Physics A (H156, H556)

Exploring - The photoelectric effect ppq
KSA Physics

Please note that you may see slight differences between this paper and the original.

Candidates answer on the Question paper.

OCR supplied materials:
Additional resources may be supplied with this paper.

Other materials required:
- Pencil
- Ruler (cm/mm)

Duration: Not set

INSTRUCTIONS TO CANDIDATES

- Write your name, centre number and candidate number in the boxes above. Please write clearly and in capital letters.
- Use black ink. HB pencil may be used for graphs and diagrams only.
- Answer **all** the questions, unless your teacher tells you otherwise.
- Read each question carefully. Make sure you know what you have to do before starting your answer.
- Where space is provided below the question, please write your answer there.
- You may use additional paper, or a specific Answer sheet if one is provided, but you must clearly show your candidate number, centre number and question number(s).

INFORMATION FOR CANDIDATES

- The quality of written communication is assessed in questions marked with either a pencil or an asterisk. In History and Geography a *Quality of extended response* question is marked with an asterisk, while a pencil is used for questions in which *Spelling, punctuation and grammar and the use of specialist terminology* is assessed.
- The number of marks is given in brackets **[ ]** at the end of each question or part question.
- The total number of marks for this paper is **67**.
- The total number of marks may take into account some 'either/or' question choices.

1(a) The diagram below shows two parallel plates, **E** and **C**, in an evacuated glass tube.

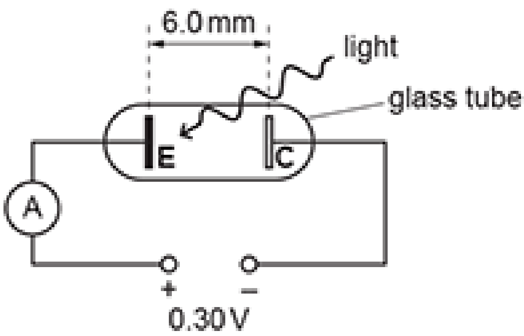


Plate **E** is made from potassium, which is sensitive to light. Plate **C** is not sensitive to light.

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.

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 8.8×10^{12} ms^{-2}.

[3]

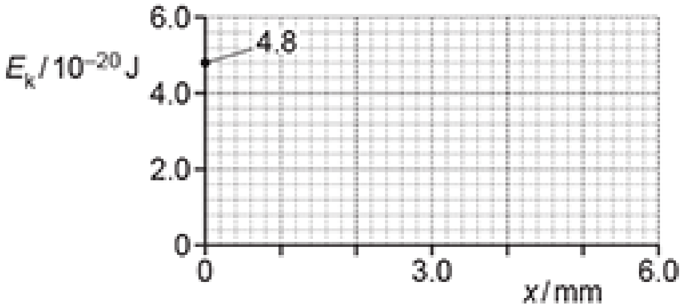
ii. Show that the initial speed of the photoelectron is about 3×10^{5} ms^{-1}.

[2]

iii. Calculate the time t taken by the photoelectron to travel from plate **E** to plate **C**.

t = ... s **[2]**

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



[2]

(b) Explain, in terms of photons, what happens to the ammeter reading when light of frequency greater than 6.3×10^{14} Hz is now incident on plate **E**.

[2]

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

work function = ... eV **[3]**

2(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.

[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]**

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]

4 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]**

5

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

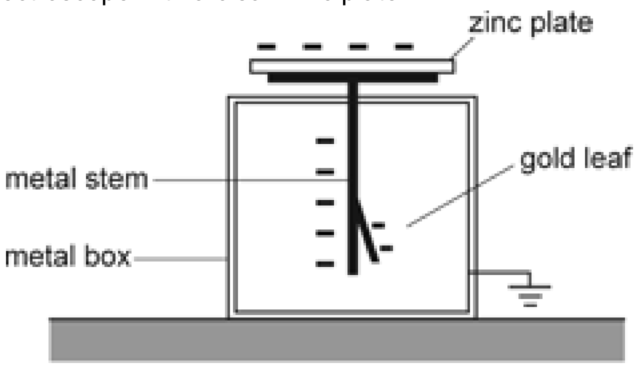


Fig. 20.2

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]

6(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.

