1 Which of the following statements is / are true about photons?

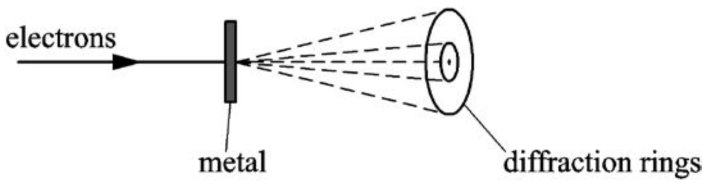
1 All photons travel at the same speed in a vacuum.
2 Photons have no charge.
3 The energy of a photon depends only on its frequency.

A 1, 2 and 3
B Only 2 and 3
C Only 1 and 2
D Only 2

Your answer

[1]

2 Electrons travelling through a thin layer of polycrystalline metal are diffracted.



Which statement is correct about these electrons?

A The electrons travel as photons through the metal.
B The electrons have a wavelength of about 10^{-10} m.
C The electrons are diffracted by holes in the metal.
D The electrons repel each other to produce the diffraction.

Your answer

[1]

3 A sodium lamp is rated at 40 W. About 12% of the power is emitted as yellow light of wavelength 5.9×10^{-7} m.

How many photons of yellow light are emitted per second from this lamp?

A $1.4 \times 10^{19}\ s^{-1}$
B $1.2 \times 10^{20}\ s^{-1}$
C $3.6 \times 10^{27}\ s^{-1}$
D $1.0 \times 10^{40}\ s^{-1}$

Your answer ☐

[1]

4(a) State what is meant by the *photoelectric effect*.

____

____

____ [1]

(b) The photoelectric effect cannot be explained in terms of the wave-model of electromagnetic waves. Discuss how the new knowledge of the particulate nature of radiation was used by physicists to validate the photon model.

____

____

____

____

____ [3]

(c) A metal plate is placed in an evacuated chamber. Electromagnetic radiation of wavelength 380 nm is incident on the plate. The work function of the metal is 1.1 eV.

(i) Calculate the maximum speed of the photoelectrons emitted from the plate.

speed = ________________ $m\ s^{-1}$ [3]

(ii) State the change, if any, to the maximum speed of the emitted photoelectrons when the intensity of the incident electromagnetic radiation on the metal plate is doubled.

____

____

____

____ [1]

5 **Fig. 22.1** shows the circular track of a positron moving in a uniform magnetic field.

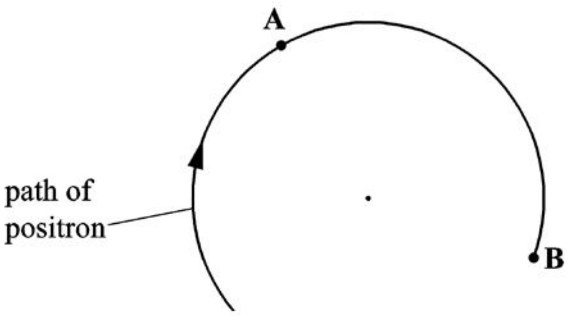


Fig. 22.1

The magnetic field is perpendicular to the plane of **Fig. 22.1**.
The speed of the positron is 5.0×10^{7} m s^{-1} and the radius of the track is 0.018 m.

At point **B** the positron interacts with a stationary electron and they annihilate each other. The annihilation process produces two identical gamma photons travelling in opposite directions.

Calculate the wavelength of the gamma photons. Assume the kinetic energy of the positron is negligible.

wavelength = ____________________ m **[3]**

6 Violet light is incident on the surface of a metal. Photoelectrons are emitted from the surface of the metal. The frequency of the radiation incident on this metal is increased but the intensity of the radiation is kept constant.

Which statement is correct?

A The value of the Planck constant increases.
B The work function of the metal increases.
C The number of photoelectrons emitted per second increases.
D The maximum kinetic energy of photoelectrons increases.

Your answer ☐

[1]

7 What is the de Broglie wavelength in nm of a proton travelling at $1.5 \times 10^4 \text{ m s}^{?1}$?

A $2.6 \times 10^{?2}$ nm

B 2.6 nm

C 49 nm

D 4.9×10^4 nm

Your answer [ ]

[1]

8(a) Fig. 19 shows a photocell.

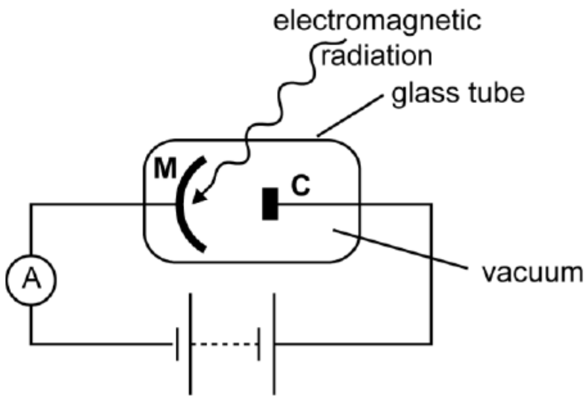


Fig. 19

When the metal **M** is exposed to electromagnetic radiation, photoelectrons are ejected from the surface of the metal. These photoelectrons are collected at the electrode **C** and the sensitive ammeter indicates the presence of a tiny current.

The work function of the metal **M** is 2.3 eV.

The incident electromagnetic radiation has wavelength 5.1×10^{-7} m.

The ammeter reading is 0.24 μA.

Calculate the maximum kinetic energy of the ejected photoelectrons.

maximum kinetic energy = ____________________ J **[3]**

(b) The wavelength of the incident radiation is kept constant but the intensity of the radiation is doubled.

State and explain the effect, if any, on the current in the photocell.

____

____

____

____ **[2]**

9 Calculate the maximum wavelength of the X-rays for the pair production process.

maximum wavelength = ____________________ m **[3]**

10 Uranium-235 is used in many fission reactors as fuel and fusion reactors are still at an experimental stage.

(i) State one major disadvantage of having fission reactors.

---

[1]

(ii) The fission of a uranium-235 nucleus releases about 200 MeV of energy, whereas the fusion of four hydrogen-1 nuclei releases about 28 MeV.

At first sight it would appear that fusion would produce less energy than fission. However the energy released in the fission of one kilogramme of uranium-235 is about eight times less than the energy released in the fusion of one kilogramme of hydrogen-1.

Explain this by considering the initial number of particles in one kilogramme of each.

---

[4]

11(a) Electromagnetic radiation of wavelength 300 nm is incident on the surface of two metals **X** and **Y**. Metal **X** has work function 2.0 eV and metal **Y** has work function 5.0 eV.

With the help of calculations, explain any difference between the emission of photoelectrons from the surfaces of the metals **X** and **Y**.

--- [4]

(b) *Two groups of researchers, **A** and **B**, conduct photoelectric effect experiments on a new material. The maximum kinetic energy KE_{max} of the photoelectrons emitted from the material is determined for different frequencies f of the electromagnetic radiation incident on the material.

Fig. 19 shows incomplete graphs of KE_{max} against f from the groups **A** and **B**.

