H2 Physics Revision Topic : Quantum Theory

Structured Questions Name: ______________________

1 **(a)** Two observations about the photoelectric effect are:

Observation 1: For light below the threshold frequency, no electrons are emitted from the metal surface.

Observation 2: For light above the threshold frequency, the emission of electrons is almost instantaneous.

For each of the observation, explain how it provides support for the particle theory of light, but not the wave theory of light.

(i) Observation 1 : ....

....

....

.... [2]

(ii) Observation 2 : ....

....

....

.... [2]

(b) A narrow parallel beam of laser light is incident on a barium surface at an angle of incidence of 30°, as shown in Fig. 6.1.

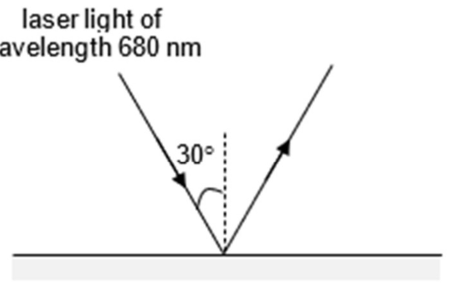

Fig. 6.1

The beam has a circular cross-section of diameter 1.5 mm.

The laser light has wavelength of 680 nm and intensity 3.2×10^3 W m^{-2}.

H2 Physics Revision Topic : Quantum Theory

Structured Questions Name: ______________________________

1 **(i)** Determine

1. the energy of a photon of the laser light; and

energy = ... J [2]

2. the number of photons incident per unit time on the surface.

number of photons per unit time = ... s^{-1} [2]

(ii) Assuming that all the photons are reflected, calculate the force *F* normal to the surface that is exerted by the laser light on the surface.

force = ... N [3]

(iii) Due to the property of metal, a percentage of the photons incident on the surface is absorbed. Explain how this would affect your answer in **(b)(ii)**.

....

....

.... [1]

2 **(a)** Some electron energy levels in atomic hydrogen are illustrated in Fig. 6.1.

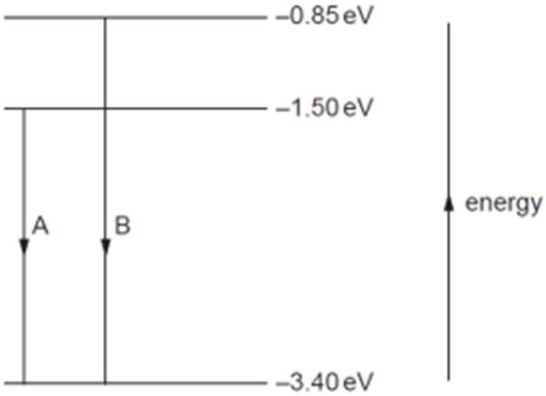

Fig. 6.1

Two possible electron transitions A and B giving rise to an emission spectrum are shown. These electron transitions cause light of wavelengths 654 nm and 488 nm to be emitted.

(i) On Fig. 6.1, draw an arrow to show a third possible transition. [1]

(ii) Calculate the wavelength of the emitted light for the transition in **(i)**.

wavelength = ... m [2]

(b) Some hydrogen gas is heated so that electrons are excited to the highest energy level shown in Fig. 6.1.

Using the values of wavelength in **(a)**, state and explain the appearance of the spectrum of the emergent light from the hydrogen gas.

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.... [3]

2 **(c)** High-speed electrons are incident on a metal target. The spectrum of the emitted X-ray radiation is shown in Fig. 6.2.

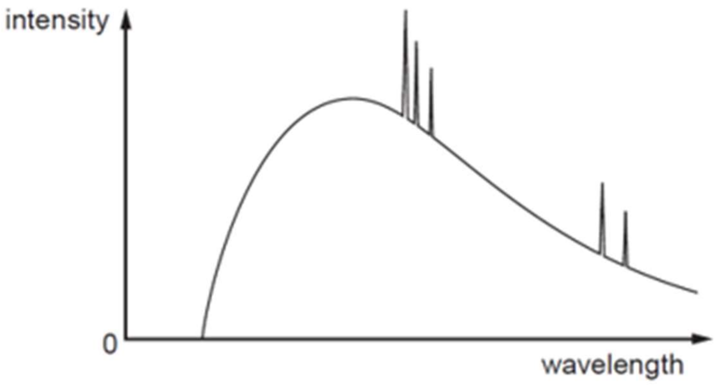

Fig. 6.2

Explain why

(i) there is a continuous distribution of wavelengths,

....

