Quantum AS Revision Pack

Name: ______________________

Class: ______________________

Date: ______________________

Time: **234 minutes**

Marks: **202 marks**

Comments:

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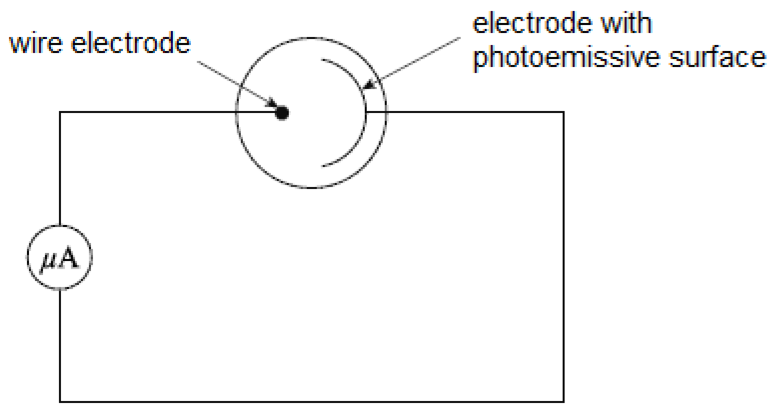
1 **Figure 1** shows a photocell which uses the photoelectric effect to provide a current in an external circuit.

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)

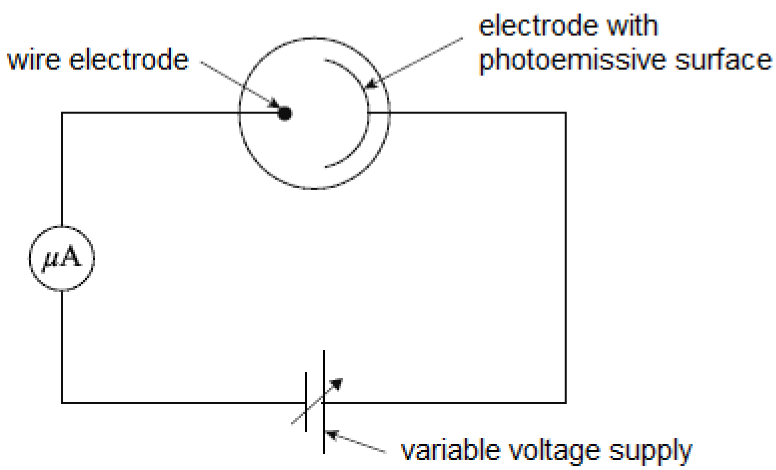
(b) State and explain the effect on the current when the intensity of the electromagnetic radiation is increased.

(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.

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(3)

(Total 12 marks)

2 (a) The mercury atoms in a fluorescent tube are excited and then emit photons in the ultraviolet region of the electromagnetic spectrum.

(i) Explain how the mercury atoms become excited.

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(3)

(ii) Explain how the excited mercury atoms emit photons.

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(2)

(b) Explain how the ultraviolet photons in the tube are converted into photons in the visible part of the electromagnetic spectrum.

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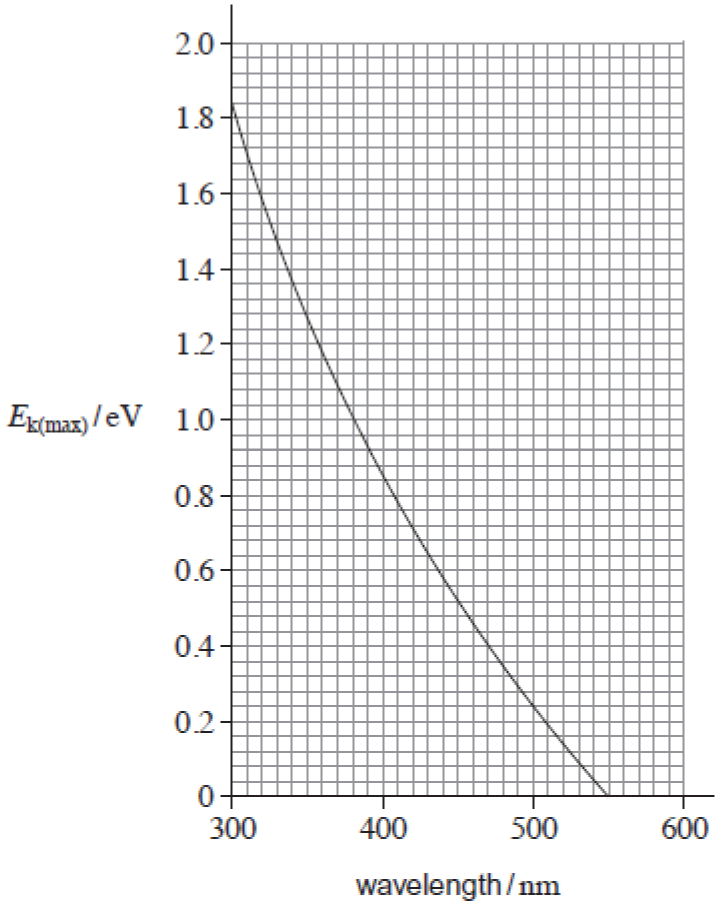
(2)

(Total 7 marks)

3 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.