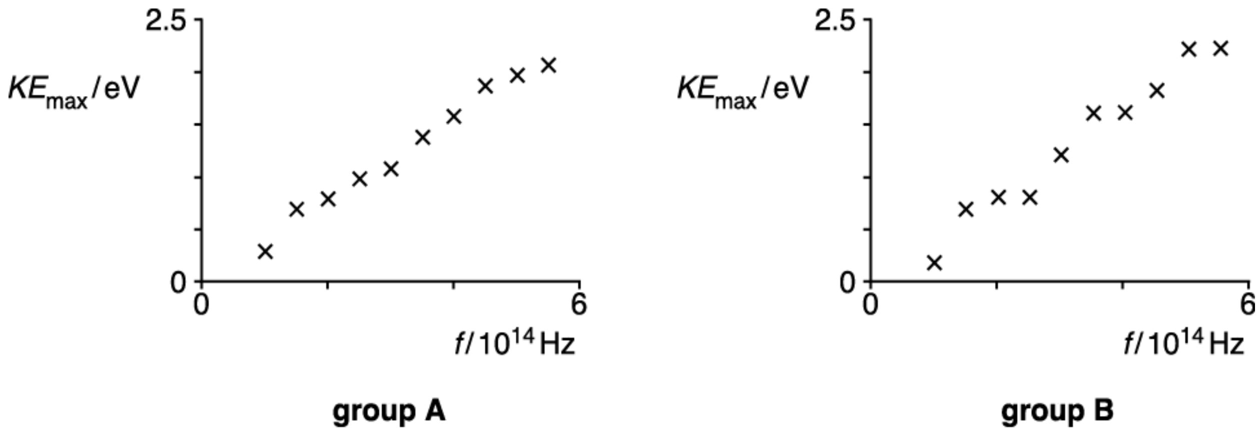


Fig. 19

The value of the Planck constant h is determined from the completed KE_{max} against f graphs.
The result from each group is shown below.

group A: $h = (6.3 \pm 0.3) \times 10^{-34}$ J s
group B: $h = (6.6 \pm 0.6) \times 10^{-34}$ J s

Explain how a graph of KE_{max} against f can be used to determine h. Discuss the accuracy and precision of the results from each group.

[6]

12 Fig. 21.1 shows two oppositely charged ions to the left of a point **X**.

Fig. 21.1

The separation between the centres of the ions is 3.0×10^{-10} m. Each ion has charge of magnitude 1.6×10^{-19} C.

(i) Explain why the direction of the **resultant** electric field strength at point **X** is to the left.

____

____

____

____ **[2]**

(ii) Calculate the minimum energy in eV required to completely separate the ions.

energy = ______________________________ eV **[3]**

13 This question is about the brightest wavelength (590 nm) of light from a sodium lamp.

Analysis of the light from the sodium lamp using a diffraction grating shows that there are photons of two different energies at wavelengths 589.0 nm and 589.6 nm.

(i) Calculate the energy difference ΔE between these two photons.

ΔE = ______________________________ J **[3]**

(ii) The light at these wavelengths can be seen as two separate lines when viewed through a diffraction grating. In order to be distinguishable from each other, the angular separation between the lines must be at least 0.02°.

Show that the lines will appear separated in the **second order** spectrum when the sodium lamp is viewed through a grating with 300 lines per millimetre.

[3]

14(a) Lasers are often used to form precision-welded joints in titanium. To form one such joint it is first necessary to increase the temperature of the titanium to its melting point. Fig. 5.1 shows the joint and the volume of titanium to be heated.

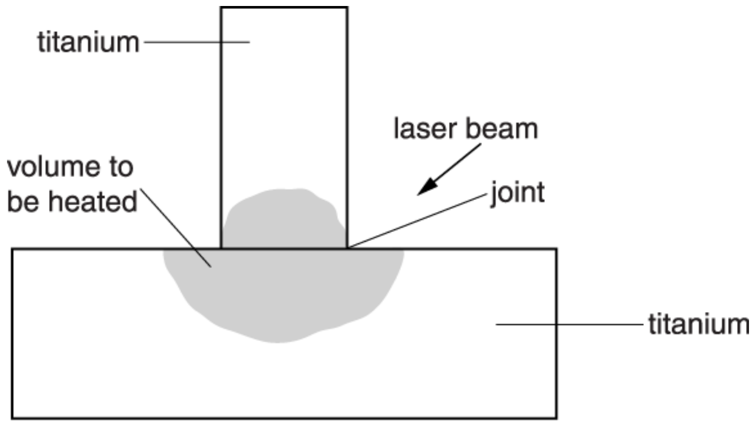


Fig. 5.1

The photon beam from the laser is focused onto the shaded volume of the joint and is converted into thermal energy in the titanium.

The wavelength of the photons is 1.1×10^{-6} m.

Show that the energy of a photon in the beam is 1.8×10^{-19} J.

[1]

(b) Photons are emitted from the laser at a constant rate of 6.3×10^{19} s^{-1}.

Estimate the time taken to raise the temperature of the shaded volume of titanium shown in Fig. 5.1 to melting point. Use the data below for your calculations.

initial temperature = 20 °C
melting point of titanium = 1700 °C
density of titanium = 4.5×10^3 kg m^{-3}
specific heat capacity of titanium = 520 J kg^{-1} K^{-1}
shaded volume of titanium being heated = 8.1×10^{-12} m^3.

time = ____________________________ s **[3]**

(c) In practice it takes a longer time to reach the melting point.
State and explain **two** factors that will increase the time taken.

____

____

____

____ **[2]**

(d) To complete the weld more photons must be focused onto the joint. During this final stage the temperature remains constant. Explain why this is to be expected.

____

____

____ **[1]**

15 Which is **not** a unit of energy?

A kW h

B eV

C J

D W

Your answer [1]

16 An electron moves in a circle of radius 2.0 cm in a uniform magnetic field of flux density 170 mT.

What is the momentum of this electron?

A 3.4×10^{-3} kg m s^{-1}

B 5.4×10^{-17} kg m s^{-1}

C 1.4×10^{-18} kg m s^{-1}

D 5.4×10^{-22} kg m s^{-1}

Your answer [ ] **[1]**

17(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.

---------- [4]

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

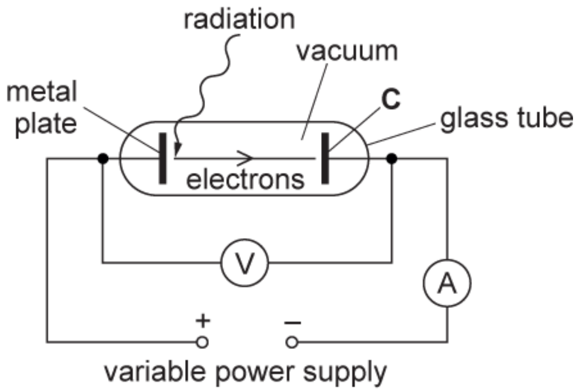


Fig. 19.1

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.