....

.... [2]

(ii) there is a sharp cut-off at short wavelength.

....

....

.... [2]

[Total: 10]

3 **(a)** The photoelectric effect may be represented by the equation

photon energy = work function energy + maximum kinetic energy of electron.

State what is meant by

(i) *a photon*,

....

.... [1]

(ii) the *work function energy*.

....

.... [1]

(b) Fig. 8.1 shows how the maximum kinetic energy of the electrons varies with the frequency of the light shining on a metal surface.

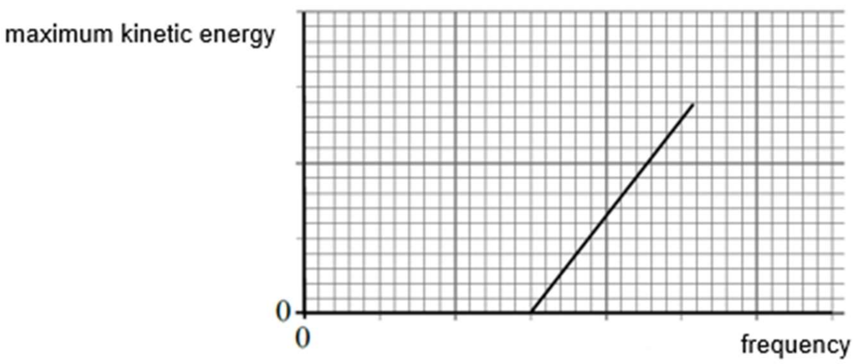

Fig. 8.1

(i) On Fig. 8.1,

1. mark the threshold frequency and label it f_0, [1]

2. draw a line for a metal which has a higher work function energy. [1]

(ii) State what information is provided by the gradient of the graph.

3

……………………………………………………………………………………………[1]

(iii) Explain why the kinetic energy of the emitted electrons varies up to a maximum value.

……………………………………………………………………………………………

……………………………………………………………………………………………[1]

(iv) Explain why the graphs on Fig. 8.1 do not depend on the intensity of the incident radiation.

……………………………………………………………………………………………

……………………………………………………………………………………………[2s]

(c) Fig. 8.2 shows part of an energy level diagram for a hydrogen atom.

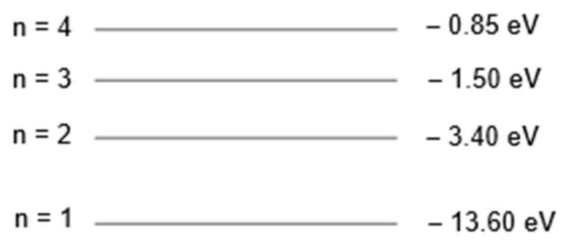

Fig. 8.2 (not to scale)

(i) State the ionisation energy of the atom.

ionisation energy = …………………… eV [1]

(ii) When an electron of energy 12.1 eV collides with the atom (initially at the ground state), photons of three different energies are emitted.

1. On Fig. 8.2, draw arrows to show the transitions responsible for these photons. [2]

2. Calculate the wavelength of the photon with the smallest energy and state the region of the electromagnetic spectrum this wavelength corresponds to.

3

wavelength = …………………… m

region of the electromagnetic spectrum = …………………… [3]

(d) Electrons having a *de Broglie* wavelength 1.2×10^{-10} m are required to investigate the crystal structure of a certain solid.

(i) State what is meant by the *de Broglie wavelength*.

……………………………………………………………………………………………

…………………………………………………………………………………………… [1]

(ii) Calculate the speed of the electron.

speed = …………………… m s^{-1} [3]

(iii) Suggest how such electrons may assist with an understanding of the crystal structure.

……………………………………………………………………………………………

……………………………………………………………………………………………

…………………………………………………………………………………………… [2]

4 **(a)** White light passes through a cloud of cool low-pressure gas, as illustrated in Fig. 8.1.