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(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 4.6×10^5 m s^{-1}.

Determine the wavelength of the incident radiation.

wavelength ____________________ m

(3)

(Total 8 marks)

4 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.

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(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.

(6)

(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.

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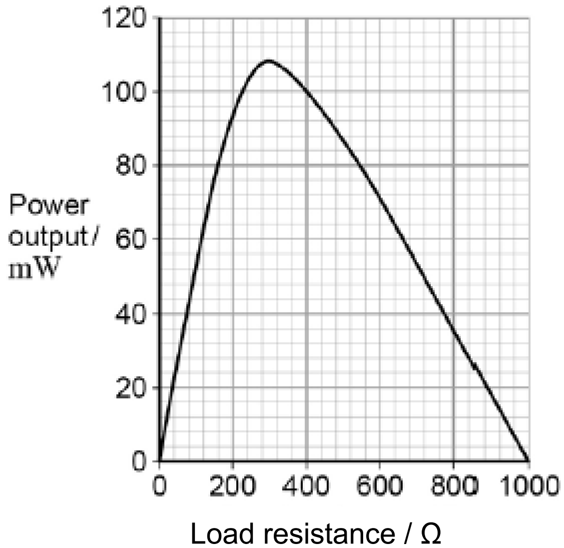
(1)

(Total 12 marks)

5 **Figure 1** shows data for the variation of the power output of a photovoltaic cell with load resistance. The data were obtained by placing the cell in sunlight. The intensity of the energy from the Sun incident on the surface of the cell was constant.

Figure 1



(a) Use data from **Figure 1** to calculate the current in the load at the peak power.

(3)

(b) The intensity of the Sun's radiation incident on the cell is 730 W m $^{-2}$. The active area of the cell has dimensions of 60 mm × 60 mm.

Calculate, at the peak power, the ratio $\frac{\textit{electrical energy delivered by the cell}}{\textit{energy arriving at the cell from the Sun}}$

(3)

(c) The average wavelength of the light incident on the cell is 500 nm. Estimate the number of photons incident on the active area of the cell every second.

(2)

(d) The measurements of the data in **Figure 1** were carried out when the rays from the sun were incident at 90° to the surface of the panel. A householder wants to generate electrical energy using a number of solar panels to produce a particular power output.

Identify **two** pieces of information scientists could provide to inform the production of a suitable system.

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(2)

(Total 10 marks)

6 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.

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(2)

(ii) State what is meant by ionisation energy.

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(2)

(b) Show that the minimum frequency of electromagnetic radiation needed for a photon to ionise an atom of sodium is about 1.2×10^{15} 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)

7 (a) A fluorescent tube is filled with mercury vapour at low pressure. After mercury atoms have been excited they emit photons.

(i) In which part of the electromagnetic spectrum are these photons?

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(1)

(ii) What is meant by an excited mercury atom?

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(1)

(iii) How do the mercury atoms in the fluorescent tube become excited?

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(2)

(iv) Why do the excited mercury atoms emit photons of characteristic frequencies?

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(3)

(b) The wavelength of some of the photons emitted by excited mercury atoms is 254 nm.

(i) Calculate the frequency of the photons.

frequency ____________________ Hz

(2)

(ii) Calculate the energy of the photons in electron volts (eV).

energy ____________________ eV

(2)

(c) Explain how the coating on the inside of a fluorescent tube emits visible light.

(2)
(Total 13 marks)

8 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.

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(2)

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

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(2)
(Total 13 marks)

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

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

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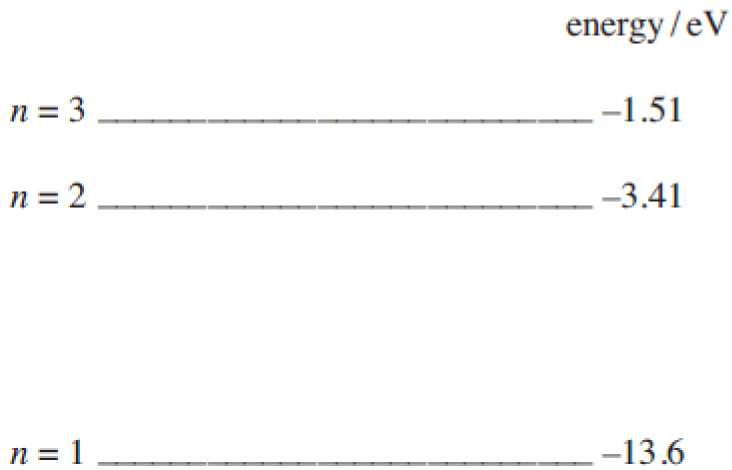
(2)

(b) Calculate the threshold frequency for sodium.

threshold frequency ____________________ Hz

(3)
(Total 5 marks)

10 The diagram below shows the lowest three energy levels of a hydrogen atom.



(a) An electron is incident on a hydrogen atom. As a result an electron in the ground state of the hydrogen atom is excited to the n = 2 energy level. The atom then emits a photon of a characteristic frequency.

