

1

- (a) Describe what occurs in the photoelectric effect.

(2)

- (b) Violet light of wavelength 380 nm is incident on a potassium surface.

Deduce whether light of this wavelength can cause the photoelectric effect when incident on the potassium surface.

work function of potassium = 2.3 eV

(4)

- (c) The photoelectric effect provides evidence for light possessing particle properties.

State and explain **one** piece of evidence that suggests that light also possesses wave properties.

(2)

(Total 8 marks)

2

In an experiment to demonstrate the photoelectric effect, a charged metal plate is illuminated with light from different sources. The plate loses its charge when an ultraviolet light source is used but not when a red light source is used.

What is the reason for this?

A The intensity of the red light is too low.

☐

B The wavelength of the red light is too short.

☐

C The frequency of the red light is too high.

☐

D The energy of red light photons is too small.

☐

(Total 1 mark)

3

The photoelectric effect can be demonstrated by illuminating a negatively charged plate, made from certain metals, with ultraviolet (UV) light and showing that the plate loses its charge.

- (a) Explain why, when ultraviolet light is shone on a **positively** charged plate, no charge is lost by the plate.

(2)

- (b) Threshold frequency and work function are important ideas in the study of the photoelectric effect.

Tables 1 and 2 summarise the work functions of three metals and photon energies of three UV light sources.

Table 1

Metal	Work function / eV
Zinc	4.3
Iron	4.5
Copper	4.7

Table 2

Light source	Photon energy / eV
1	4.0
2	4.4
3	5.0

Discuss the combinations of metal and UV light source that could best be used to demonstrate the idea of threshold frequency and the idea of work function.

- (c) Calculate the maximum kinetic energy, in J, of the electrons emitted from a zinc plate when illuminated with ultraviolet light.

work function of zinc = 4.3 eV

frequency of ultraviolet light = 1.2×10^{15} Hz

maximum kinetic energy _____ J

(3)

- (d) Explain why your answer is a maximum.

(1)

(Total 12 marks)

4

Monochromatic radiation from a source of light (source A) is shone on to a metallic surface and electrons are emitted from the surface. When a second source (source B) is used no electrons are emitted from the metallic surface. Which property of the radiation from source A must be greater than that from source B?

A amplitude ☐

B frequency ☐

C intensity ☐

D wavelength ☐

(Total 1 mark)

5

In a photoelectric experiment, light is incident on the metal surface of a photocell. Increasing the intensity of the illumination at the surface leads to an increase in the

A work function



B minimum frequency at which electrons are emitted



C current through the photocell



D speed of the electrons

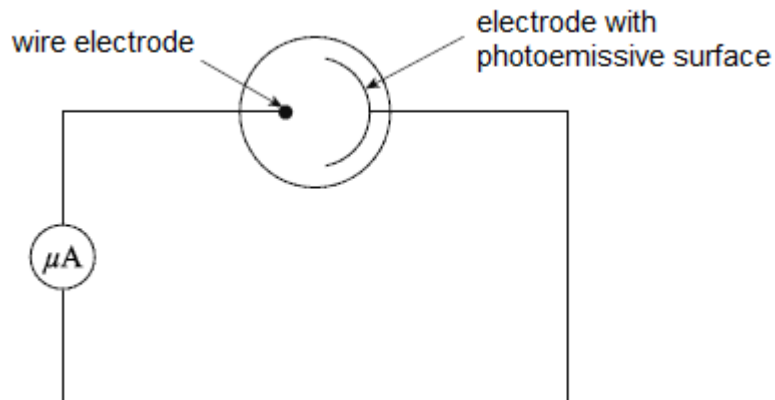


(Total 1 mark)

6

Figure 1 shows a photocell which uses the photoelectric effect to provide a current in an external circuit.

Figure 1



(a) Electromagnetic radiation is incident on the photoemissive surface.

Explain why there is a current only if the frequency of the electromagnetic radiation is above a certain value.

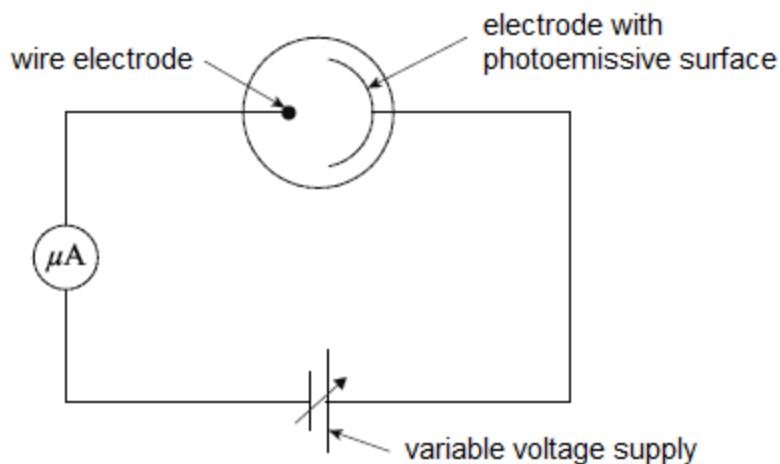
(3)

- (b) State and explain the effect on the current when the intensity of the electromagnetic radiation is increased.