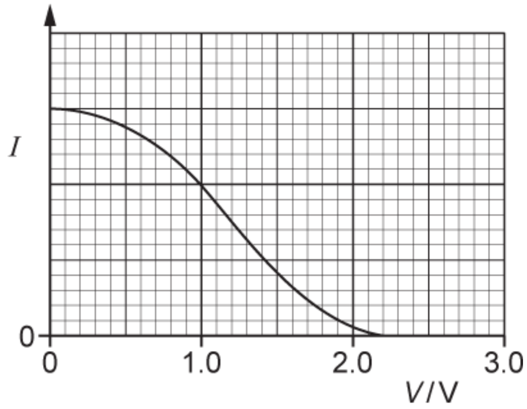


Fig. 19.2

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

--- **[3]**

18

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**.

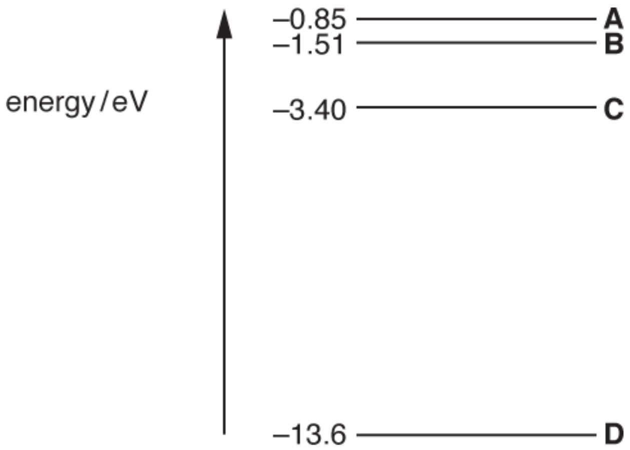


Fig. 21.1 (not to scale)

(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]**

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

wavelength = ___________________ nm **[3]**

19(a) A stationary uranium-238 nucleus $\left({}^{238}_{92}\text{U}\right)$ decays into a nucleus of thorium-234 by emitting an alpha-particle.

The chemical symbol for thorium is Th. Write a nuclear equation for this decay.

[2]

(b) The mass of the uranium nucleus is 4.0×10^{-25} kg. After the decay the thorium nucleus has a speed of 2.4×10^{5} m s^{-1}.

Calculate the kinetic energy, in MeV, of the alpha-particle.

kinetic energy = ____________________ MeV **[4]**

(c) The uranium-238 $\left({}^{238}_{92}\text{U}\right)$ nucleus starts the decay chain which ends with a nucleus of lead-206 $\left({}^{206}_{82}\text{Pb}\right)$.
Show that 14 particles are emitted during this decay chain. Explain your reasoning.

[3]

20(a) 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]

(b) 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.

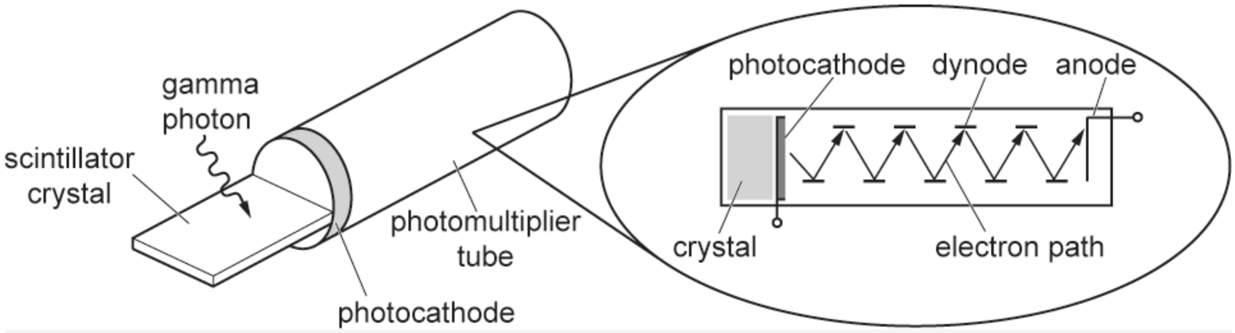


Fig. 6.1

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]**

21 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} kg m s^{-1}
B 10^{-27} kg m s^{-1}
C 10^{-23} kg m s^{-1}
D 10^{-18} kg m s^{-1}

Your answer ☐ **[1]**

22

Fig. 20.2 shows a gold-leaf electroscope with a clean zinc plate.

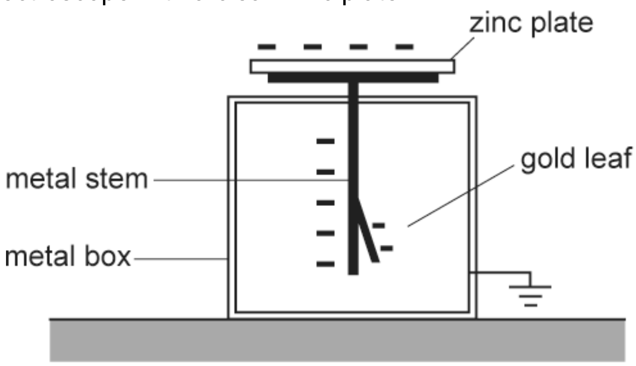


Fig. 20.2

The zinc plate, metal stem and the gold-leaf are given a negative charge by briefly connecting the zinc plate to the negative electrode of a high-voltage supply.

The gold leaf is fully diverged.

The position of the leaf is not affected by intense white light from a table lamp incident on the zinc plate. The gold leaf collapses very quickly when low-intensity ultraviolet radiation from a mercury lamp is incident on the zinc plate.

Explain these observations in terms of photons.

[4]

23

A proton with kinetic energy 0.52 MeV is travelling directly towards a stationary nucleus of cobalt-59 ($^{59}_{27}Co$) in a head-on collision.

(i) Explain what happens to the electric potential energy of the proton-nucleus system.

____

____

____ **[1]**

(ii) Calculate the **minimum** distance *R* between the proton and cobalt nucleus.

R = ______________________________ m **[3]**

The nuclear reaction below shows how the isotope of fluorine-18 ($^{18}_{9}F$) is made from the isotope of oxygen-18 ($^{18}_{8}O$) .

$$^{18}_{8}O + ^{1}_{1}p \rightarrow ^{18}_{9}F + ^{1}_{0}n + \gamma$$

The oxygen-18 nucleus is **stationary** and the proton has kinetic energy of 0.25×10^{-11} J.

The binding energy of the $^{18}_{8}O$ nucleus is 2.24×10^{-11} J and the binding energy of the $^{18}_{9}F$ nucleus is 2.20×10^{-11} 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).

λ = -------------------------------- 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]

25 An 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 = ...S^{-1} [3]

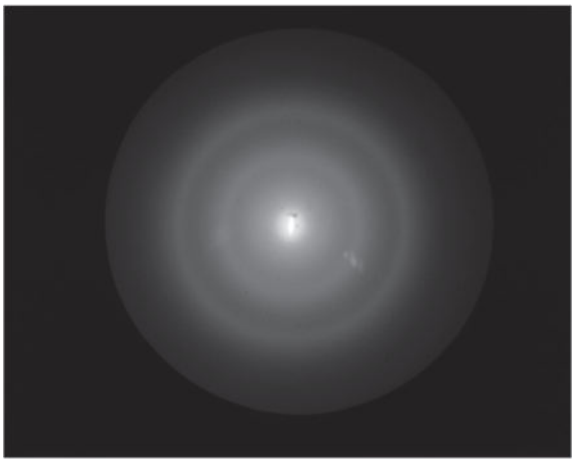
(ii) The light from the LED is incident on a metal of work function 2.3 eV.