(i) Explain why the electron in the ground state becomes excited to the n = 2 energy level.

(2)

(ii) Calculate the frequency of the photon.

frequency = ____________________ Hz

(3)

(iii) The initial kinetic energy of the incident electron is 1.70×10^{-18} J.

Calculate its kinetic energy after the collision.

kinetic energy = ____________________ J

(2)

(iv) Show that the incident electron cannot excite the electron in the ground state to the n = 3 energy level.

(2)

(b) When electrons in the ground state of hydrogen atoms are excited to the n = 3 energy level, photons of more than one frequency are subsequently released.

(i) Explain why different frequencies are possible.

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(1)

(ii) State and explain how many possible frequencies could be produced.

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(2)

(Total 12 marks)

11 (a) When monochromatic light is shone on a clean cadmium surface, electrons with a range of kinetic energies up to a maximum of 3.51×10^{-20} J are released. The *work function* of cadmium is 4.07 eV.

(i) State what is meant by work function.

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(2)

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

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(4)

(iii) Calculate the frequency of the light. Give your answer to an appropriate number of significant figures.

answer = ____________________ Hz

(4)

(b) In order to explain the photoelectric effect the wave model of electromagnetic radiation was replaced by the photon model. Explain what must happen in order for an existing scientific theory to be modified or replaced with a new theory.

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(2)

(Total 12 marks)

12 (a) When free electrons collide with atoms in their *ground state*, the atoms can be excited or ionised.

(i) State what is meant by ground state.

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(1)

(ii) Explain the difference between excitation and ionisation.

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(3)

(b) An atom can also become excited by the absorption of photons. Explain why only photons of certain frequencies cause excitation in a particular atom.

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(4)

(c) The ionisation energy of hydrogen is 13.6 eV. Calculate the minimum frequency necessary for a photon to cause the ionisation of a hydrogen atom. Give your answer to an appropriate number of significant figures.

answer ____________________ Hz

(4)

(Total 12 marks)

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

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(1)

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

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

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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

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(2)

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

(2)

(Total 8 marks)

14 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 3.0×10^{-10} J s^{-1}. The frequency of the light is 1.5×10^{15} 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 3.0×10^{-22} J s^{-1}.
The minimum energy required to liberate the electron is 6.8×10^{-19} 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)

15 When monochromatic light is shone on a clean metal surface, electrons are emitted from the surface due to the photoelectric effect.

(a) State and explain the effect on the emitted electrons of

(i) increasing the frequency of the light,

(2)

(ii) increasing the intensity of the light.

(2)

(b) The wave model was once an accepted explanation for the nature of light. It was rejected when validated evidence was used to support a particle model of the nature of light. Explain what is meant by **validated evidence**.

(2)

(c) The threshold frequency of lithium is 5.5×10^{14} Hz.

(i) Calculate the work function of lithium, stating an appropriate unit,

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answer ______________________

(3)

(ii) Calculate the maximum kinetic energy of the emitted electrons when light of frequency 6.2×10^{14} HZ is incident on the surface of a sample of lithium.

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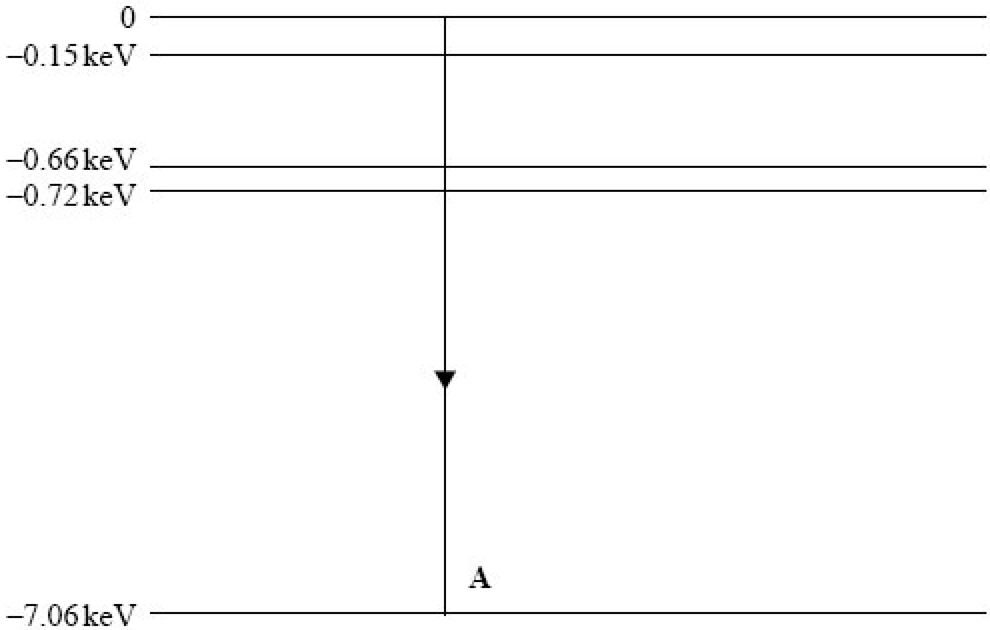
answer ______________________ J