(2)

- (c) A student investigates the properties of the photocell. The student uses a source of electromagnetic radiation of fixed frequency and observes that there is a current in the external circuit. The student then connects a variable voltage supply so the positive terminal is connected to the electrode with a photoemissive surface and the negative terminal is connected to the wire electrode. As the student increases the supply voltage, the current decreases and eventually becomes zero. The minimum voltage at which this happens is called the stopping potential. The student's new circuit is shown in **Figure 2**.

Figure 2



The photoemissive surface has a work function of 2.1 eV. The frequency of the electromagnetic radiation the student uses is 7.23×10^{14} Hz.

Calculate the maximum kinetic energy, in J, of the electrons emitted from the photoemissive surface.

maximum kinetic energy = _____ J

(3)

- (d) Use your answer from **part (c)** to calculate the stopping potential for the photoemissive surface.

stopping potential = _____ V

(1)

- (e) The student increases the frequency of the electromagnetic radiation.

Explain the effect this has on the stopping potential.

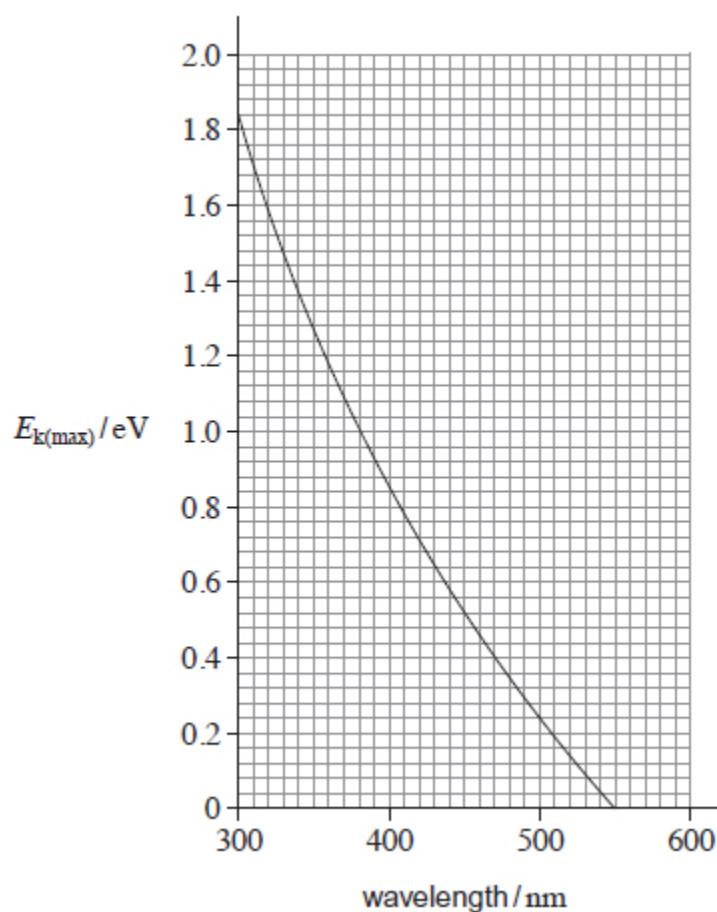
(3)

(Total 12 marks)

7

The maximum kinetic energy, $E_{k(\max)}$, of photoelectrons varies with the wavelength of electromagnetic radiation incident on a metal surface.

This variation is shown in the graph.



- (a) (i) Define the term work function.

(2)

- (ii) Show that the work function of the metal is approximately 4×10^{-19} J.

Use data from the graph in your calculation.

(3)

- (b) Monochromatic radiation is incident on the metal surface.
Photoelectrons are ejected with a maximum speed of $4.6 \times 10^5 \text{ m s}^{-1}$.

Determine the wavelength of the incident radiation.

wavelength _____ m

(3)

(Total 8 marks)

8

Sodium metal has a work function of 2.28 eV. An atom of sodium has an ionisation energy of 5.15 eV.

- (a) (i) State what is meant by work function.

(2)

- (ii) State what is meant by ionisation energy.

(2)

- (b) Show that the minimum frequency of electromagnetic radiation needed for a photon to ionise an atom of sodium is about $1.2 \times 10^{15} \text{ Hz}$.

(2)

- (c) Electromagnetic radiation with the frequency calculated in part (b) is incident on the surface of a piece of sodium.

Calculate the maximum possible kinetic energy of an electron that is emitted when a photon of this radiation is incident on the surface.

Give your answer to an appropriate number of significant figures.

maximum kinetic energy = _____ J

(3)

- (d) Calculate the speed of an electron that has the same de Broglie wavelength as the electromagnetic radiation in part (b).

speed = _____ m s⁻¹

(3)

(Total 12 marks)

9

When ultraviolet light of frequency 3.0×10^{15} Hz is incident on the surface of a metal, electrons of maximum kinetic energy 1.7×10^{-18} J are emitted.

- (a) Explain why the emitted electrons have a range of kinetic energies up to a maximum value.

(3)

- (b) (i) Show that the work function of the metal is 1.8 eV.

(3)

- (ii) Calculate the threshold frequency of the metal. Give your answer to an appropriate number of significant figures.

threshold frequency _____ Hz

(3)

- (c) (i) State and explain the effect on the emitted electrons of decreasing the frequency of the incident radiation whilst keeping the intensity constant.

(2)

- (ii) State and explain the effect on the emitted electrons of doubling the intensity of the incident radiation whilst keeping the frequency constant.

(2)

(Total 13 marks)

10

The *work function* of sodium is 2.28 e V.

