
		(ii)1	$\ln N = -\mu d + \ln N_0$ compared to $y = mx + c$ (so $m = -\mu$ and $c = \ln N_0$)	B1	or $\ln N = \ln(N_0 e^{-\mu d}) = \ln N_0 - \mu d$
		(ii)2	5.70 ± 0.14	B1 B1	Both answers must be to 2d.p. Allow ± 0.13 not second B1 mark without correct working shown e.g. $\ln 300 - \ln 260$ or $(5.83-5.56)/2$ Allow $\Delta N/N$ ($= 40/300$) but only if $\Delta(\ln N) \approx \Delta N/N$ is quoted
		(ii)3	Point plotted correctly to within $\frac{1}{2}$ small square Best fit and worst fit line(s) drawn	B1 B1	Ignore accuracy of length of error bar ECF (ii)2 for incorrect value(s) in table ECF (ii)2 for incorrect value(s) in table Best fit line should have an equal scatter of points about the line Worst fit line should be steepest/shallowest possible line that passes through <u>all</u> the error bars (allow $\pm \frac{1}{2}$ small square tolerance vertically)

H556/03			Mark Scheme		June 2019
Question			Answer	Marks	Guidance
		(ii)4	gradient of best fit line = $(-) \mu = (-) 54 \text{ (m}^{-1}\text{)}$	B1	Allow 51 to 56 Allow value of μ up to 4 SF ECF(ii)3 for wrongly plotted point
			large triangle used to determine gradient of best fit line	B1	$\Delta d > 25\text{mm}$ (seen from graph or working)
			calculation of absolute uncertainty using their values in the formula ($ \text{wfl gradient} - \text{bfl gradient} $)	B1	ECF (ii)3 for worst fit line Ignore any POT error in gradients Allow value of absolute uncertainty up to 3 SF only
			uncertainty and value of μ to same number of dp	B1	e.g. 53.4 ± 5.6 or 54 ± 6
		(ii)5	$\mu d_{1/2} = \ln 2$ (or 0.693)	C1	ECF (ii)4 for μ <u>Alternative method:</u> $\ln(N_0 / 2) = 7.67$ (C1)
			$d_{1/2} = 0.013 \text{ (m)}$	A1	then use of graph to give $d_{1/2} = 0.013 \pm 0.001 \text{ (m)}$ (A1)
			Total	15	

H556/03		Mark Scheme		June 2019
Question	Answer	Marks	Guidance	