(3)

(Total 12 marks)

16 (a) The diagram below shows some of the energy levels for an iron atom.



(i) Draw another arrow on the diagram above to represent the smallest energy change possible for an electron moving between two of the energy levels shown.
The electron energy change selected must result in energy being emitted from the atom.
Label this arrow **B**.

(1)

(ii) In the diagram above, when the energy change labelled **A** occurs an X-ray photon is emitted.
Show that the frequency of the photon is approximately 2×10^{18} Hz.

(3)

(b) (i) Radiation of frequency 2×10^{18} Hz has a wavelength of 1.5×10^{-10} m.
Calculate the speed of an electron that has a de Broglie wavelength of 1.5×10^{-10} m.

speed ____________________ m s^{-1}

(2)

(ii) Explain why electrons of this wavelength would be suitable to investigate the structure of a metallic crystal.

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(2)

(Total 8 marks)

17 Electrons exhibit *wave properties*.

(a) What phenomenon can be used to demonstrate the wave properties of electrons? Details of any apparatus used are not required.

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(1)

(b) Calculate the de Broglie wavelength of electrons travelling at a speed of 4.50×10^5 m s^{-1}.

answer = ______________________ m

(2)

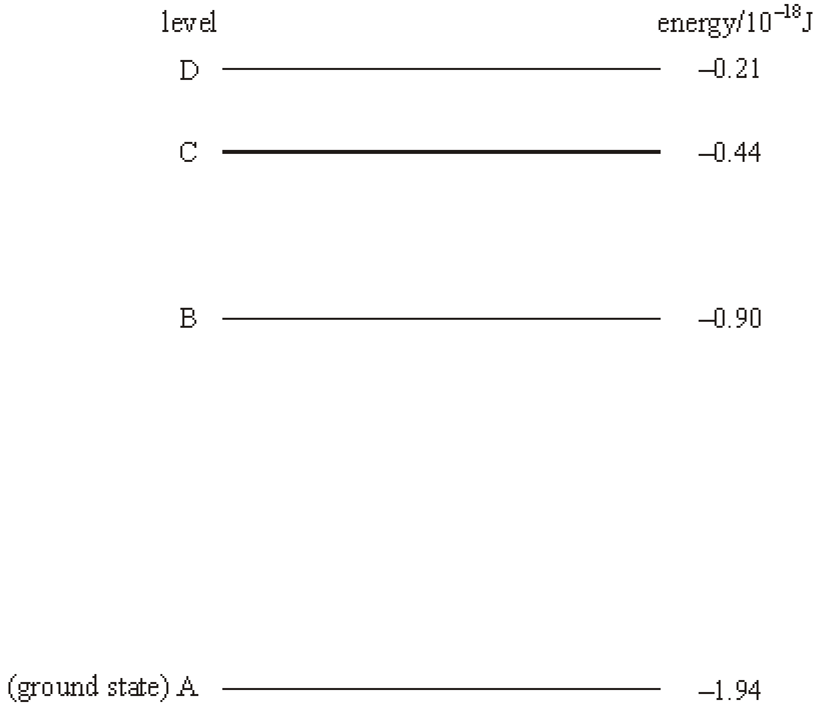
(c) The muon has a mass equal to 207 times the mass of an electron.
Calculate the speed of muons with the same de Broglie wavelength as the electrons in part (b).

answer = ______________________ m s^{-1}

(3)

(Total 6 marks)

18 The diagram shows some of the electron energy levels of an atom.



An incident electron of kinetic energy 4.1×10^{-18} J and speed 3.0×10^{6} m s^{-1} collides with the atom represented in the diagram and excites an electron in the atom from level B to level D.

(a) For the incident electron, calculate

(i) the kinetic energy in eV,

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(ii) the de Broglie wavelength.

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(4)

(b) When the excited electron returns directly from level D to level B it emits a photon. Calculate the wavelength of this photon.

(3)

(Total 7 marks)

19 (a) When monochromatic light is incident on a metal plate, electrons are emitted only when the frequency of the light exceeds a certain threshold frequency. Explain, in terms of energy, why this threshold frequency exists.