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

--- [2]

26 * A student is investigating electron diffraction. A beam of electrons is directed towards a thin slice of graphite in an evacuated tube.

The electrons are accelerated by a potential difference of 2000 V. The diagram below shows the pattern formed on the fluorescent screen of the evacuated tube.



Describe and explain how the pattern changes as the potential difference is increased. Include how the de Broglie wavelength λ of the electron is related to the potential difference V.

[6]

27 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]

28 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.

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

Calculate the wavelength λ of this red light.

λ = ... m **[3]**

29 What can be deduced from the diffraction of electrons by a thin film of graphite?

A Electrons are leptons.

B Electrons are negatively charged.

C Electrons interact with atoms on a one-to-one basis.

D Electrons travel as waves.

Your answer [ ] **[1]**

30 A researcher is investigating the de Broglie wavelength of charged particles.

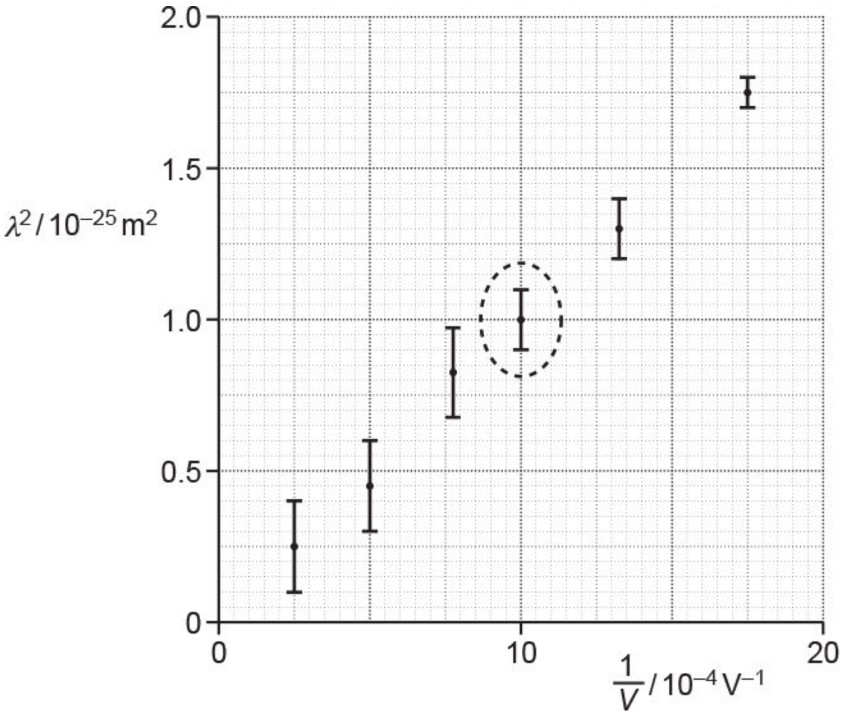
The charged particles are accelerated through a potential difference V. The de Broglie wavelength λ of these particles is then determined by the researcher.

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]

31 The total energy released in a single fusion reaction is 4.0 MeV.

What is the change in mass in this fusion reaction?

A 7.1×10^{-36} kg

B 7.1×10^{-30} kg

C 2.1×10^{-21} kg

D 4.4×10^{-17} kg

Your answer ☐ **[1]**

32 The Planck constant h is an important fundamental constant in quantum physics.

Determine the S.I. base units for h.

base units = ... **[2]**

END OF QUESTION PAPER

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
1			A	1	
			Total	1	
2			B	1	
			Total	1	
3			A	1	
			Total	1	
4	a		The emission of electrons from the surface of a metal when electromagnetic waves (of frequency greater than the threshold frequency) are incident on the metal.	B1	
	b		The wave model cannot explain why there is a threshold frequency for metals. The new model / photon model proposed one-to-one interaction between photons and electrons and this successfully explained why threshold frequency exists. Any further one from: Energy of photon (hf) must be greater than or equal to work function of metal. The kinetic energy of emitted electrons was independent of the incident intensity. Correct reference to hf = Φ + KEmax	B1 B1 B1	
	c	i	$E = \frac{6.63 \times 10^{-34} \times 3.0 \times 10^{8}}{380 \times 10^{-9}}$ or $\phi = 1.1 \times 1.6 \times 10^{-19}$	C1	
		i	$\frac{6.63 \times 10^{-34} \times 3.0 \times 10^{8}}{380 \times 10^{-9}} = 1.1 \times 1.6 \times 10^{-19} + \frac{1}{2} \times 9.11 \times 10^{-31} v^2$	C1	This is substituting values into $\frac{hc}{\lambda} = \phi + \frac{1}{2} mv^2$
		i	speed = 8.7×10^5 (m s^{-1})	A1	
		ii	The energy of a photon depends only on wavelength or frequency, so intensity does not change the maximum speed of the photoelectrons.	B1	
			Total	8	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
5			energy of <u>two</u> photons = 2 × mc^2 or $2\times\frac{hc}{\lambda}=2\times mc^2$	C1	
			$\lambda=\frac{h}{mc}=\frac{6.63\times10^{-34}}{9.11\times10^{-31}\times3.0\times10^{8}}$	C1	Correct use of $\frac{hc}{\lambda}=mc^2$
			wavelength = 2.4 × 10^{-12} (m)	A1	
			Total	3	
6			D	1	
			Total	1	
7			A	1	
			Total	1	
8	a		$\frac{hc}{\lambda}=\phi+KE_{max}$ and ϕ = 2.3 × 1.6 × 10^{-19}	C1	
			$\frac{6.63\times10^{-34}\times3.00\times10^{8}}{5.1\times10^{-7}}=2.3\times1.6\times10^{-19}+KE_{max}$	C1	
			KE_{max} = 2.2 × 10^{-20} (J)	A1	**Allow** 3 marks for an answer of 2.0 × 10^{-20} J; value of *h* to 2 s.f. is used.
	b		The rate of photons incident on **M** is doubled.	B1	
			The rate of emission of photoelectrons / current is doubled.	B1	
			Total	5	
9			$\frac{hc}{\lambda}=2\times9.11\times10^{-31}\times(3.0\times10^{8})^2$	C1	
			$\lambda=\frac{6.63\times10^{-34}\times3.0\times10^{8}}{2\times9.11\times10^{-31}\times(3.0\times10^{8})^2}$	C1	
			λ = 1.2 × 10^{-12} (m)	A1	**Allow** 2 marks for 2.4 × 10^{-12} (m); factor of 2 omitted in the first line.
			Total	3	