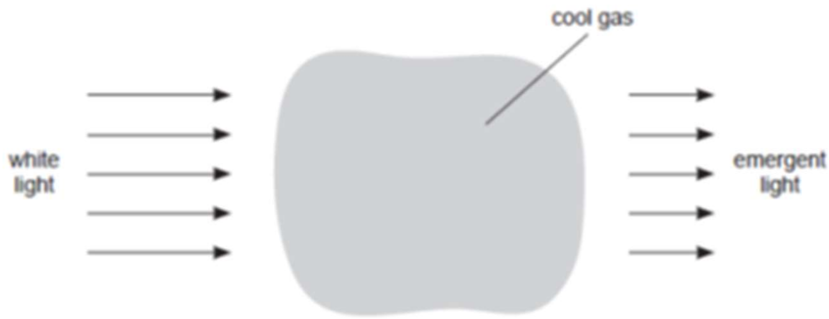

Fig. 8.1

For light that has passed through the gas, its continuous spectrum is seen to contain a number of darker lines.

Use the concept of discrete electron energy levels to explain the existence of these darker lines.

....

....

....

....

....

.... [3]

4

(b) Electrons in a beam are travelling at high speed in a vacuum. The electrons are incident on a metal target, causing X-ray radiation to be emitted.

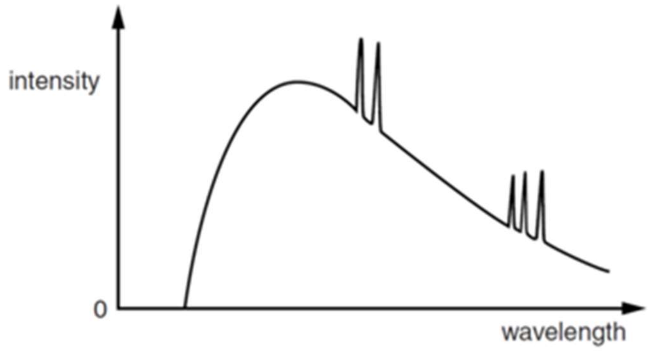

Fig. 8.2

The variation with wavelength of the intensity of the emitted X-ray radiation is shown in Fig. 8.2.

Explain why:

(i) there is a continuous distribution of wavelengths.

....

....

....

....

.... [3]

(ii) at certain wavelengths, there are narrow peaks of increased intensity.

....

....

....

....

.... [3]

[Total: 9]

5 **(a)** Electromagnetic radiation is incident on a metal surface.

It is observed that there is a minimum frequency of electromagnetic radiation below which emission of electrons does not occur.

This observation provides evidence for a particulate nature of electromagnetic radiation.

State **two** other observations associated with photoelectric emission that provide evidence for a particulate nature of electromagnetic radiation.

1. ....

....

2. ....

....

[2]

(b) The maximum kinetic energy E_{MAX} of electrons emitted from a metal surface is determined for different wavelengths λ of the electromagnetic radiation incident on the surface.

The variation with $\frac{1}{\lambda}$ of E_{MAX} is shown in Fig. 6.1.

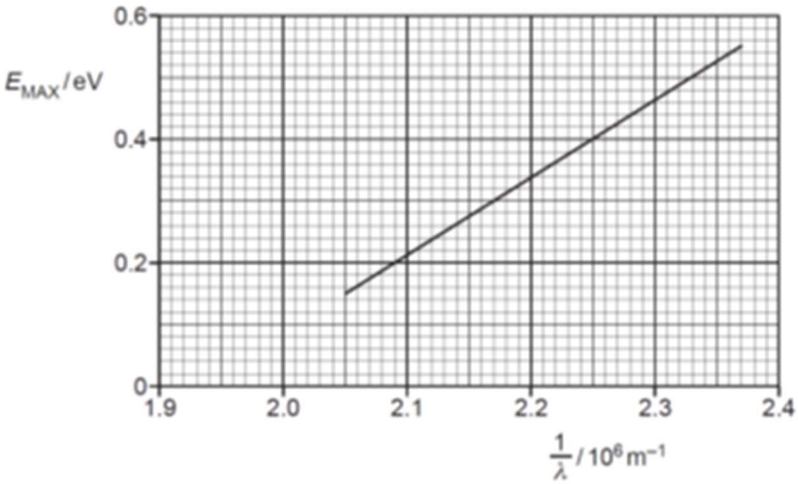

Fig. 6.1

(i) Use Fig. 6.1 to determine the threshold frequency f_0.

f_0 = ... Hz [2]

5

(ii) Use Fig. 6.1 to determine a value for the Planck constant h.

Explain your working.

h = ... J s [4]

(c) The electromagnetic radiation is now incident on a metal with a larger work function energy than the metal in **(b)**.