- (a) State what is meant by the term work function.

(2)

- (b) Calculate the threshold frequency for sodium.

threshold frequency _____ Hz

(3)

(Total 5 marks)

11

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

(1)

- (b) Violet light of wavelength 380 nm is incident on a potassium surface.

- (i) Calculate the energy of a photon of this light.

photon energy _____ J

(3)

- (ii) Show that this photon can cause the photoelectric effect when incident on the potassium surface.

work function of potassium = 2.3 eV

(2)

- (c) The potassium surface is now given a positive charge.
Explain why no photoelectric effect is observed.

(2)

(Total 8 marks)

12

When a clean metal surface in a vacuum is irradiated with ultraviolet radiation of a certain frequency, electrons are emitted from the metal.

- (a) (i) Explain why the kinetic energy of the emitted electrons has a maximum value.

(2)

- (ii) Explain with reference to the work function why, if the frequency of the radiation is below a certain value, electrons are not emitted.

(2)

- (iii) State a unit for work function.

(1)

- (b) Light energy is incident on each square millimetre of the surface at a rate of $3.0 \times 10^{-10} \text{ J s}^{-1}$. The frequency of the light is $1.5 \times 10^{15} \text{ Hz}$.

- (i) Calculate the energy of an incident photon.

answer = _____ J

(2)

- (ii) Calculate the number of photons incident per second on each square millimetre of the metal surface.

answer = _____

(2)

- (c) In the wave theory model of light, electrons on the surface of a metal absorb energy from a small area of the surface.

- (i) The light striking the surface delivers energy to this small area at a rate of $3.0 \times 10^{-22} \text{ J s}^{-1}$.

The minimum energy required to liberate the electron is $6.8 \times 10^{-19} \text{ J}$.

Calculate the minimum time it would take an electron to absorb this amount of energy.

answer = _____ s

(1)

- (ii) In practice the time delay calculated in part c (i) does not occur. Explain how this experimental evidence was used to develop the particle model for the behaviour of light.

(2)

(Total 12 marks)

13

- (a) When illuminated with electromagnetic waves, a metal surface can exhibit the photoelectric effect. The maximum wavelength that causes the emission of photoelectrons with zero kinetic energy is 6.8×10^{-7} m.

- (i) Show that the threshold frequency for the surface is approximately 4.4×10^{14} Hz.

(2)

- (ii) Show that the work function for the surface is approximately 2.9×10^{-19} J.

(2)

- (iii) Calculate the maximum kinetic energy of electrons emitted from the surface when it is illuminated with ultraviolet radiation of frequency 7.8×10^{14} Hz.

maximum kinetic energy _____ J

(2)

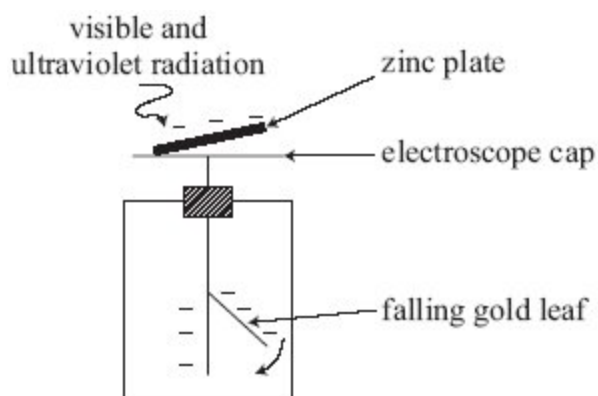
- (b) Explain why the photoelectric effect cannot be explained by the wave theory of light.

(2)

(Total 8 marks)

14

The diagram below shows the apparatus used to demonstrate the photoelectric effect. A clean zinc plate is placed on the cap of a gold leaf electroscope. The plate is then charged negatively and both visible and ultraviolet radiation are shone onto the plate. The gold leaf is seen to fall.



- (a) Explain why the gold leaf falls.

(2)

- (b) A clear sheet of glass, placed between the radiation sources and the zinc plate, absorbs some of the radiation.

- (i) Which type of radiation is absorbed?

(1)

- (ii) Explain why this effect stops the gold leaf from falling further.

(1)

- (c) The glass sheet is removed and the zinc plate is now charged positively. Again visible and ultraviolet radiation are shone onto the surface. Suggest why the gold leaf does not fall.

(1)

- (d) Calculate the maximum speed of electrons emitted when radiation of wavelength 320 nm is shone onto a caesium plate.

work function of caesium = 3.04×10^{-19} J

maximum speed _____ m s⁻¹

(4)

(Total 9 marks)

15

- (i) Calculate the longest wavelength of electromagnetic radiation that will cause photoelectric emission at a clean lithium surface.

