1)

(a) State **one** experiment for each case which provides evidence that electromagnetic radiation can behave like

(i) a stream of particles, called *photons*

..... **[1]**

(ii) waves.

..... **[1]**

(b) A beam of ultraviolet light is incident on a clean metal surface. The graph of Fig. 7.1 shows how the maximum kinetic energy KE_{max} of the electrons ejected from the surface varies with the frequency f of the incident light.

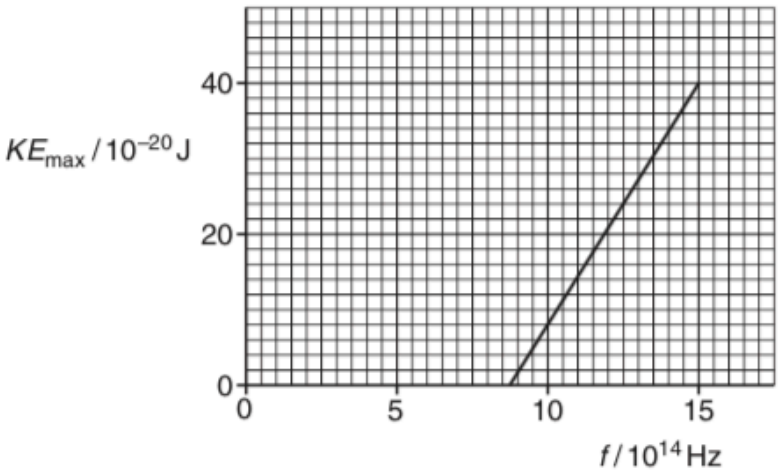

Fig. 7.1

(i) Define the work function ϕ of the metal.

.....

.....

.....

..... **[1]**

(ii) Write down the relationship between KE_{max} and f. Use it to explain why the y-intercept of the graph in Fig. 7.1 is equal to the work function of the metal and the gradient of the line is equal to the Planck constant.

.....

.....

.....

.....

.....

.....

..... **[3]**

(iii) Use data from Fig. 7.1 to find a value of

1 the Planck constant

Planck constant = ... Js **[2]**

2 the threshold frequency of the metal

threshold frequency = ... Hz **[1]**

3 the work function of the metal.

work function = ... J **[2]**

[Total: 11]

2)

A photoelectric cell is an electronic device that can detect photons.

(a) Fig. 4.1 shows a cross-section through a simple photocell.

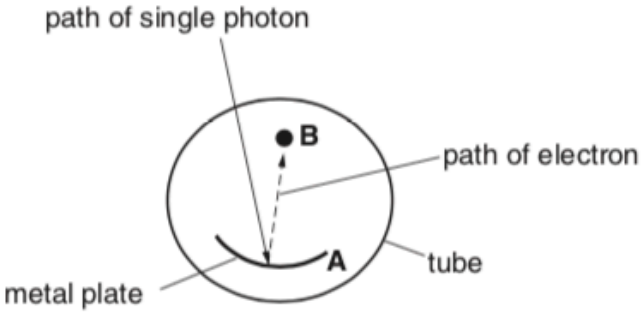

Fig. 4.1

A metal plate **A** is coated with potassium in an evacuated transparent tube. A photon entering the tube is absorbed by the plate, causing one electron to be released from the surface towards the collector rod **B**.

(i) State the name of this process.

..... **[1]**

(ii) Potassium has a work function of 3.5×10^{-19} J.

1 Define the term *work function*.

.....

..... **[1]**

2 Calculate the threshold frequency of potassium.

threshold frequency = ... Hz **[2]**

(iii) The photon incident on plate **A** has a wavelength of 4.2×10^{-7} m. Show that its energy is about 5×10^{-19} J.

[2]

(iv) Calculate the maximum kinetic energy of the electron emitted from the potassium surface of plate **A**.

maximum kinetic energy = ... J **[2]**

(b) An electron is released with zero speed from plate **A**. It is accelerated from plate **A** through a potential difference of 12V to the metal rod **B** in Fig. 4.1.

(i) **1** State the increase in kinetic energy of the electron in electronvolts (eV).

increase in k.e. = ... eV **[1]**

2 Show that this increase is about 2×10^{-18} J.

[1]

(ii) Calculate the speed of the electron as it hits rod **B**.

speed = ... $m s^{-1}$ **[3]**

(c) The photocell is connected to a 12V d.c. supply through a very sensitive ammeter. Light of wavelength 4.2×10^{-7} m shines on plate **A**. The plate absorbs 1.2×10^{-6} J of light energy every second. One per cent of the absorbed photons cause electrons to be emitted from the plate. Estimate the current in the circuit.

current = ... A **[3]**

[Total: 16]

3)

(a) A 5.0 eV photon can cause the photoelectric effect from most metals.

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

.....

..... **[1]**

(ii) State what is meant by an *electron volt* (eV).

.....