On Fig. 6.1, sketch the variation with $\frac{1}{\lambda}$ of E_{MAX}. [2]

[Total: 10]

6 In a photoelectric emission experiment, ultra-violet (UV) radiation of wavelength 254 nm is incident on a metal made of silver. The metal has a surface area of 12 mm^2. The intensity of the light incident on the surface is 210 W m^{-2}.

A maximum photocurrent of 4.80×10^{-10} A is collected at an adjacent electrode.

(a) **(i)** Explain what is meant by a *photon*.

....

....

.... [2]

(ii) Show that the rate of incidence of UV photons on the silver surface is 3.2×10^{15} s^{-1}.

[2]

(iii) The photoelectric quantum yield is defined as

$$\frac{\text{rate of photoelectrons emitted from surface}}{\text{rate of photons incident on surface}} \times 100\%.$$

Calculate the photoelectric quantum yield.

quantum yield = ... % [2]

6 **(b)** The potential difference between the electrodes is adjusted to decrease the current until there is zero current in the circuit. The experiment is then repeated for different frequencies of UV radiation.

Fig. 6.1 shows the variation of frequency f of the UV radiation with the potential difference V_S for zero current.

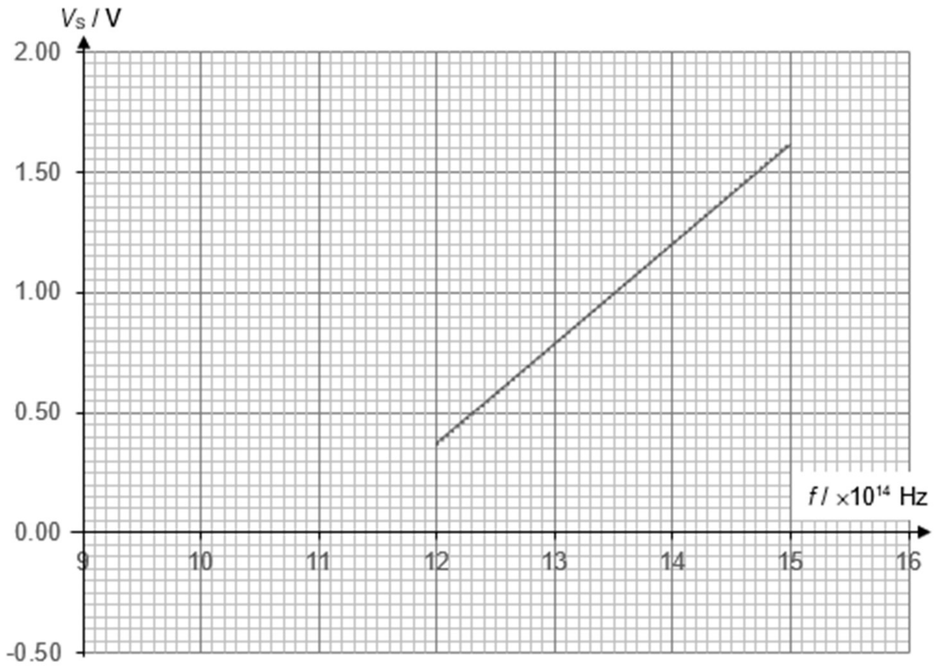

Fig. 6.1

Use Fig. 6.1 to determine

(i) the Planck constant,

Planck constant = ... J s [3]

6 **(ii)** the work function of silver.

work function = ... eV [2]

[Total: 11]

7 **(a)** Fig. 7.1 shows some spectral lines emitted from a discharge tube filled with low pressure mercury vapour.

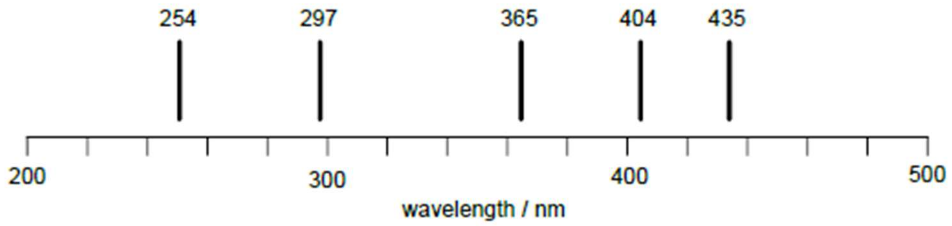

Fig. 7.1

Explain how the line spectrum of atoms, such as those shown in Fig. 7.1, provides evidence for the existence of discrete electron energy levels.

....

....

....

....

....

.... [3]

(b) The photons emitted from the discharge tube in **(a)** are incident on a metal surface in a vacuum tube, as shown in Fig. 7.2.