work function for lithium $\phi = 4.6 \times 10^{-19}$ J

Longest wavelength = _____ m

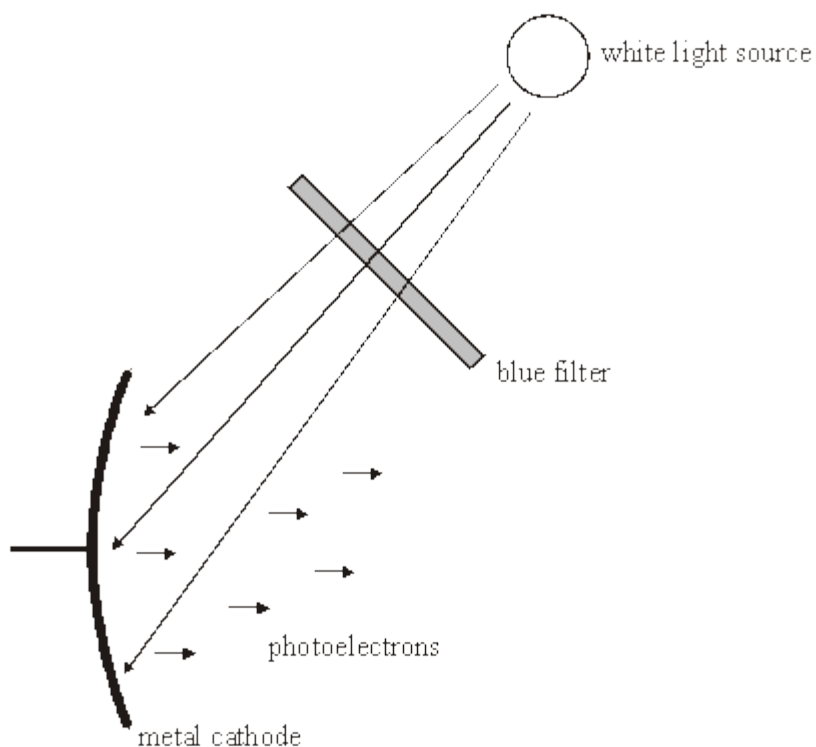
- (ii) Calculate maximum kinetic energy of the electrons emitted when electromagnetic radiation of frequency 8.5×10^{14} Hz is incident on the surface.

Maximum energy = _____ J

(Total 6 marks)

16

The apparatus shown in the figure below can be used to demonstrate the photoelectric effect. Photoelectrons are emitted from the metal cathode when it is illuminated with white light which has passed through a blue filter.



You may be awarded additional marks to those shown in brackets for the quality of written communication in your answers to parts (a) and (b).

- (a) The intensity of the light source is reduced. State and explain the effect of this on the emitted photoelectrons.

(3)

- (b) Explain why no photoelectrons are emitted when the blue filter is replaced by a red filter.

(3)

- (c) When a metal of work function $2.30 \times 10^{-19} \text{ J}$ is illuminated with ultraviolet radiation of wavelength 200 nm, photoelectrons are emitted.

Calculate

- (i) the frequency of the ultraviolet radiation,

- (ii) the threshold frequency of the metal,

- (iii) the maximum kinetic energy of the photoelectrons, in J.

(5)

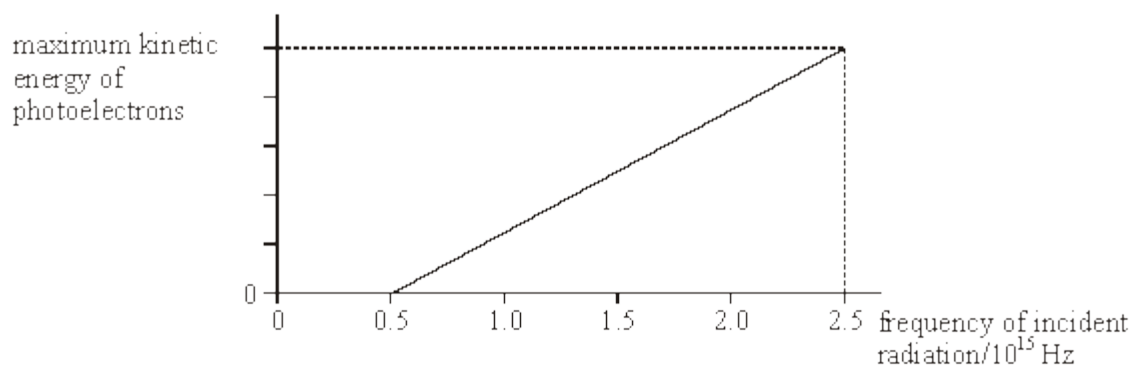
(Total 11 marks)

17

- (a) Explain what is meant by the term *work function* of a metal.

(2)

- (b) In an experiment on the photoelectric effect, the maximum kinetic energy of the emitted photoelectrons is measured over a range of incident light frequencies. The results obtained are shown in the figure below.



- (i) A metal of work function ϕ is illuminated with light of frequency f . Write down the equation giving the maximum kinetic energy, E_K , of the photoelectrons emitted in terms of ϕ and f .

$$E_K =$$

- (ii) Use the data in the figure to determine the work function of the metal.

- (iii) Determine the maximum kinetic energy of the photoelectrons when the frequency of the incident radiation is 2.5×10^{15} Hz.

(6)

- (c) The experiment is repeated but with the light incident on a metal of lower work function. Draw a new line on the figure that results from this change.

(2)

(Total 10 marks)

18

When light of a certain frequency is shone on a particular metal surface, electrons are emitted with a range of kinetic energies.