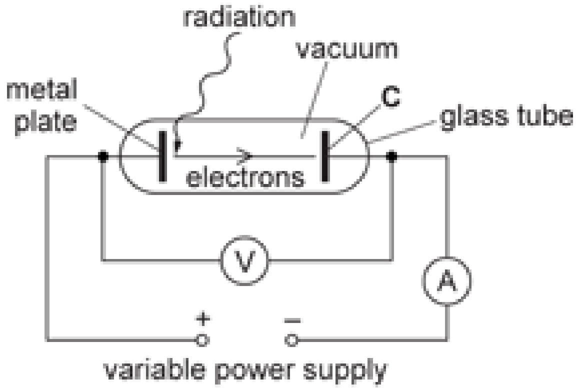


Fig. 19.1

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.

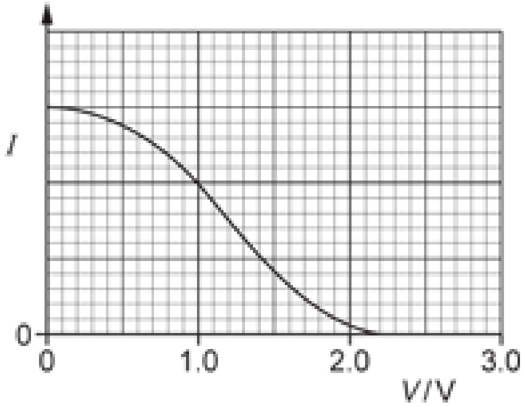


Fig. 19.2

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

[3]

7(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**.

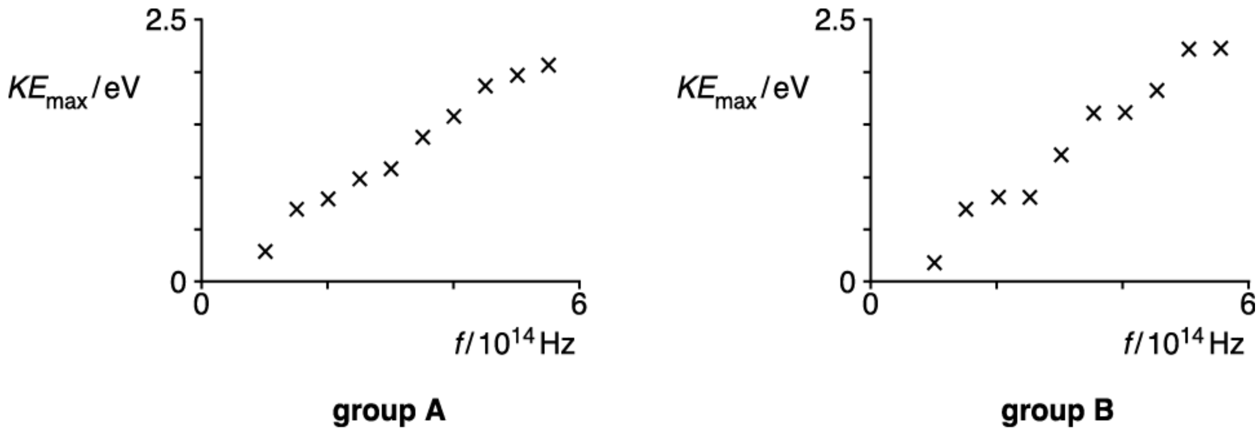


Fig. 19

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.

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[6]

8(a) Fig. 19 shows a photocell.

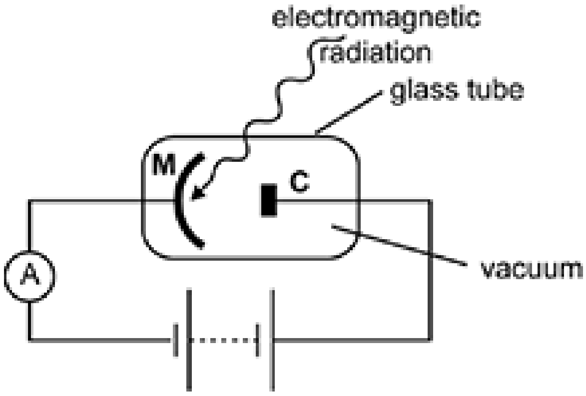


Fig. 19

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 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]

10(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]