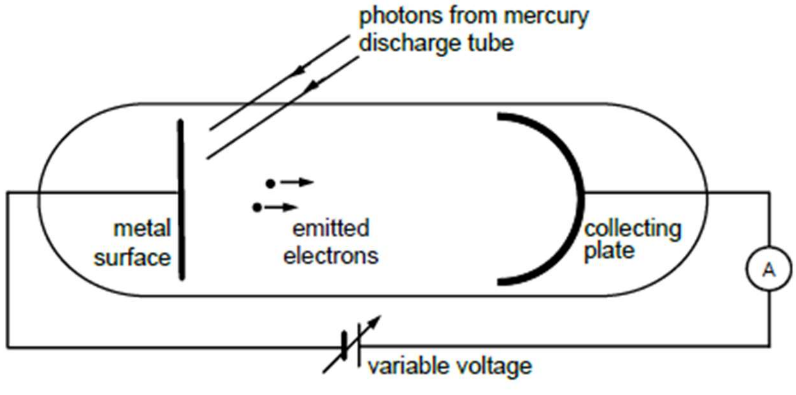

Fig. 7.2

The metal surface that has a work function of 3.2 eV.
Electrons are emitted from the metal surface.

7 Photons from the mercury discharge tube corresponding to the shortest wavelength of 254 nm cause emission of electrons from the metal surface with different kinetic energies.

(i) Explain why the electrons are emitted with different kinetic energies.

....

....

....

....

....

....

.... [3]

(ii) **1.** Deduce the other wavelengths from the mercury discharge tube that can also cause emission of electrons.

wavelengths .... [2]

2. Explain whether your answer to **(b)(ii)1.** is affected by the intensity of the electromagnetic radiation from the mercury discharge tube.

....

....

....

.... [2]

[Total: 10]

8 **(a)** X-rays are produced in an X-ray tube when high-speed electrons are accelerated toward and hit a metal target. Fig. 7.1 shows the variation with wavelength of the intensity of X-ray radiation emitted.

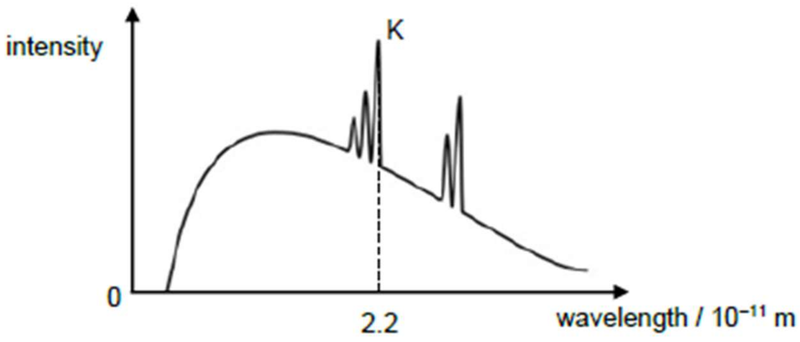

Fig. 7.1

(i) Explain why there is a continuous distribution of wavelengths.

....

....

....

....

....

.... [2]

8

(ii) A series of characteristic lines shown by the high intensity peaks, such as K, are observed in Fig. 7.1.

1. Calculate the energy difference, in keV, associated with the characteristic line K.

energy difference = ………………………………… keV [2]

2. Suggest why there are other series of characteristic lines produced at wavelengths longer than K.

……

……

……

……

…… [2]

8 **(b)** A simple model of an atom with one electron can be represented by the electron as a stationary wave confined in a box of length 1.0×10^{-10} m equal to the diameter of the atom, as shown in Fig. 7.2.

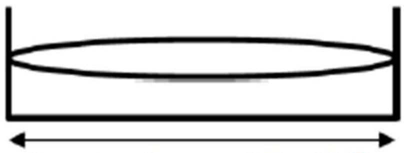

Fig. 7.2

(i) State the uncertainty in locating the position of the electron.

uncertainty in position = ... m [1]

(ii) Calculate the uncertainty in the velocity of the electron.

uncertainty in velocity = ... m s^{-1} [1]

(iii) The diameter of a nucleus is 10^4 times smaller than the diameter of an atom. Using the model above, suggest why an electron cannot be found inside the nucleus.

....

....

....[1]

[Total: 9]

9 **(a)** An electron is moving with a kinetic energy of 4.96×10^{-24} J.