(a) Explain

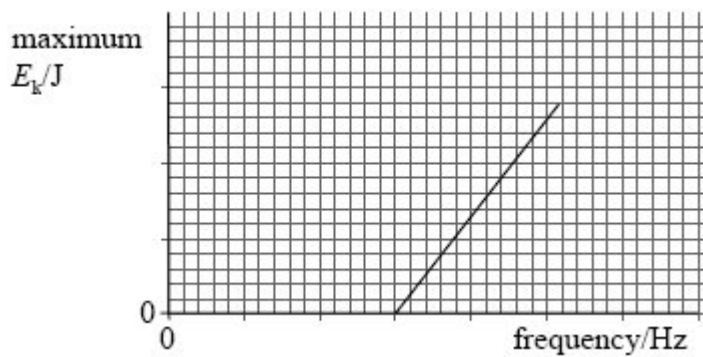
- in terms of photons why electrons are released from the metal surface, and
- why the kinetic energy of the emitted electrons varies upto a maximum value.

The quality of your written communication will be assessed in this question.

This image shows a blank sheet of white paper with horizontal ruling lines. The lines are evenly spaced and extend across the width of the page. There are no margins, text, or other markings on the paper.

(6)

(b) The graph below shows how the maximum kinetic energy of the electrons varies with the frequency of the light shining on the metal surface.



(i) On the graph mark the *threshold frequency* and label it f_0 .

(1)

(ii) On the graph draw a line for a metal which has a higher threshold frequency.

(2)

(iii) State what is represented by the gradient of the graph.

(1)

- (c) The threshold frequency of a particular metal surface is 5.6×10^{14} Hz. Calculate the maximum kinetic energy of emitted electrons if the frequency of the light striking the metal surface is double the threshold frequency.

answer = _____ J

(3)

(Total 13 marks)

Mark schemes

1	(a) <u>Photons of light incident on the metal surface cause the emission of electrons</u> ✓ The electrons emitted are those near the <u>surface of the metal</u>✓	2	[8]
	(b) Use of $= hc / \lambda$ condone errors in powers of 10✓ $5.2 \times 10^{-19}\text{J}$✓ Converts their energy in J to eV or work function to J photon energy = 3.3 eV or work function = $3.7 \times 10^{-19}\text{J}$✓ Compares the two values and draws conclusion✓	4	
	(c) Diffraction effects (spreading of light) when light passes through a single slit OR interference patterns (light and dark fringes) using two slits or diffraction grating✓ Only waves diffract and interfere✓	2	
2	D	[1]	
3	(a) The process involves the ejection of electrons which are negatively charged. ✓ Any electrons ejected will only make the positive charge greater. ✓	1	
		1	

- (b) The mark scheme gives some guidance as to what statements are expected to be seen in a 1 or 2 mark (L1), 3 or 4 mark (L2) and 5 or 6 mark (L3) answer. Guidance provided in section 3.10 of the '*Mark Scheme Instructions*' document should be used to assist in marking this question.

Mark	Criteria	QoWC
6	Both ideas fully analysed, with full discussion of alternatives.	The student presents relevant information coherently, employing structure, style and sp&g to render meaning clear. The text is legible.
5	Both ideas analysed with supporting discussion but without alternatives	
4	Both ideas analysed, with one dealt with satisfactorily and the other with some supporting discussion	The student presents relevant information and in a way which assists the communication of meaning. The text is legible. Sp&g are sufficiently accurate not to obscure meaning.
3	Both ideas analysed, with only one dealt with satisfactorily	
2	One idea analysed with some supporting discussion	The student presents some relevant information in a simple form. The text is usually legible. Sp&g allow meaning to be derived although errors are sometimes obstructive.
1	One idea analysed, with little supporting discussion	
0	Unsupported combination or no relevant analysis	The student's presentation, spelling, punctuation and grammar seriously obstruct understanding.

The following statements are likely to be present.

To demonstrate threshold frequency:

The metal should be kept the same, and the light source varied.

Using any metal, and light sources 1 and 3,

no charge will be lost with light source 1

but charge will be lost with light source 3

because light source three has a greater photon energy

and therefore frequency (from $E=hf$)

and is above the threshold frequency

as the photon energy is greater than the work function of the metal

but light source 1 has a photon energy less than the work function of the metal

so its frequency is below the threshold frequency.

To demonstrate work function

The light source should be kept the same, and the metal varied

Use light source 2 as the other two will either cause all three metals to lose their charge, or none of the metals to lose their charge.

Use each metal in turn, so that zinc loses its charge, due to its low work function, but copper and iron do not lose their charge.

6

- (c) Work function in joules = $1.6 \times 10^{-19} \times 4.3 = 6.9 \times 10^{-19} \text{ J}$ ✓

The first mark is for converting the work function into J

1

Use of $hf = \text{work function} + KE_{\text{max}}$

The second mark is for substituting into the photoelectric equation

1

$KE_{\text{max}} = hf - \text{work function}$

$= (6.63 \times 10^{-34}) \times (1.2 \times 10^{15}) + 6.9 \times 10^{-19} \text{ ✓}$

$= 7.9 \times 10^{-19} - 6.9 \times 10^{-19}$

$= 1.0 \times 10^{-19} \text{ J ✓}$

The third mark is for the final answer

Allow 1.1

1

- (d) The work function is the minimum amount of energy needed to remove the electron from the zinc surface ✓

Alternative

Reference to max ke corresponding to emission of surface electrons whilst electrons from deeper in the metal will be emitted with smaller ke

1

[12]

4 B

[1]

5 C

[1]

6 (a) energy of photon ✓

1

is greater than the work function ✓

1

so electrons are emitted ✓

1

if correct reference to threshold frequency and no mention of work function then only score one of first two marks and can be awarded third mark

- (b) increased intensity means more photons incident per second ✓

only need to see per second once

1

current greater OR more electrons emitted per second ✓

rate of photons incident OK (or rate of electrons emitted)