END OF QUESTION PAPER

Question			Answer/Indicative content	Marks	Guidance
1	a	i	$a = \frac{VQ}{dm}$ OR $a = \frac{EQ}{m}$ OR $KE = ½\ mv^2$ and $v^2 = u^2 + 2as$ OR $KE = F \times d$ and $F = m \times a$ $a = \frac{0.30 \times 1.6 \times 10^{-19}}{6.0 \times 10^{-3} \times 9.11 \times 10^{-31}}$ / $a = \frac{50 \times 1.6 \times 10^{-19}}{9.11 \times 10^{-31}}$ / (Use of $KE = ½\ mv^2$) = $4.8 \times 10^{-20} = ½ \times 9.11 \times 10^{-31} \times v^2$ and (use of $v^2 = u^2 + 2as$ =) $v^2 = (1.05 \times 10^{11}) = 2 \times a \times 6 \times 10^{-3}$ (± 0^2) (Use of $KE = F \times d$) = $4.8 \times 10^{-20} = F \times 6 \times 10^{-3}$ and (use of $F = m \times a$) $F = (8.0 \times 10^{-18}) = 9.11 \times 10^{-31} \times a$ $a = 8.78 \ldots. \times 10^{12}$ (ms^{-2})	C1 M1 A1	**Allow** u and v interchangeably throughout **Allow** calculation of E = ($0.30 / 6 \times 10^{-3}$) = 50 (V m^{-1}) or $v = 3.2 \times 10^5$ (ms^{-1}) or $v^2 = 1.05 \times 10^{11}$ ($(ms^{-1})^2$) or $F = 8.0 \times 10^{-18}$ (N) for C1 mark 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 $KE = ½\ mv^2$ and $v^2 = u^2 + 2as$ Method 3: using $KE = F \times d$ and $F = m \times a$ **Note** must be more than 2 SF (not paper SF penalty) **Ignore** negative sign <u>**Examiner's Comments**</u> There were many different routes to showing the acceleration, and marks were given for each method or part method. No one method was seen significantly more than others, and some candidates used a variety of pathways to come to their answer. The main principle in the question (and the subsequent one) where the candidate is being asked to "show that" a given value is correct is that the examiner must be convinced that the candidate has clearly demonstrated that they have carried out the calculation and evaluated it on their calculator. The instructions which examiners used was: first marking point for providing one (or two) equations that would lead to the solution, or calculation of an intermediate value; second marking point for a full substitution into one or more equations; third marking point for using this full substitution to produce an answer to more sf than given in the question. As the second marking point was deemed to be an M mark, the full substitution needed to be seen to gain the A mark. A small number of (often higher end)

Question			Answer/Indicative content	Marks	Guidance
					candidates did not show the full substitution, often missing out the value of m_e in their calculation, and another common error was to not show the extra significant figure. Over half of the candidates were able to achieve full marks on this question and it generally discriminated well. **Assessment for learning** When a question asks a candidate to "show that" a given value is correct, the following two points should be considered: • Each stage of the calculation should be clearly shown. Preferably setting out any equation first, and then showing a full substitution of all values into that equation • If the value calculated by the candidate would correctly round to the given value, then the candidate should show their calculated value to at least one more significant figure than the given value. Both of these are evidence that the complete calculation has taken place and that the candidate has not somehow artificially generated the required value. This advice should be viewed as "best practice" rather than a rigid set of rules. Reverse arguments are often possible where a candidate can work backwards from their given value, however this is not the advised approach.

Question			Answer/Indicative content	Marks	Guidance
		ii	(Use of $KE = ½\ mv^2$) = $4.8 \times 10^{-20} = ½ \times m \times v^2$ OR ($u^2 = v^2 - 2as$) = $0^2 - [2 \times (-)\ 8.8 \times 10^{12} \times s]$ Full substitution leading to $v = 3.2… \times 10^5$ (ms^{-1})	C1 A1	**Allow** u and v interchangeably 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 __Examiner's Comments__ The vast majority of candidates were able to clearly show that the speed of the photoelectron could be calculated as $3.2 \times 10^5\ ms^{-1}$, most often through substitution into the kinetic energy formula. As in Question 19 (b) (i), it is important to show all variables and constants used in the equation for full marks and to give the answer to at least one more d.p. than given in the question, to show the calculation has taken place. An alternative solution using an equation of motion and the acceleration given (or calculated) in Question 19 (b) (i) would yield the same result.
		iii	$t = \frac{3.2\ \times 10^5}{8.8 \times 10^{12}}$ $t = 3.6 \times 10^{-8}$ (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) __Examiner's Comments__ Only around half of the candidates were able to obtain answers within the required range. Candidates used a variety of rounded or none-rounded values from prior calculations, so a generous range of responses was given to allow for this. A common error among less successful responses was to simply use speed = distance/time usually leading to 2.0×10^{-8} s. Those using $s = ut + ½\ at^2$ often encountered problems in solving the equation as it could lead to imaginary roots and tended to produce solutions way outside of the accepted values. However, marks could be given for setting up the calculation correctly.