(3)

(b) A sodium metal surface is illuminated with incident light of frequency 9.70×10^{14} Hz. The maximum kinetic energy of an emitted electron is 2.49×10^{-19} J.

Calculate

(i) the wavelength of the incident light,

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____

(ii) the energy, in J, of each incident photon,

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____

(iii) the work function, in J, of sodium,

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____

(iv) the work function, in eV, of sodium.

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(7)

(Total 10 marks)

20 The diagram below shows some of the energy levels of the hydrogen atom.

energy/10^{-19}J

0 ______________________________ n = ∞

–2.4 ______________________________ n = 3

–5.4 ______________________________ n = 2

–22 ______________________________ n = 1 (ground state)

(a) Explain how changes of electron energies can produce a line emission spectrum.

(3)

(b) (i) What is meant by *ionisation*?

(ii) State the energy, in J, required to ionise a hydrogen atom from its ground state.

(iii) Calculate the minimum frequency of radiation that can ionise a hydrogen atom from its ground state.

(iv) Explain what happens to an electron in the ground state of a hydrogen atom when it receives radiation of a frequency greater than the minimum frequency obtained in part (b)(iii).

(5)

(c) Calculate the wavelength of the radiation emitted when an electron falls from level n = 3 to level n = 2 in the hydrogen atom.

(3)

(Total 11 marks)

Mark schemes

1 (a) energy of <u>photon</u> ✓ 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 $hf = \varnothing + E_k$)*

$\varnothing = 2.1 \times 1.6 \times 10^{-19} = 3.36 \times 10^{-19}$ ✓(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

$E_k = 1.4(3) \times 10^{-19}$ ✓(J) 1

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

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

CE from 05.3

RANGE 0.70 – 0.90 1

(e) stopping potential would be greater ✓ 1

because the <u>energy</u> of the <u>photons</u> (of the electromagnetic radiation) would be greater ✓ 1

(hence) <u>maximum</u> kinetic energy of (photo)electrons would be greater ✓ 1

[12]

2 (a) (i) electrons passing through tube collide with electrons in mercury atom ✓

Allow mercury atoms collide with each other

transferring energy / atom gains energy from a collision ✓

causing orbital electrons / electrons in mercury atom to move to higher energy level ✓

Atomic electrons move from ground state 3

(ii) (each) excited electron / atom relaxes to a lower (energy) level ✓

allow excited electron / atom de-excites / relaxes

Allow excited electron / atom relaxes to ground state

Condone moves for relaxes

emitting a photon of energy <u>equal</u> to the energy difference between the levels ✓

2

(b) coating absorb (uv) photons (causing excitation) / (uv)photons collide with electrons in the coating (causing excitation) / electrons in coating are excited

allow <u>atoms</u> in coating absorb (uv) photons (causing excitation)

Atomic <u>electrons</u> de-excite indirectly to previous lower level (and in doing so emit lower energy photons) ✓

Owtte (must convey smaller difference between energy levels in a transition) cascade

2

[7]

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

2

(ii) Read off λ = 550 (nm)
Use of $E = hc / \lambda$ or $E = hf$ and $c = f\lambda$
3.6×10^{-19}
or
Reads st of coordinates correctly
Use of $hc/\lambda = \Phi + E_{k(max)}$
3.6×10^{-19}(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

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

$hc/\lambda = 4.96 \times 10^{-19}$ (using given value in (aii))
or 4.6×10^{-19} using calculated value
or $f = 7.5 \times 10^{14}$(Hz)

4×10^{-7} to 4.4×10^{-7} (m)

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

3

[8]

4 (a) The process involves the ejection of electrons which are negatively charged. ✓

1

Any electrons ejected will only make the positive charge greater. ✓

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.**

<table>
<tr><td>Mark</td><td>Criteria</td><td>QoWC</td></tr>
<tr><td>6</td><td>Both ideas fully analysed, with full discussion of alternatives.</td><td rowspan="2">The student presents relevant information coherently, employing structure, style and sp&g to render meaning clear. The text is legible.</td></tr>
<tr><td>5</td><td>Both ideas analysed with supporting discussion but without alternatives</td></tr>
<tr><td>4</td><td>Both ideas analysed, with one dealt with satisfactorily and the other with some supporting discussion</td><td rowspan="2">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.</td></tr>
<tr><td>3</td><td>Both ideas analysed, with only one dealt with satisfactorily</td></tr>
<tr><td>2</td><td>One idea analysed with some supporting discussion</td><td rowspan="2">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.</td></tr>
<tr><td>1</td><td>One idea analysed, with little supporting discussion</td></tr>
<tr><td>0</td><td>Unsupported combination or no relevant analysis</td><td>The student's presentation, spelling, punctuation and grammar seriously obstruct understanding.</td></tr>
</table>

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 = $1.6 \times 10^{-19} \times 4.3 = 6.9 \times 10^{-19}$ J ✓