1

- (c) (use of $hf = \phi + E_k$)

$$\phi = 2.1 \times 1.6 \times 10^{-19} = 3.36 \times 10^{-19} \text{ ✓(J)}$$

if incorrect or no conversion to J then CE for next two marks

1

$$E_k = 6.63 \times 10^{-34} \times 7.23 \times 10^{14} - 3.36 \times 10^{-19}$$

1

$$E_k = 1.4(3) \times 10^{-19} \text{ ✓(J)}$$

1

- (d) (use of $eV = E_k$)

$$V_s = 1.43 \times 10^{-19} / 1.6 \times 10^{-19} = 0.89 \text{ (V) ✓}$$

CE from 05.3

RANGE 0.70 – 0.90

1

- (e) stopping potential would be greater ✓

1

because the energy of the photons (of the electromagnetic radiation) would be greater ✓

1

(hence) maximum kinetic energy of (photo)electrons would be greater ✓

1

[12]

7

- (a) (i) Energy required to remove an electron
Minimum energy required to remove an electron from a (metal) surface

2

- (ii) Read off $\lambda = 550 \text{ (nm)}$

Use of $E = hc / \lambda$ or $E = hf$ and $c = f\lambda$

$$3.6 \times 10^{-19}$$

or

Reads st of coordinates correctly

Use of $hc/\lambda = \phi + E_{k(\max)}$

$$3.6 \times 10^{-19} \text{ (J)}$$

3

- (b) $E_k = 9.6 \times 10^{-20}$
 J converted to eV / 0.6 eV
 4.35 to 4.40×10^{-7} (m), using graph

OR

$$E_k = 9.6 \times 10^{-20} \text{ or } \Phi = 6.4 \times 10^{-19}(\text{J})$$

$$hc/\lambda = 4.96 \times 10^{-19} \text{ (using given value in (aii))}$$

$$\text{or } 4.6 \times 10^{-19} \text{ using calculated value}$$

$$\text{or } f = 7.5 \times 10^{14}(\text{Hz})$$

$$4 \times 10^{-7} \text{ to } 4.4 \times 10^{-7} \text{ (m)}$$

Allow ecf for second mark only (i.e. for adding incorrect KE to work function)

3

[8]

8

- (a) (i) the minimum energy required by an electron✓
 to escape from a (metal)surface✓

if refer to atom / ionisation zero marks

2

- (ii) the (minimum) energy to remove an electron(from an atom)✓
 from the ground state✓

2

- (b) (use of $hf = eV$)

$$6.63 \times 10^{-34} \times f = 5.15 \times 1.60 \times 10^{-19} \checkmark$$

$$f = \frac{5.15 \times 1.60 \times 10^{-19}}{6.63 \times 10^{-34}} \checkmark = 1.24 \times 10^{15}(\text{Hz})$$

if no working and $1.24 \times 10^{15}(\text{Hz})$ 1 mark

2

- (c) (use of $hf = E_k + \Phi$)

$$\Phi = 2.28 \times 1.60 \times 10^{-19} = 3.648 \times 10^{-19} \text{ (J)} \checkmark$$

$$E_k = 5.15 \times 1.60 \times 10^{-19} - 3.648 \times 10^{-19} = 4.59 \times 10^{-19} \text{ J } \checkmark \checkmark$$

3 sig figs

if clearly used 1.2×10^{15} then final answer must be to 2 sig. figs. for last mark to be awarded

accept 4.57 in place of 4.59

3

(d) (use $ofc = f\lambda$)

$$\lambda = \frac{3.0 \times 10^8}{1.24 \times 10^{15}} = 2.42 \times 10^{-7} \checkmark$$

$$v = h / m\lambda = 6.63 \times 10^{-34} / (9.11 \times 10^{-31} \times 2.42 \times 10^{-7})$$

$$v = 3010 \text{ m s}^{-1} \checkmark \checkmark$$

first mark minimum working – determination of wavelength

bald answer gets 2 marks

range to 3 sig figs 2900 – 3030

3

[12]

9

- (a) energy of photon is constant / fixed OR energy given to electron is fixed ✓
energy required for electron to leave / escape / emit from the surface / metal
OR electron has to overcome work function ✓
maximum kinetic energy is the energy of photon minus the work function ✓
deeper electrons require energy to get to the surface OR have less E_k than surface electrons ✓

mention of energy levels means can only score first mark

photoelectric equation alternative for third mark if ϕ and hf defined

3 max

- (b) (i) (use of $E = hf$)

$$\text{energy of photon} = 6.63 \times 10^{-34} \times 3.0 \times 10^{15} \checkmark = 1.989 \times 10^{-18} \text{ (J)}$$

$$\text{work function} = hf - E_k = 1.989 \times 10^{-18} - 1.7 \times 10^{-18} = 2.89 \times 10^{-19} \checkmark$$

$$\text{work function} = 2.89 \times 10^{-19} / 1.6 \times 10^{-19} \checkmark = (1.8 \text{ eV})$$

hf gets first mark even if in wrong equation

3

- (ii) work function = hf_0

$$f_0 = 1.8 \times 1.6 \times 10^{-19} / 6.63 \times 10^{-34} \checkmark = 4.3 \times 10^{14} \checkmark \text{ (Hz)} \checkmark (2 \text{ sig figs})$$