Question			Answer/Indicative content	Marks	Guidance
		iv	Any line with negative slope starting from 0, 4.8×10^{-20} A straight line finishing at 6.0,0	M1 A1	½ square tolerance. **ALLOW** a curve with negative gradient. **ALLOW** a region of zero gradient, but not whole line ½ square tolerance on axis intercepted Examiner's Comments Nearly all candidates appreciated that this line would start at 4.8×10^{-20} J and decrease to zero at 6.0 mm. However, the vast majority drew a curved line of decreasing gradient. This may well have come from a confusion from $KE \propto v^2$ and attempting to draw a parabola.
	b		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 *kinetic* energy of photons **Do not allow** explanation in terms of increased number of **emitted** electrons (per second) **Allow** photoelectrons for electrons Examiner's Comments There were several misconceptions in candidates' responses to this question. Many candidates did not appreciate that the increased frequency would result in electrons of greater KE and thought that it was the increased energy of the photons crossing the 6.0mm gap that caused an ammeter reading. A significant number of candidates also described increasing frequency causing an increase in *kinetic* energy of photons, and some also linked the increasing frequency to a greater number of photons or photoelectrons.

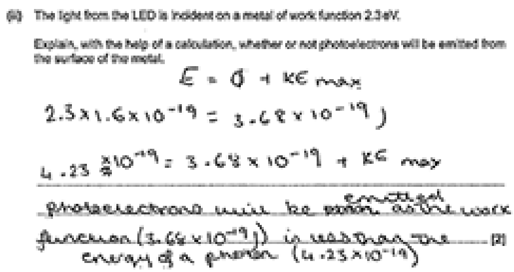
Question			Answer/Indicative content	Marks	Guidance
	c		($hf = \varphi + KE_{max}$)= $6.63 \times 10^{-34} \times 6.3 \times 10^{14} = \varphi + 4.8 \times 10^{-20}$	C1	**OR** (in eV) $hf = 6.63 \times 10^{-34}\ 6.3 \times 10^{14} / 1.6 \times 10^{-19}$
			$\varphi = 3.6969 \times 10^{-19}$ (J)	C1	$\varphi = 2.6 - 0.30$ (eV)
			$\varphi = 2.3$ (eV)	A1	$\varphi = 2.3$ (eV) Examiner's Comments This question was successfully completed by many candidates. It was clear that the use of Einstein's equation was well known, and the conversion to eV (generally done at the end) only caused a few candidates difficulties, mostly by multiplying their work function (in J) by *e*. Several candidates wrote down the answer with no working – while this will score full marks here, it is a risky tactic should an arithmetic error occur on their calculator.
			Total	14	

Question			Answer/Indicative content	Marks	Guidance
2	a		The minimum energy needed to remove an electron (from the surface of a metal)	B1	**Allow** work done for energy **Allow** photoelectron for electron Examiner's Comments This is a standard definition which candidates should be able to state. Candidates should remember that the work function is a minimum energy. There is occasionally a misconception regarding ionisation, and also some careless use of language for the removal of the electron. Words such as escape and eject are acceptable, but terms such as dislocation are not clear enough. The definition does not require the statement that it is from the surface of the metal this time, but that does not mean that it will not be required in the future.

Question			Answer/Indicative content	Marks	Guidance
	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/λ* 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/λ* <u>Examiner's Comments</u> The question is clear that the response needs to be given in terms of photons and energies. Many candidates discussed threshold frequencies, and although often correct, does not answer the question. The link between photon energy and frequency needs to be clear and not just a simple dependency – the simple solution for this is to state the equation. The final marking point requires the candidate to appreciate that only one photon can be absorbed by one electron. Standalone statements such as "there is a 1:1 relation" is meaningless in this context unless qualified. Many good candidates were able to score at least 3 marks on this question and it was clear that this is a well understood aspect. There is sufficient space for a fully clear answer and candidates are always to be reminded of the need for conciseness in such a response. Misconception Some candidates missed opportunities for marks by describing the effect wholly in terms of frequency, rather than energy.