The first mark is for converting the work function into J

1

Use of hf = work function + KE_{max}

The second mark is for substituting into the photoelectric equation

1

$KE_{max} = hf$ – work function
$= (6.63 \times 10^{-34}) \times (1.2 \times 10^{15}) + 6.9 \times 10^{-19}$ ✓
$= 7.9 \times 10^{-19} - 6.9 \times 10^{-19}$
$= 1.0 \times 10^{-19}$ 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]

5 (a) Peak power = 107 / 108 mW and load resistance = 290 / 310 Ω ✓

1

Use of power = I^2R with candidate values✓

1

0.0186 – 0.0193 A ✓

1

(b) Area of cell = 36×10^{-4} m^2 and solar power arriving = 730 × (an area)✓

1

$\frac{0.108}{2.63}$ seen✓

1

0.041 (correct answer only; lose if ratio given unit) ✓

1

(c) energy of one photon = $\frac{hc}{\lambda}$ = 4.0 ×10^{-19}J✓

1

Number of photons = $\frac{730 \times 36 \times 10^{-4}}{4.0 \times 10^{-19}}$ = 6.6 × 10^{18} s^{-1}✓

1

(d) **Two** from

Intensity of the sun at the Earth's surface
Average position of the sun
Efficiency of the panel
Power output of 1 panel
Weather conditions at the installation=
✓✓

Allow other valid physics answers=

2

[10]

6 (a) (i) the <u>minimum energy</u> required by an <u>electron</u>✓
to escape from a (metal)<u>surface</u>✓

if refer to atom / ionisation zero marks

2

(ii) the (minimum) energy to remove an electron(from an atom)✓
from the <u>ground state</u>✓

2

(b) (use of $hf = eV$)
6.63 × 10^{-34} × f = 5.15 × 1.60 × 10^{-19}✓

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

if no working and 1.24 × 10^{15}(Hz) 1 mark

2

(c) (use of $hf = E_k + \Phi$)
Φ = 2.28 × 1.60 × 10^{-19} = 3.648 × 10^{-19} (J) ✓
E_k = 5.15 × 1.60 × 10^{-19} - 3.648 × 10^{-19}= 4.59 × 10^{-19} J ✓✓

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 of $c = f\lambda$)

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

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

$v = 3010\ m\ s^{-1}$ ✓✓

first mark minimum working – determination of wavelength

bald answer gets 2 marks

range to 3 sig figs 2900 – 3030

3

[12]

7 (a) (i) ultraviolet / UV / UV light / ultra(-)violet ✓

1

(ii) electron(in ground state) has moved / in to higher (energy) level / shell / orbital / state OR up level / shell / orbital / state ✓

Ignore reference to photons

1

(iii) (free) electrons collide with orbital electrons / mercury electrons / electrons in atom ✓

transferring energy ✓

Ignore any reference to photons

2

(iv) (mercury) atoms have discrete / fixed / specific energy levels ✓

when electrons change levels they lose an exact / fixed / specific / discrete / set amount of energy OR photons emitted with exact / fixed / specific / discrete / set amount of energy ✓

(leading to photons of) fixed / particular / certain / discrete / specific / unique frequencies ✓

Each mark independent

Don't accept characteristic for 3rd mark

3

(b) (i) (*use of $\lambda = c / f$*)

$f = 3 \times 10^8 / (254 \times 10^{-9})$ ✓

$f = 1.18 \times 10^{15}$ (Hz) ✓

AE penalty if give answer to 1 sig fig

2

(ii) (*use of $E = hf$*)

$E = 6.63 \times 10^{-34} \times 1.18 \times 10^{15} = 7.82 \times 10^{-19}$ J ✓

$E = 7.82 \times 10^{-19} / 1.6 \times 10^{-19}$ ✓ = 4.9 (4.875) eV

CE part (i)

Range 4.8 − 5.0 acceptable

2

(c) coating <u>absorbs</u> photons / uv light ✓

and re-emits (photons) of low(er) energy / long(er) wavelength / low(er) frequency ✓

Ignore any description of mechanism

2

[13]

8 (a) energy of photon is constant / fixed OR energy given to electron is fixed ✓

energy required for electron to <u>leave / escape / emit</u> from the <u>surface / metal</u>

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*)

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

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

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

hf gets first mark even if in wrong equation

3

(ii) work function = hf_0

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

2 sig . fig stand alone mark

Accept 4.4×10^{14}

3

(c) (i) decrease the energy of(incident) <u>photons</u> ✓

decrease the <u>maximum</u> kinetic energy of electrons ✓

OR

decrease the energy of(incident) <u>photons</u> ✓

hence fewer deeper electrons escape ✓

OR

below <u>threshold frequency</u> ✓

no electrons emitted ✓

OR

as energy of each <u>photon</u> decreases but intensity is constant (there are more photons / sec) ✓

number of emitted electrons(/sec) must increase ✓

for <u>last two</u> alternatives must get first mark before can qualify for second mark