Question			Answer/Indicative content	Marks	Guidance
10		i	Fission reactors produce radioactive by-products which affect future generations and the environment in terms of possible contamination / exposure to humans and animals.	B1	
		ii	No of particles in 1000 g U = 1000/235 × 6.02 × 10^{23} = 2.56 × 10^{24} No of reactions for U = 2.56 × 10^{24}	B1	Appreciate that the key to the answer is the difference in numbers of atoms / nuclei **or** equal number of nucleons involved scores one mark if nothing else achieved.
		ii	Energy from U = 2.56 × 10^{24} × 200 = 5.12 × 10^{26} MeV	B1	
		ii	No of particles in 1000g H = 6.02 × 10^{26} No of reactions = 6.02 × 10^{26}/4 Energy from H = 6.02 × 10^{26}/4 × 28 = 42.14 × 10^{26} MeV	B1	
		ii	Hence energy 42/5 = 8.2 times higher	B1	
		ii	*second method* 235 g of U and 4 g of H / He contain 1 mole of atoms	or B1	
		ii	there are 4.26 moles of U and 250 moles of He	B1	
		ii	so at least 58 times as many energy releases in fusion ratio of energies is only 7 fold in favour of U	B1	
		ii	therefore 58/7 times as much energy released by 1 kg of H	B1	
		ii	*similar alternative argument,* e.g. For U each nucleon 'provides' 0.85 MeV	B1	
		ii	For H each nucleon 'provides' 7 MeV	B1	
		ii	(Approx) same number of nucleons per kg of U or H	B1	

Question			Answer/Indicative content	Marks	Guidance
		ii	so 8.2 times as much energy from H	B1	
			Total	5	

Question			Answer/Indicative content	Marks	Guidance
11	a		5.0 eV = 8.0 × 10^{-19} (J) and 2.0 eV = 3.2 × 10^{-19} (J)	B1	**Allow** correct answers in terms of threshold frequency / wavelength for the metals and the frequency / wavelength of the photon
			photon energy = $\frac{6.63\times10^{-34}\times3.0\times10^{8}}{300\times10^{-9}} = 6.6(3)\times10^{-19}$ (J)	B1	**Allow** first two B1 marks for photon energy quoted as 6.6 × 10^{-19} J and 4.1 eV
			energy of photon > work function of **X** Or energy of photon < work function of **Y**	B1	
			Hence electrons emitted from **X** with speed / KE from zero to a maximum value and no electrons are emitted from **Y**	B1	
	b		***Level 3 (5–6 marks)** Clear explanation and discussion *There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.* **Level 2 (3–4 marks)** Some explanation and some discussion *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 explanation **or** limited discussion *The information is basic and communicated in an unstructured way. The information is supported by limited evidence and the relationship to the evidence may not be clear.* **0 marks** No response or no response worthy of credit.	B1 × 6	**Indicative scientific points may include:** **Explanation** • $hf = \Phi + KE_{max}$ (any subject) • A graph of KE_{max} against f is a straight line graph with gradient = h (and intercept = $-\Phi$) • Draw a straight best-fit line through points and determine the gradient using a 'large triangle' **Discussion of accuracy and precision** • % uncertainties are 4.8% for **A** and 9.1% for **B** • Data points widely spread out for **B**. (ORA) • For **B** the value of h is accurate because its closer to the real / actual value (but the results are not precise) • For **A** the value of h is precise because of the smaller % uncertainty (but the result is not accurate)
			Total	10	

Question			Answer/Indicative content	Marks	Guidance
12		i	The direction of the electric field due to the negative charge is to the left and right for the positive charge.	B1	
		i	The magnitude of the electric field strength due to the positive charge is smaller than that for the negative charge (because of greater distance). (Hence the resultant electric field strength is to the left.)	B1	
		ii	energy = $\frac{Qq}{4\pi\varepsilon_0 r} = \frac{(1.60\times10^{-19})^2}{4\pi\varepsilon_0\times3.0\times10^{-10}}$	C1	
		ii	energy = 7.67(2) × 10^{-19} (J)	C1	
		ii	energy = 4.8 (eV)	A1	
			Total	5	
13		i	E = hc/λ; Δ*ε* = E1 – E_2 = hcΔλ/λ^2	C1	**allow** calculation of E = hc/λ twice and difference taken
		i	Δ*ε* = 6.63 × 10^{-34} × 3 × 10^8 × 0.6 × 10^{-9}/ 5.9^2 × 10^{-14}	C1	
		i	Δ*ε* = 3.4 × 10^{-22} (J)	A1	
		ii	sin θ = nλ/d; 1/d = 3 × 10^5 (m^{-1})	C1	
		ii	$\theta_1 - \theta_2$ = $\sin^{-1}$ (2 × 589.6 × 3 × 10^{-4}) – $\sin^{-1}$ (2 × 589 × 3 × 10^{-4})	M1	**or** similar
		ii	$\theta_1 - \theta_2$ = 20.717 – 20. 695 = 0.022^0	A1	**allow** 20.72 – 20.70
			Total	6	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
14	a		$E = \frac{6.63\times10^{-34}\times3.0\times10^{8}}{1.1\times10^{-6}}$	B1	Values must be substituted
			$E = 1.8 \times 10^{-19}$ (J)	A0	Answer to 3sf is 1.81×10^{-19} (J) **Examiner's Comments** This question was specifically included to give a hint as to the method to be used in (b). The question was written in a 'show' format to enable candidates to answer (b) even if they could not recall this area of synoptic work. However this did mean that all working, including substitution, had to be shown and this did result in a small number losing the mark.
	b		$m = pV = 8.1 \times 10^{-12} \times 4.5 \times 10^{3} = (3.645 \times 10^{8})$	C1	
			Thermal energy gained = *(mc Δθ)* = 3.645 × 10^{-8} × 520 × [1700 – 20] (= 0.0318) $1.81 \times 10^{-19} \times 6.3 \times 10^{19} \times t = 0.0318$	C1	**Allow:** ecf from (a) and mass of titanium
			$t = 2.8 \times 10^{-3}$ (s)	A1	**Examiner's Comments** Again this question had three distinct strands to the physics. The vast majority of candidates were capable of determining the correct mass and thermal energy required to raise the temperature of the titanium. A small number of errors were seen in these two strands however: mainly in transposition of the density formula and converting temperature changes incorrectly to kelvin scale. The final stage to determine the time was less confidently handled with transposition errors and some strange manipulation of the equations which usually resulted in the reciprocal of the correct answer. Perhaps the very small time involved in this form of welding surprised a few candidates.
	c		Thermal energy is conducted / transferred to the rest of titanium / metal	B1	**Not:** heat lost to surroundings