Question			Answer/Indicative content	Marks	Guidance
		ii	(φ =) 2.3 × 1.6 × 10^{-19} **or** $(E=)\ \frac{6.63\times10^{-34}\times3.0\times10^{8}}{320\times10^{-9}}$ $(KE_{max}=)\ \frac{6.63\times10^{-34}\times3.0\times10^{8}}{320\times10^{-9}} - 2.3\times1.6\times10^{-19}$ $(v=)\ \sqrt{\frac{2\times2.5356\times10^{-19}}{9.11\times10^{-31}}}$ (wavelength =) $\frac{6.63\times10^{-34}}{9.11\times10^{-31}\times7.46\times10^{5}}$ wavelength = 9.8 × 10^{-10} (m)	C1 C1 C1 A1	φ = 3.68 × 10-*19* (J); E = 6.2156 × 10-*19* (J) KE_{max} = 2.5356 × 10^{-19} (J) v = 7.46 × 10^{5} (m s^{-1}) Examiner's Comments This is a novel development on what is a common calculation of kinetic energy and as such created some challenge for some candidates. Many were able to score the first marking point, either by converting from eV to joules, or by the calculation of the photon energy. Few candidates scored 2 or 3 marks, as generally an error such as using the speed of light for the electrons occurred. However, a good number of stronger candidates were able to achieve all 4 marks and set out their solutions clearly. It should be noted that the first 3 marks are for setting up the calculations and not the evaluations. This is to not penalise candidates too early for calculational errors and as always highlights the clear need for setting out working as well as possible.
			Total	9	
3			A	1	
			Total	1	

Question			Answer/Indicative content	Marks	Guidance
4		i	(*P* =) 0.01 × 2.5 **or** 0.01^2 × 250 **or** 2.5^2/250 **or** 0.025 (W) (E_{photon} =) $\frac{6.63\times10^{-34}\times3.0\times10^{8}}{4.7\times10^{-7}}$ **or** 4.23 × 10^{-19} (J) (number per second = $\frac{0.025}{4.23\times10^{-19}}$) 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}) <u>Examiner's Comments</u> 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** (λ0 =) 5.40 × 10^{-7} (m) 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)	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* > ϕ **Note** this can be implied by calculating the KE of the emitted electron <u>Examiner's Comments</u> Most candidates showed excellent knowledge and understanding of electronvolts and the photoelectric equation. A variety of answers were

Question			Answer/Indicative content	Marks	Guidance
					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
5					**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: • Photons were emitted from the zinc plate (rather than electrons) • Threshold frequency and work function

Question			Answer/Indicative content	Marks	Guidance
					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
6	a		Photon(s) mentioned One-to-one interaction between photons and electrons 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 ∝ $1/\lambda$ 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** ≥ 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		$\phi = \frac{6.63\times10^{-34}\times3.0\times10^{8}}{2.9\times10^{-7}}$ or 6.86×10^{-19} (J)	C1	
			$E = 5.1 \times 1.60 \times 10^{-19}$ or 8.16×10^{-19} (J) max kinetic energy = $(8.16 – 6.86) \times 10^{-19}$	C1	**Note:** Using 5.1 and not 8.16×10^{-19} cannot score this mark or the next mark
			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.
	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 = $e \times V$ **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'.*

Question			Answer/Indicative content	Marks	Guidance
			Total	10	

Question			Answer/Indicative content	Marks	Guidance
7	a		$5.0\text{ eV} = 8.0 \times 10^{-19}$ (J) and $2.0\text{ eV} = 3.2 \times 10^{-19}$ (J)	B1	**Allow** correct answers in terms of threshold frequency / wavelength for the metals and the frequency / wavelength of the photon
			photon energy = $\frac{6.63\times10^{-34}\times3.0\times10^{8}}{300\times10^{-9}} = 6.6(3)\times10^{-19}\text{(J)}$	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
8	a		$\frac{hc}{\lambda} = \phi + KE_{max}$ and $\phi = 2.3 \times 1.6 \times 10^{-19}$	C1	
			$\frac{6.63\times10^{-34}\times3.00\times10^{8}}{5.1\times10^{-7}} = 2.3\times1.6\times10^{-19} + KE_{max}$	C1	
			$KE_{max} = 2.2 \times 10^{-20}$ (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			D	1	
			Total	**1**	

Question			Answer/Indicative content	Marks	Guidance
10	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**	