1)

(a) Experiments based on the photoelectric effect support the particle nature of light. In such experiments light is directed at a metal surface.

(a) (i) State what is meant by the threshold frequency of the incident light.

.....

.....

(1 mark)

(a) (ii) Explain why the photoelectric effect is **not** observed below the threshold frequency.

.....

.....

.....

.....

(2 marks)

(b) Monochromatic light of wavelength 5.40×10^{-7} m is incident on a metal surface which has a work function of 1.40×10^{-19} J.

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

answer = ... J

(2 marks)

(b) (ii) Calculate the maximum kinetic energy of an electron emitted from the surface.

answer = ... J

(2 marks)

(b) (iii) Calculate the maximum speed of the emitted electron.

answer = ... $m\,s^{-1}$

(2 marks)

(b) (iv) Calculate the de Broglie wavelength of the fastest electrons.

answer = ... m

(2 marks)

2)

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 marks]

.....

.....

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

[2 marks]

.....

.....

(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 marks]

(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.

[3 marks]

maximum kinetic energy = ... J

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

[3 marks]

speed = ... $m\ s^{-1}$

3)

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

(a) (i) increasing the frequency of the light,

.....

.....

.....

.....

(2 marks)

(a) (ii) increasing the intensity of the light.

.....

.....

.....

.....

(2 marks)

(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 marks)

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

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

.....

.....

.....

.....

answer .....

(3 marks)

(c) (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.

.....

.....

.....

.....

.....

.....

answer .....J

(3 marks)

4)

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 marks)

(a) (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 marks)

(a) (iii) State a unit for work function.

.....

(1 mark)

(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 $1.5 \times 10^{15}\,\text{Hz}$.

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

answer = ... J

(2 marks)

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

answer = ...

(2 marks)

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

(c) (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 mark)

(c) (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 marks)

5)

(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 e V.

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

.....

.....

.....

.....

(2 marks)

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

.....

.....

.....

.....

.....

.....

(4 marks)

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

answer = ... Hz

(4 marks)

(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.

.....

.....

.....

(2 marks)

6)

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.

.....

.....

.....

.....

.....

.....

.....

.....

.....

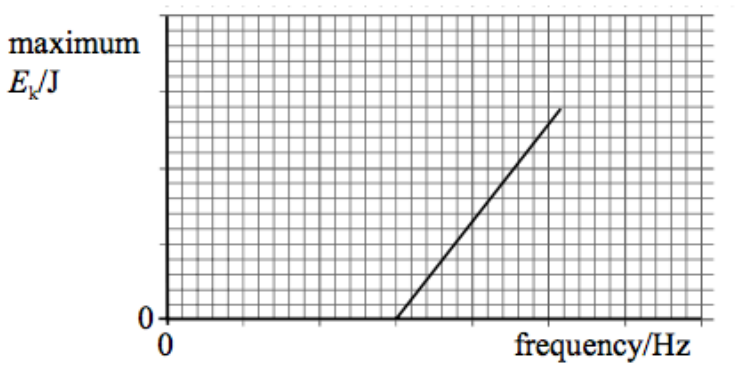
.....

.....

.....

(6 marks)

(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.



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

(1 mark)

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

(2 marks)

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

.....

(1 mark)

(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 marks)

7)

(a) The photoelectric effect suggests that electromagnetic waves can exhibit particle - like behaviour. Explain what is meant by threshold frequency and why the existence of a threshold frequency supports the particle nature of electromagnetic waves.

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

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

(6 marks)

(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 marks)

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

.....

.....

.....

.....

(2 marks)

answer = ...

(3 marks)

(b) (iii) Calculate the de Broglie wavelength of the alpha particle.

answer = ... m

(2 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 marks)

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

(3 marks)

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

threshold frequency ..... Hz

(3 marks)