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
			Photons are reflected / scattered from / not absorbed the titanium surface	B1	Examiner's Comments The answers given for this question were disappointing. All too often the only factor quoted was the vague '*heat lost to the surroundings'*. A significant number of candidates scored one mark by identifying the loss of thermal energy to the non-shaded volume of titanium. Only a tiny minority realised that some photons would be reflected from the metal surface. Other suggestions such as *'photons are absorbed in the air', 'photons would miss the target', 'not all photons have the same energy', 'the laser needs to heat up as well'* were not given any credit. Marks for this discriminating question were mostly awarded only to the more able candidates.
	d		(Photon) energy is converted into potential energy (rather than kinetic energy) OR Energy is used to change solid to liquid / phase (rather than increase kinetic energy) OR Energy provides (specific) latent heat of fusion (rather than increase kinetic energy)	B1	**Allow:** energy is used to overcome the forces between atoms / breakdown the crystal structure of titanium (rather than increase kinetic energy) Examiner's Comments This question discriminated across the entire spectrum of ability, largely as a result of candidates writing about the lack of a temperature change rather than focusing on what actually happened to the energy supplied at this stage. Many answers were merely statements lacking in the vital explanation. It was, however, encouraging to see that the physics involved in this unfamiliar situation was broadly understood by the candidates.
			Total	7	
15			D	1	
			Total	1	
16			D	1	
			Total	1	

Question			Answer/Indicative content	Marks	Guidance
17	a		Photon(s) mentioned	B1	
			One-to-one interaction between photons and electrons	B1	**Allow** 'photon absorbed by an electron' **Allow:** collide etc. for interaction
			Energy of photon is independent of intensity / intensity is to do with rate (of photons / photoelectric emission) / photon energy depends on frequency / energy of photon depends on wavelength / photon energy ∝ frequency / photon energy ∝ 1/*λ*	B1	**Allow** $E = hf$ or $E = hc/\lambda$
			energy of uv photon(s) > work function (of zinc) / frequency of uv > threshold frequency	B1	**Allow** energy of light photon(s) < work function (of zinc) / frequency of light > threshold frequency **Allow** ≥ instead of > here **Not** $f > f_0$ **Examiner's Comment** Many candidates wrote enthusiastically about photoelectric effect and understood the significance of work function energy (or threshold frequency) and the one-to-one interaction between photon and an electron. Some candidates did not mention 'photons' and this limited the marks they could acquire. The role of intensity was less understood. Many candidates thought it was linked to 'the *number of photons'* or *'the amount of electrons emitted.* The important term **rate** of the missing ingredient. Top-end candidates gave eloquent answers, typified by the response: *'intensity of visible light only affects the rate of photons incident on the plate but not the energy of each photon'.* Two common misconceptions were: • Photons were emitted from the negative plate. • Confusing threshold frequency and work function energy.

Question			Answer/Indicative content	Marks	Guidance
	b		$\phi = \dfrac{6.63\times10^{-34}\times3.0\times10^{8}}{2.9\times10^{-7}}$ or 6.86×10^{-19} (J)	C1	
			$E = 5.1 \times 1.60 \times 10^{-19}$ or 8.16×10^{-19} (J)	C1	**Note:** Using 5.1 and not 8.16×10^{-19} cannot score this mark or the next mark
			max kinetic energy = $(8.16 – 6.86) \times 10^{-19}$		
			max kinetic energy = 1.3×10^{-19} (J)	A 1	**Allow** 2 marks for 0.81 eV **Examiner's Comment** This was a notable success for most of the candidates. Examiners were pleased to see a range of techniques being used to get the correct answer of 1.3×10^{-19} J. Many answers showed excellent structure, effortless conversion of energy from electronvolt to joule and excellent use of the calculator when dealing with powers of ten. Most candidates scored three marks. A small number of candidates left the final answer as 0.81 eV; the only thing missing was the conversion to J.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
	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* × *V* **Examiner's Comment** The electrons emitted from the metal plate have a **range** of kinetic energy. The emitted electrons are repelled by the negative electrode **C.** Fewer electrons reach **C** as the p.d. is increased. When the p.d. is about 2.2 V, and the current zero, the most energetic electron are stopped from reaching **C.** This makes the maximum kinetic energy of the electrons equal to 2.2 eV or 3.4 × 10^{-19} J. The question baffled most candidates. Some top-end candidates commented on *'the electrons repelled by **C**'* and the maximum kinetic energy of the emitted electrons being 2.2 eV. Such answers were rare. Too many candidates made guesses with answers such as *'the current drops because resistance increases'* and *'temperature increases and hence the current decreases'.*
			Total	10	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
18		i	electron bound to nucleus / represents energy electron must gain to leave the atom / total energy of electron 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. **Examiner's Comments** This item provided good discrimination between the candidates. Many responses referred incompletely to the negative charge of the electron being the only factor, whereas the correct explanation is much more to do with the electron requiring energy to leave the atom and the ionization level being defined as the zero point. Some candidates were on the right path when they referred to the equivalent statement for gravitational potential energies.
		ii	**1** energy = 2.55 (eV) **2** energy = 2.55 × 1.60 × 10^{-19} (J) $\lambda = \frac{6.63\times10^{-34}\times3.0\times10^{8}}{2.55\times1.60\times10^{-19}}$ (Allow any subject) wavelength = 4.9 × 10^{-7} (m) wavelength = 490 (nm)	B1 C1 C1 A1	Ignore sign Possible ECF from **(ii)1** **Note:** wavelength = 488 (nm) to 3 sf **Examiner's Comments** Virtually all candidates correctly evaluated the energy difference to be 2.55 eV. Negative values were condoned but are unlikely to be accepted in future series. Many candidates correctly calculated the wavelength of emitted light, although a minority did not convert the energy into joules or performed the required conversion to nanometres incorrectly.
			Total	5	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
19	a		$^{238}_{92}U \rightarrow \ ^{234}_{90}Th$ + ….. $^{4}_{2}He$ or $^{4}_{2}\alpha$	B1 B1	**allow** proton and / or nucleon number to the right of symbol **allow** γ-photon; zero for any other extra particle **Examiner's Comments** Most candidates made a good start to the paper writing a correct equation for the nuclear decay.
	b		mv = (4.00 – 0.0665) × 10^{-25} × 2.40 × 10^{5} = 9.44 × 10^{-20} v = 9.44 × 10^{-20}/ 6.65 × 10^{-27} = 1.42 × 10^{7} k.e. = ½ × 6.65 × 10^{-27} × (1.42 × 10^{7})^{2} = 6.70 × 10^{-13} (J) 6.70 × 10^{-13} / 1.60 × 10^{-13} = 4.19 (MeV)	C1 C1 A1 B1	**allow** 0.07 × 10^{-25} for α-particle mass **max** 3 if use 4.00 instead of 3.93 in momentum eq'n **allow** ratio of masses 234 and 4 **or** calculations using 234u and 4u **allow** $p^2/2m$ calculation for k.e. **accept** 4.0 to 4.2; **ecf** (calculated value of k.e. in J)/e **N.B.** the correct answer automatically gains all 4 marks **Examiner's Comments** One mark in this question was reserved for converting units from joule into mega electronvolt. This was the only mark awarded to half of the candidates. Few recognised this to be an isolated system, applying the conservation of momentum to solve the problem. Few appeared to realise that the mass of an alpha particle is given in the Data, Formulae, and Relationships Booklet, calculating it instead by summing the masses of neutrons and protons. The most common incorrect approach was to use the formula $E = mc^2$ or to equate the kinetic energies of the thorium nucleus and alpha particle.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
	c		$\Delta A = 32 = 4n_\alpha$ so $n_\alpha = 8$ $\Delta Z = 10 = 2n_\alpha - n_\beta$ so $n_\beta = 6$ argument / reasoning given for both n_α and n_β	B1 B1 B1	**allow** 8 (decays), i.e no mention of α particles **allow** 10 – 16 = –6; **NOT** 14 – 8 = 6; **must state** β(–) particles e.g. change in mass number caused by α decay,change in proton number combination of α and β Examiner's Comments A significant number had no idea where to start and left the page blank. Of the rest most managed to decide on 8 alpha particles. A minority worked initially with the proton number rather than the nucleon number incorrectly choosing 5. The explanations about the choice of 6 beta particles were often just restricted to equating the numbers correctly rather than giving any description of the transformation of neutrons into protons.
			Total	9	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
20	a		$E = (hc/\lambda =)\ 6.63 \times 10^{-34} \times 3.0 \times 10^{8}/450 \times 10^{-9}$ $E = 4.42 \times 10^{-19}$ (J) energy = 2.76 (eV)	C1 C1 A1	 **N.B.** the answer here must be 2 SF or more
	b	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) <u>Examiner's Comments</u> Almost all of the candidates attempted this last section of the paper with some success. In part (i) most candidates showed that they understood the theory behind the question and subtracted the appropriate two numbers from part (b) to gain the mark. Part (ii) was done well with a significant number obtaining the correct answer. Another large group forgot that 2000 electrons were released and performed the calculation for only a single electron being multiplied up and so forfeited the final mark.
			Total	7	
21			C	1	
			Total	1	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
22					**Allow** *f* for frequency, *λ* for wavelength and *φ* for work function throughout **Allow** 'overcome' / 'met' / 'reached' when describing > or < **Allow** photon<u>s</u>
			Any <u>one</u> from: Energy of visible light photon < work function (of zinc) (frequency of) visible (light/photon) < threshold frequency	B1	**Not** f_0 for threshold frequency **Allow** equivalent statement with wavelength
			Any <u>one</u> from: Energy of UV photon > work function (of zinc) (frequency of) UV (radiation/photon) > threshold frequency	B1	**Allow** = instead of > or < throughout for UV **Allow** equivalent statement with wavelength
			Any <u>two</u> 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 × 2	**Ignore** stem / plate / leaf / electroscope becoming positive <u>Examiner's Comments</u> This question on the photoelectric effect was enthusiastically answered by candidates. Good discrimination enabled many of the top-end candidates to score full marks. The question was scrutinised well with many candidates explaining why the leaf fell with the ultraviolet radiation. The one-to-one interaction between UV photons and surface electrons was nicely embedded in the descriptions. Some of the candidates would have benefitted by writing their answers in bullet points. There were a few missed opportunities and misconceptions, these are outlined below:

Question			Answer/Indicative content	Marks	Guidance
					• Photons were emitted from the zinc plate (rather than electrons) • Threshold frequency and work function were properties of the photons or electrons (and not zinc) • Threshold frequency and work function were synonymous • Intensity was linked to number of photons (rather than to the **rate** of photons) • Referring to ‘*not enough energy*’ instead of work function of the metal in the description
			Total	4	

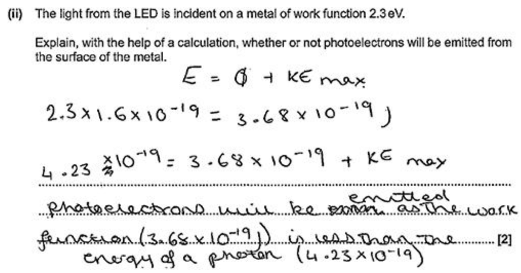
Question			Answer/Indicative content	Marks	Guidance
23		i	Kinetic energy (of proton) changes to potential (energy) **or** Potential energy increases as the kinetic energy (of the proton) decreases **or** Potential energy increases as work is done against the field / against repulsion / positive charge	**B1**	**Allow** ‘it’ / PE for (electric) potential energy **Allow** KE / E_k

Question			Answer/Indicative content	Marks	Guidance
		ii	energy = $0.52 \times 10^{6} \times 1.60 \times 10^{-19}$ **or** $8.3(2) \times 10^{-14}$ (J)	C1	
			$\frac{1.60 \times 10^{-19} \times 27 \times 1.60 \times 10^{-19}}{4\pi\varepsilon_0 R} = 8.32 \times 10^{-14}$	C1	
			$R = 7.5 \times 10^{-14}$ (m)	A1	**Allow** 2 mark for 1.6×10^{-13} (m); Z = 59 used **Allow** 2 mark for 8.9×10^{-14} (m); Z = 32 used **Allow** 1 mark for 2.8×10^{-15} (m); Z = 1 used **Allow** 1 mark for 1.2×10^{-32} (m); energy = 5.2×10^{5} used **Examiner's Comments** The above question on electric potential energy provided excellent discrimination with middle and upper quartile candidates showing how to produce immaculate answers – identify the physics, write down the correct physical equation, do any necessary conversions (e.g. MeV to J), rearrange the equation, substitute correctly and then write the final answer in standard form to the correct number of significant figures. About a third of the candidates scored full marks. ? Some of the missed opportunities or errors were: • Using an incorrect equation with the distance squared • Not correctly converting the kinetic energy 0.52 MeV into joule (J) • Using the equation $r = r_0A^{1/3}$ for the mean radius of a nucleus to determine the minimum distance
			Total	4	

Question			Answer/Indicative content	Marks	Guidance
24		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)] × 10^{-11} (J) **or** 0.21 × 10^{-11} (J) $\lambda = \frac{6.63 \times 10^{-34} \times 3.00 \times 10^{8}}{0.21 \times 10^{-11}}$ (Any subject) λ = 9.5 × 10^{-14} (m)	C1 C1 A1	 **Allow** 2 marks for 6.9 × 10^{-14}; E = 0.29 × 10^{-11} used **Allow** 1 mark for a value correctly calculated based on any other incorrect value for E (e.g. 8(.0) × 10^{-14} for E = 0.25 × 10^{-11} and 5(.0) × 10^{-13} for E = 0.04 × 10^{-11})
		iii	Used in PET (scans) Any <u>one</u> from: Used to diagnose function of organ / brain / body Detection of cancer / tumour Non-invasive / no surgery / no infection 3D (image)	M1 A1	Enter text here.
			Total	7	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
25		i	(P =) 0.01 × 2.5 **or** 0.01^2 × 250 **or** $2.5^2/250$ **or** 0.025 (W)	C1	
			(E_{photon} =) $\frac{6.63\times10^{-34}\times3.0\times10^{8}}{4.7\times10^{-7}}$ **or** 4.23 × 10^{-19} (J) (number per second = $\frac{0.025}{4.23\times10^{-19}}$)	C1	**Allow** 4.0 × 10^{-19} (J); which is 2.5 eV
			number per second = 5.9 × 10^{16} (s^{-1})	A1	**Note** using 4.0 × 10^{-19} (J) gives 6.25 × 10^{16} (s^{-1}) **Examiner's Comments** This question required knowledge of both power and energy of photons. It discriminated well with many of the top end candidates getting the correct of 5.9 × 10^{16} s^{-1}. A significant number of candidates scored 1 mark for the energy of the photons. Using the power of 0.025 W in the final step of the calculation proved to be the main obstacle in this calculation. Alternative answers using the energy of a photon as 2.5 eV were allowed. This gave the rate of photons emission to be 4.0 × 10^{16} s^{-1}. **Misconception** The most common mistake was to calculate the energy of the photon in joule, but to write the frequency 6.4 × 10^{14} on the answer line. This wayward answer can perhaps be explained by frequency and the rate of photon emissions having the same units – s^{-1}.
		ii	(E_{photon} =) 2.64 (eV) **or** (ϕ =) 3.68 × 10^{-19} (J) **or** (f_0 =) 5.55 × 10^{14} (Hz) **or** ($\lambda 0$ =) 5.40 × 10^{-7} (m)	M1	Possible ECF from **(i)** **Allow** 2.6 (eV) **or** 3.7 × 10^{-19} (J) **Allow** 2.5 (eV) as the energy of the photon
			Photoelectrons are emitted and 2.6(4) > 2.3 **or** 4.23 × 10^{-19} > 3.68 × 10^{-19} **or** 6.38 × 10^{14} (Hz) > 5.55 × 10^{14} (Hz) **or** 4.7 × 10^{-7} (m) < 5.40 × 10^{-7} (m)	A1	**Note** the conclusion must be consistent with **(i)** **Allow** $hf > \phi$ **Note** this can be implied by calculating the KE of the emitted electron