2 sig . fig stand alone mark

Accept 4.4×10^{14}

3

- (c) (i) decrease the energy of(incident) photons ✓
decrease the maximum kinetic energy of electrons ✓
OR
decrease the energy of(incident) photons ✓
hence fewer deeper electrons escape ✓
OR
below threshold frequency ✓
no electrons emitted ✓
OR
as energy of each photon decreases but intensity is constant (there are more photons / sec) ✓
number of emitted electrons(/sec) must increase ✓

for last two alternatives must get first mark before can qualify for second mark

2

- (ii) increase in photons cause increase in (emitted) electrons ✓
double number of electrons / photons OR reference to rate /per second ✓
if refer to energy levels / atoms can only award first mark

2

[13]

10

- (a) Minimum energy to remove an electron

B1

from a (metal) surface

B1

2

- (b) Converts 2.28 (e V) to 3.6×10^{-19} (J) / $2.28 \times 1.6 \times 10^{-19}$

C1

Condone minus sign here on energy or charge

Use of $hf = \phi_0$

e.g. $f = 2.28 / h$ (will need to see subject)

or $2.28 = 6.6(3) \times 10^{-34} \times f$ or $f =$

$2.28 / 6.6(3) \times 10^{-34}$ (will need to see subject)

Makes f subject or substitutes correctly for h and ϕ_0

C1

allow equivalent substitution into $hf = \phi_0 + KE_{max}$ where $KE = 0$

Penalise minus sign on answer

$(f =) 5.5(0) \times 10^{14}$ (Hz) cao

A1

3

[5]

11

- (a) release of electrons from (metal) surface when electromagnetic radiation is incident on the surface

B1

1

- (b) (i) use of $c = f\lambda$ or $f = 7.9 \times 10^{14}$ seen (condone power of ten)

C1

correct sub into $E = hf$ (condone power of ten error)

C1

$$5.2(3) \times 10^{-19} \text{ (J)}$$

A1

3

- (ii) work function = $2.3 \times 1.6 \times 10^{-19}$ (3.7×10^{-19})
or converts 5.2×10^{-19} to 3.27 eV

M1

allow conversion to frequency if comparison made

less than answer to (b) (i) so yes (based on comparison of **cna**) (allow **ecf** from (b) (i))

A1

2

- (c) surface attracts negative electron back to positive surface

B1

photons have insufficient energy/energy required increased

B1

2

[8]

12

- (a) (i) hf is energy available/received **or** same energy from photons **(1)**

energy required to remove the electron varies (hence kinetic energy of electrons will vary) **(1)**

2

- (ii) (work function is the) minimum energy needed to release an electron **(1)**
 (or not enough energy to release electron)

below a certain frequency energy of **photon** is less than work function **or** energy of **photon** correctly related to f **(1)**

2

- (iii) joule **(1)** (accept eV)

1

- (b) (i) (use of $E = hf$)
 energy = $6.63 \times 10^{-34} \times 1.5 \times 10^{15}$ **(1)**
 energy = 9.9×10^{-19} (J) **(1)** 2
- (ii) number of photons per second = $3.0 \times 10^{-10} / 9.9 \times 10^{-19}$ **(1)**
 number of photons per second = 3.0×10^8 **(1)** 2
- (c) (i) (time taken = $6.8 \times 10^{-19} / 3 \times 10^{-22}$)
 time taken = 2.3×10^3 s **(1)** 1
- (ii) light travels as particles/ photons **(1)**
 (or has a particle(like) nature)
 (which transfer) energy in discrete packets **(1)**
or 1 to 1 interaction
or theory rejected/modified (in light of validated evidence) 2

[12]

13

- (a) (i) $f = c/\lambda$ seen in this form C1
 4.41 $\times 10^{14}$ seen A1 2
- (ii) $\Phi = hf$ C1
 2.917 $\times 10^{-19}$ to 2.93 $\times 10^{-19}$ seen A1 2
- (iii) $h(7.8 \times 10^{14})$ – their (ii) C1
 2.2 $\times 10^{-19}$ (J) to 2.3 $\times 10^{-19}$ (J) A1 2

- (b) no photoemission below threshold frequency (even with bright light)

B1

wave theory would allow gradual accumulation of energy to cause emission

B1

2

[8]

14

- (a) energy in uv is greater than work function of zinc (1)

B1

photoelectrons emitted so electroscope discharges (1)

B1

2

- (b) (i) uv (1)

B1

- (ii) (visible has) lower frequencies **or** (visible energy) less than work function (1)

B1

2

- (c) higher voltage means harder for electrons to leave zinc (owtte) (1)

B1

1

- (d) use of photoelectric equation (1)

C1

correct selection of h , c and m_e (1)

C1

correct $\frac{1}{2}mv^2$ (3.1×10^{-19}) (1)

C1

8.3×10^5 (1)

C1

4

[9]

15

- (i) recognition that work function =
- hf_0
- or
- hc/λ_0
- (1)**

rearrangement or correct substitution of values **(1)**

$$4.3 \times 10^{-7} \text{ m (1)}$$

- (ii) Einstein's equation seen or used
- (1)**

work function subtracted from energy of incident photon **(1)**

$$1.0(1) \times 10^{-19} \text{ J (1)}$$

[6]**16**

- (a) intensity determines the number of photons per second
- (1)**

fewer photoelectrons per second **(1)**(individual) photon energies are not changed **(1)**with no change in the (kinetic) energy/speed **(1)**one photon interacts with one electron **(1)**