2

(ii) increase in photons cause increase in (emitted) electrons ✓

<u>double number</u> of electrons / photons OR reference to rate /per second ✓

if refer to energy levels / atoms can only award first mark

2

[13]

9 (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 $hf = \varphi_0$

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 $hf = \varphi_0 + KE_{max}$ where $KE = 0$

Penalise minus sign on answer

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

A1

3

[5]

10 (a) (i) absorbs enough energy (from the incident) electron(by collision) OR incident electron loses energy (to orbital electron) ✓
exact energy / 10.1((eV) needed to make the transition / move up to level 2 ✓

For second mark must imply exact energy

2

(ii) *(use of* $E_2 - E_1$*)* $= hf$
$-3.41 - - 13.6 = 10.19$ ✓
energy of photon = $10.19 \times 1.6 \times 10^{-19} = 1.63 \times 10^{-18}$ (J) ✓
$6.63 \times 10^{-34} \times f = 1.63 \times 10^{-18}$
$f = 2.46 \times 10^{15}$(Hz) ✓
(accept 2.5 but not 2.4)

CE from energy difference but not from energy conversion

3

(iii) $Ek = 1.7 \times 10^{-18} - 1.63 \times 10^{-18}$ ✓ $= 7.0 \times 10^{-20}$ J ✓

2

(iv) energy required is 12.09 eV / 1.9 × 10^{-18} ✓
energy of incident electron is only 10.63 eV / energy of electron less than this (1.7 × 10^{-18} J) ✓

State and explain must have consistent units i.e. eV or J

2

(b) (i) Electrons return to lower levels by different routes / cascade / not straight to ground state✓

1

(ii) 3✓
n=3 to n=1 or n=3 to n=2 and n=2 to n=1 ✓

no CE from first mark

2

[12]

11 (a) (i) <u>minimum energy</u> required ✓

to remove electron from metal (surface) OR cadmium OR the material ✓

2

(ii) photons have energy dependent on frequency OR energy of photons constant ✓

one to one interaction between photon and electron ✓

Max KE = photon energy – work function in words or symbols ✓

more energy required to remove deeper electrons ✓

4

(iii) *(use of $hf = Ø + E_{k(max)}$)*

$6.63 \times 10^{-34} \times f = 4.07 \times 1.60 \times 10^{-19}$ ✓ $+ 3.51 \times 10^{-20}$ ✓

f = 1.04 × 10^{15} (Hz) OR 1.03 × 10^{15} (Hz) ✓ ✓(3 sig figs)

4

(b) theory makes predictions tested ✓ by repeatable/checked by other scientists/peer reviewed (experiments) OR new evidence that is repeatable/ checked by other scientists/peer reviewed✓

2

[12]

12 (a) (i) when electrons/atoms are in their lowest/minimum energy (state) **or** most stable (state) they (are in their ground state) ✓

1

(ii) in either case an electron receives (exactly the right amount of) energy ✓

excitation promotes an (orbital) electron to **a higher energy/up a** level ✓

ionisation occurs (when an electron receives enough energy) **to leave** the atom ✓

3

(b) electrons occupy discrete energy levels ✓

and need to absorb an exact amount of/enough energy to move to a higher level ✓

photons need to have certain frequency to provide this energy **or** e = hf ✓

energy required is the same for a particular atom or have different energy levels ✓

all energy of photon absorbed ✓

in 1 to 1 interaction or clear **a/the photon** and **an/the electron**s ✓

4

(c) energy = $13.6 \times 1.60 \times 10^{-19} = 2.176 \times 10^{-18}$ (J) ✓

$hf = 2.176 \times 10^{-18}$ ✓

$f = 2.176 \times 10^{-18} \div 6.63 \times 10^{-34} = 3.28 \times 10^{15}$ Hz ✓ 3 sfs ✓

4

[12]

13 (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

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

14 (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]

15 (a) (i) the (maximum) kinetic energy/speed/velocity/momentum of released electrons increases **(1)**

this is because increasing the frequency of the photons increases their energy **or** correct application of photoelectric equation **(1)**

(ii) the number of electrons emitted (per second) increases **(1)**

because there are now more photons striking the metal surface (per second) **(1)**

4

(b) experiment/observation needs to be performed (to test a theory) **(1)**

the results of (the experiment) need to be proved/repeatable/replicated/ confirmed **(1)**

[**or** threshold frequency **(1)** could not be explained by the wave model **(1)**]

2

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

$\phi = 6.63 \times 10^{-34} \times 5.5 \times 10^{14}$ **(1)**

$\phi = 3.65 \times 10^{-19}$ **(1)** J **(1)**

(ii) $E_k = 6.63 \times 10^{-34} \times 6.2 \times 10^{14}$ **(1)** $- 3.65 \times 10^{-19}$ **(1)**

$E_k = 4.6 \times 10^{-20}$ J (accept 5.1×10^{-20} J) **(1)**

6

[12]