Question			Answer/Indicative content	Marks	Guidance
					Examiner's Comments Most candidates showed excellent knowledge and understanding of electronvolts and the photoelectric equation. A variety of answers were accepted. The most common approach was to calculate the energy of the photon in eV, and then either show that this was greater than the work function of the metal or to calculate the kinetic energy of the emitted photoelectron. A lot of confidence in the topic of quantum physics was evident in the answers from the candidates. This is illustrated by exemplar 8 below from a middle-grade candidate. **Exemplar 8**  (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. $E = \phi + KE_{max}$ $2.3 \times 1.6 \times 10^{-19} = 3.68 \times 10^{-19}$ J $4.23 \times 10^{-19} = 3.68 \times 10^{-19} + KE_{max}$ Photoelectrons will be emitted as the work function (3.68×10^{-19} J) is less than the energy of a photon (4.23×10^{-19}) [2] This exemplar shows the right blend of calculations and scientific text to support the response. Good command of quantum physics earned this candidate full marks. **OCR support** Being aware of the contents of the data, formulae and relationship booklet and its layout will support candidates, alleviating the need to recall numerical values of constants and allowing retrieval of correct formulae, or giving assurance that the student has recalled correctly.
			Total	5	

Question			Answer/Indicative content	Marks	Guidance
26			**Level 3 (5–6 marks)** Description and explanation of pattern changes **and** quantitatively explains link between de Broglie wavelength and potential difference. *There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.* **Level 2 (3–4 marks)** Clear description of how pattern changes and explanation of pattern changes and qualitatively explains link between de Broglie wavelength and potential difference **or** limited description of how pattern changes and quantitatively explains link between de Broglie wavelength and potential difference. *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 how pattern changes and limited attempts to explain qualitatively the link between de Broglie wavelength and potential difference **or** qualitatively explains link between de Broglie wavelength and potential difference. *The information is basic and communicated in an unstructured way. The information is supported by limited evidence and the relationship to the evidence may not be clear.* **0 marks** No response or no response worthy of credit.	B1 ×6	***Indicative scientific points may include:*** ***Description of pattern changes*** • Rings become closer (not just smaller) • Rings become brighter ***Qualititative explanation of pattern changes in terms of de Broglie wavelength and potential difference*** • Electrons gain greater energy • Electrons have a greater speed • Electrons have a greater momentum • Implies smaller wavelength • Smaller wavelength means less diffraction • Shorter wavelength gives shorter path differences between areas of constructive and destructive interference ***Quantitative explanation of pattern changes in terms of de Broglie wavelength and potential difference*** • $eV = \frac{1}{2}mv^2$ • $p = mv$ • $v^2 \propto V$ or $p^2 \propto V$ • $\lambda = \frac{h}{p}$ or $\lambda \propto \frac{1}{v}$ • $\lambda = \frac{h}{\sqrt{2meV}}$ or $\lambda \propto \frac{1}{\sqrt{V}}$ <u>Examiner's Comments</u> This question tested an understanding of electron diffraction. Many candidates gave a good qualitative explanation of how the pattern would change. High achieving candidates clearly demonstrated how the de Broglie wavelength λ was related to the potential difference V by equating the energy eV to kinetic energy, then using the definition of momentum and the de Broglie wavelength. Some candidates confused speed v with potential difference V. Many candidates gave a good qualitative explanation. Many candidates did not state that the rings would become brighter.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
					AfL Candidates should be able to describe how to use light gates. In particular, candidates should be able to indicate the measurements that are needed to determine speed and acceleration. Candidates should state that the light gates should be connected to a timer or data-logger. **AfL** When analysing experimental data, candidates should be able to determine appropriate graphs to plot which will give a straight line (if the given relationship is true). Candidates should also be able to describe how unknown quantities may be determined using the gradient and / or *y* -intercept. **Misconception** There is some confusion between the equations to use for photoelectric effect and the equations to use when considering the de Broglie wavelength. For the de Broglie wavelength, a common misconception is to relate the energy to wavelength by the equation for the energy of a photon, $E = \frac{hc}{\lambda}$
			Total	6	
27			A	1	
			Total	1	
28			(E =) 1.8 × 1.6 × 10^{-19} **or** 2.88 × 10^{-19} (J)	C1	
			$1.8 \times 1.6 \times 10^{-19} = \frac{6.63 \times 10^{-34} \times 3.0 \times 10^{8}}{\lambda}$	C1	
			λ = 6.9 × 10^{-7} (m)	A1	
			Total	3	

Question			Answer/Indicative content	Marks	Guidance
29			D	1	
			Total	1	
30		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% **2** Straight line of best fit passes through all error bars **3** gradient = 1.0 (× 10^{-22}) $\frac{h^2}{2mq} =$ gradient $\frac{(6.63 \times 10^{-34})^2}{2 \times m \times 3.2 \times 10^{-19}} =$ gradient $m = 6.9 \times 10^{-27}$ (kg) (hence about 10^{-26} kg)	C1 A1 B1 C1 C1 C1 A1	**Note** 10 (%) on answer line will score the C1 mark **Ignore** POT for this mark; **Allow** ± 0.20 (× 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**: 1.37×10^{-26} kg scores 3 marks for $q = 1.6 \times 10^{-19}$ C because answer is about 10^{-26} kg
			Total	9	
31			B	1	
			Total	1	
32			$h \rightarrow$ J s / $h \rightarrow$ N m s / J $\rightarrow$ kg m^2 s^{-2} base unit = kg m^2 s^{-1}	C1 A1	
			Total	2	