3

- (b) energy of a photon is proportional to frequency (or
- $E = hf$
-)
- (1)**

photon of red light has less energy than a photon of blue light

[or $f_{\text{red}} < f_{\text{blue}}$ or $\lambda_{\text{red}} > \lambda_{\text{blue}}$] **(1)**

the energy is insufficient to overcome the work function of the metal

[or the frequency is below the threshold frequency] **(1)**

3

- (c) (i)
- $f \left(= \frac{3.0 \times 10^8}{200 \times 10^{-9}} \right) = 1.5 \times 10^{15} \text{ Hz (1)}$

(ii) $f_0 \left(= \frac{\phi}{h} \right) = \frac{2.3 \times 10^{-19}}{6.63 \times 10^{-34}} \text{ (1)}$

$$= 3.5 \times 10^{14} \text{ Hz (1)}$$

$$(3.47 \times 10^{14} \text{ Hz})$$

- (iii) (use of
- $hf = \phi + E_k$
- gives)

$$E_x = (6.63 \times 10^{-34} \times 1.5 \times 10^{15}) - 2.3 \times 10^{-19} \text{ (1)}$$

$$7.6 \times 10^{-19} \text{ (J) (1)}$$

$$(7.645 \times 10^{-19} \text{ (J)})$$

(allow C.E for value of f from (i))

5

[11]**17**

- (a) minimum (energy/work done)
- (1)**

energy required to remove an electron from
the surface (of the metal) **(1)**

2

(b) (i) $E_k = hf - \phi$ **(1)**

$$f_0 = 0.50 \times 10^{15} \text{ (Hz)} \text{ **(1)**}$$

$$\phi (= hf_0) = 6.6 \times 10^{-34} \times 0.50 \times 10^{15} \text{ **(1)**}$$

$$= 3.3 \times 10^{-19} \text{ J **(1)**}$$

(ii) (use of $E_k = hf - \phi$ gives)

$$E_k = (6.6 \times 10^{-34} \times 2.5 \times 10^{15}) - 3.3 \times 10^{-19} \text{ **(1)**}$$

$$= 1.3(2) \times 10^{-18} \text{ J **(1)**}$$

(allow C.E. for incorrect value of ϕ from (ii))

[or (using gradient = $h = \Delta E_k / \Delta f$)

$$\Delta E_k = 6.6 \times 10^{-34} \times 2 \times 10^{15} \text{ **(1)**}$$

$$= 1.3(2) \times 10^{-18} \text{ J **(1)**}$$

6

(c) same gradient **(1)**

drawn above existing line with smaller x intercept **(1)**

2

[10]

QWC	descriptor	mark range
good-excellent	The candidate provides a comprehensive and logical explanation which recognises that light consists of photons of energy hf and that an electron at or near the metal surface can only gain the energy of a single photon when it interacts with a photon. In addition, the candidate should recognise the significance of the work function (of the metal) in this context in relation to the maximum kinetic energy that an emitted electron can have. The candidate should also provide some indication of why the kinetic energy of an emitted electron may be less than the maximum kinetic energy. Although the term 'work function' might not be defined or used, the candidate's explanation should clearly state that each electron needs a minimum amount of energy to escape from the metal.	5-6
modest-adequate	The candidate provides a logical and coherent explanation which includes the key ideas including recognition that light consists of photons of energy hf and that an electron at or near the metal surface can only gain the energy of a single photon when it interacts with a photon. In addition, the candidate should be aware that each electron needs a minimum amount of energy to escape from the metal. They should appreciate that the kinetic energy of an emitted electron is equal to the difference between the energy it gains from a photon and the energy it needs (or uses) to escape from the metal. However, the explanation may lack a key element such as why the kinetic energy of the emitted electrons varies.	3-4
poor-limited	The candidate provides some correct ideas including recognition that light consists of photons of energy hf and that electrons in the metal (or at its surface) absorb photons and thereby gain energy. Their ideas lack coherence and they fail to recognise or use in their explanation the key idea that one photon is absorbed by one electron.	1-2

The explanations expected in a good answer should include most of the following physics ideas

energy is needed to remove an electron from the surface

work function ϕ (of the metal) is the minimum energy needed by an electron to escape from the surface

light consists of photons , each of energy $E = hf$

one photon is absorbed by one electron

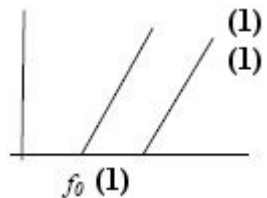
an electron can escape (from the surface) if $hf > \phi$

kinetic energy of an emitted electron cannot be greater than $hf - \phi$

an electron below the surface needs to do work/uses energy to reach the surface

kinetic energy of such an electron will be less than $hf - \phi$

(b) (i)



(ii) parallel line, higher threshold frequency **(1)(1)**

(iii) Planck's constant **(1)**

4

(c) (use of $hf_0 = \phi$)

$$hf = 6.63 \times 10^{-34} \times 2 \times 5.6 \times 10^{14} \text{ (1)}$$

$$\phi = 3.7(1) \times 10^{-19} \text{ J (1)}$$

$$E_k = 2 \times 3.7 \times 10^{-19} - 3.7 \times 10^{-19} = 3.7 \times 10^{-19} \text{ J (1)}$$

3

[13]