16 (a) (i) –0.66 to –0.72keV line marked as **B** downward arrow

B1

(ii) uses 7.06 (eV) (condone negative sign)

B1

attempts to multiply by 1.6×10^{-16} (condone incorrect power of 10) and to divide by 6.63×10^{-34}

B1

$1.7(0) \times 10^{18}$ (Hz) cao

B1

4

(b) (i) $\lambda = h/mv$ or $\lambda = h/p$ or correct substitution

C1

$4.4(2) \times 10^{6}$ (m s^{-1}) [4.8(5) with *h* to 2 sf]

A1

(ii) same order of magnitude as atomic spacing

B1

produces wide **diffraction** angle/good **diffraction**

B1

4

[8]

17

(a) (electron) diffraction/interference/superposition **(1)**

1

(b) (use of $\lambda = h/mv$)

$\lambda = 6.63 \times 10^{-34}/(9.11 \times 10^{-31} \times 4.50 \times 10^{5})$ **(1)**

$\lambda = 1.6 \times 10^{-9}$ (m) **(1)**

2

(c) $207 \times 9.11 \times 10^{-31}$ **(1)** $\times v = 6.63 \times 10^{-34}/1.6 \times 10^{-7}$ **(1)**

$v = 2200$ (2170) (m s^{-1}) **(1)**

3

[6]

18

(a) (i) k.e. = $\dfrac{4.1 \times 10^{-18}}{1.6 \times 10^{-19}}$ **(1)**

= 26 (eV) **(1)** (25.6 eV)

(ii) (use of $\lambda_{dB} = \dfrac{h}{mv}$ gives) $\lambda_{dB} = \dfrac{6.6 \times 10^{-34}}{9.1 \times 10^{-31} \times 3.0 \times 10^{6}}$ **(1)**

= 2.4×10^{-10} m **(1)** (2.42×10^{-10} m)

4

(b) (use of $hf = E_1 - E_2$ gives) $f = \dfrac{(0.90 - 0.21) \times 10^{-18}}{6.6 \times 10^{-34}}$ **(1)**

(= 1.05×10^{15} (Hz))

(use of $\lambda = \dfrac{c}{f}$ gives) $\lambda = \dfrac{3.0 \times 10^{8}}{1.05 \times 10^{15}}$ **(1)**

= 2.9×10^{-7} m **(1)** (2.86×10^{-7} m)

3

[7]

19 (a) the energy of each photon/the light increases with frequency **(1)**
electrons need a minimum amount of energy to leave the metal **(1)**
this amount of energy is equal to the work function **(1)**

3

The Quality of Written Communication marks are awarded for the quality of answers to this question.

(b) (i) (use of $v = f\lambda$ gives) $\lambda = \dfrac{300 \times 10^{8}}{9.70 \times 10^{14}}$

= 3.09×10^{-7}m **(1)**

(ii) (use of $E = hf$ gives) $E = 6.63 \times 10^{-34} \times 9.70 \times 10^{14}$ **(1)**

= 6.43×10^{-19}(J) **(1)**

(iii) (use of $hf = \phi + E_k$ gives) $6.43 \times 10^{-19} = \phi + 2.49 \times 10^{-19}$ **(1)**

(allow C.E. from (b)(ii))

$\phi = 3.94 \times 10^{-19}$(J) **(1)**

(iv) $\phi = \left[\dfrac{3.94 \times 10^{-19}}{1.60 \times 10^{-19}}\right]$ = 2.46 (eV) **(1)** (allow C.E. from (b)(iii)

7

[10]

20 (a) need for excitation **(1)**
electrons in an atom can only exist at definite/discrete energy levels / orbits **(1)**
an electron falls from one level to another **(1)**
photon emitted **(1)**
photon has definite wavelength **(1)**

The Quality of Written Communication marks were awarded primarily for the quality of answers to this part

(5)

(b) (i) an electron is removed from a (neutral) atom **(1)**

(ii) 2.2×10^{-18} (J) **(1)**

(iii) ($f_{min} = E/h$ gives) $f_{min} = 2.2 \times 10^{-18}/6.6(3) \times 10^{-34}$ **(1)**
(allow e.c.f from result of (b)(ii)) **(1)**
$= 3.3(2) \times 10^{15}$ Hz **(1)**

(iv) ionised electron gains kinetic energy (or electron breaks free of atom) **(1)**

(5)

(c) $\left(f = \frac{(E_2 - E_1)}{h} \text{gives}\right) f = \frac{5.4 \times 10^{-19} - 2.4 \times 10^{-19}}{6.6(3) \times 10^{-34}}$ **(1)** (= 4.52×10^{14} Hz)

($\lambda = c/f$ gives) $\lambda = 3.0 \times 10^{8}/4.52 \times 10^{14}$ **(1)** (allow e.c.f. for f)

$= 6.6(3) \times 10^{-7}$ m **(1)**

(3)

[13]