..... **[1]**

(iii) Calculate the value of 5.0 eV in SI units.

value = ... unit ..... **[1]**

(b) A photon of energy 8.0×10^{-19} J incident on a clean zinc surface can cause photoelectric emission. The maximum kinetic energy of an electron emitted from the surface is 1.1×10^{-19} J.

(i) **1** Define the term *work function* of a metal.

.....

..... **[1]**

2 Calculate the work function for zinc.

work function = ... unit ..... **[1]**

(ii) **1** Show that the maximum speed v of an electron emitted from the surface is about $5 \times 10^5 \text{ m s}^{-1}$.

[2]

2 Calculate the de Broglie wavelength of an electron emitted from the surface at the maximum speed.

de Broglie wavelength = ... m **[3]**

(c) The spacing between atoms in a thin sheet of graphite is about 2.5×10^{-10} m.

(i) A beam of electrons in a vacuum can travel through a thin sheet of graphite placed perpendicular to the beam to produce a pattern of **rings** on a fluorescent screen beyond the graphite sheet. Explain why this pattern is produced.

.....

.....

.....

.....

.....

.....

..... **[3]**

(ii) Explain whether or not the electrons in **(b)(ii)** would be suitable for use in such an experiment.

.....

.....

..... **[1]**

[Total: 14]

4)

In a demonstration experiment of the photoelectric effect, light of wavelength 440 nm incident on a clean metal surface causes electrons to be emitted. No electrons are emitted from the surface when the wavelength of the incident light is greater than 550 nm.

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

.....

..... **[2]**

(ii) Explain how the work function is related to the threshold frequency.

.....

.....

..... **[2]**

(iii) Calculate the value of the work function for this metal.

work function = ... J **[2]**

(b) (i) Show that the maximum speed of the emitted electrons in the experiment is about $4.5 \times 10^5 \text{ m s}^{-1}$.

[3]

(ii) Calculate the minimum de Broglie wavelength of an emitted electron.

wavelength = ... m **[2]**

(c) The light source for this experiment is a discharge lamp containing excited atoms which emit light at several wavelengths. Fig. 8.1 shows the three lowest energy levels of one of these atoms, labelled $n = 1$, 2 and 3.

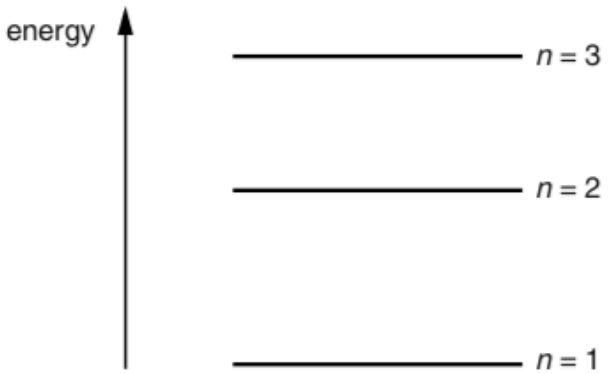

Fig. 8.1

Electron transitions between these energy levels can produce three different wavelengths of radiation. The transition between $n = 2$ and $n = 1$ causes the 440 nm photons.

(i) Photons at 590 nm are also emitted. Which transition causes these photons?

..... **[1]**

(ii) Hence calculate the wavelength of the photons emitted by the third transition.

wavelength = ... m **[3]**

[Total: 15]

5)

In an experiment it is observed that when blue light is shone on a clean metal surface electrons are emitted, but with red light there is no electron emission.

(a) State the name of the effect observed in this experiment.

..... **[1]**

(b) Describe Einstein's theory to explain these observations.

In your answer you should include technical terms to explain how the physics of quantum behaviour is used to explain the observations.

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

..... **[4]**

(c) The longest wavelength of light incident on the metal surface which causes electrons to be emitted is 480 nm.

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

[3]

(ii) Calculate the maximum speed of an emitted electron when a photon of energy 5.2×10^{-19} J is incident on the metal surface.

speed = ... $m\,s^{-1}$ **[3]**

(d) (i) Describe briefly one piece of evidence for believing that electrons sometimes behave like waves.

.....

.....

.....

..... **[2]**

(ii) Calculate the de Broglie wavelength of an electron moving at 500 $km\,s^{-1}$.

wavelength = ... m **[3]**

6)

A physical quantity is also conserved in the photoelectric effect. Describe and explain the photoelectric effect.

In your answer you should link the description to the conservation of this quantity.

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

..... **[6]**

7)

In 1905 Einstein presented a theory to explain the photoelectric effect using the concept of quantisation of radiation proposed by Planck in 1900.

(a) Show, with the aid of a suitably labelled diagram, the arrangement of apparatus that could be used to demonstrate the photoelectric effect. Describe how you would use the apparatus and what would be observed.

In your answer you should make clear how your observations provide evidence for the photoelectric effect.

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

..... **[5]**

(b) Describe how the photoelectric effect can be explained in terms of the physics of quantum behaviour.

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

..... **[5]**

[Total: 10]