(i) Show that its momentum is 3.0×10^{-27} kg m s^{-1}.

[1]

(ii) Hence, determine the wavelength of ultraviolet light with the same momentum as that calculated in **(a) (i)**.

wavelength = ... m [2]

(b) A heated filament at one end of a fluorescent tube emits electrons through a process known as thermionic emission. These electrons are then accelerated by a potential difference applied between the two ends of the tube.

The accelerated electrons collide with the atoms of mercury vapour contained within the tube as shown in Fig. 7.1 to emit UV light.

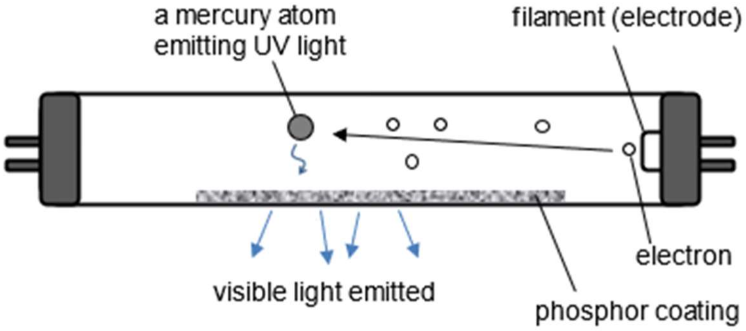

Fig. 7.1

9 Some of the energy levels of a mercury atom are represented in Fig. 7.2.

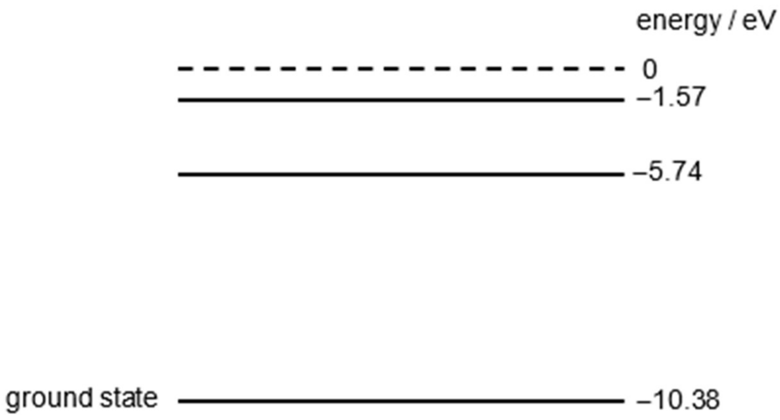

Fig. 7.2 (not to scale)

(i) Explain why the energy of each energy level is negative.

....

.... [1]

(ii) In one particular interaction, an electron with kinetic energy 9.0 eV collides with a mercury atom at ground state.

Use Fig. 7.2 to determine the longest wavelength of UV radiation that can be emitted due to this interaction.

wavelength = ... m [3]

9

(iii) The UV photons emitted by the mercury atoms strike the phosphor coating on the inside of the fluorescent tube. The phosphor absorbs the UV photons and emits visible light by “fluorescence”. Some amount of infrared radiation is also emitted.

Fig. 7.3 shows three energy levels E_1, E_2 and E_3 of an atom in the phosphor that are involved in the absorption of UV and emission of infrared and visible light.

On Fig. 7.3, draw arrows to indicate the following transitions:

(1) absorption of a UV photon
(2) emission of an infrared photon
(3) emission of a red light photon

Label the transitions clearly.

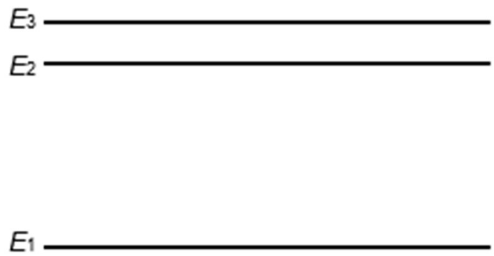

Fig. 7.3

[1]

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

(i) State what is meant by the threshold frequency of the metal.

....

....

.... [1]

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

....

....

....

....

....

.... [2]

(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.

(i) Calculate the threshold frequency for the metal.

threshold frequency = ... Hz [2]

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

energy of photon = ... J [2]

10 **(iii)** Calculate the maximum speed of the emitted electrons.

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

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

de Broglie wavelength = ... nm [2]

(c) Fig. 8.1 below represents the energy levels of the four lowest states of the hydrogen atom.

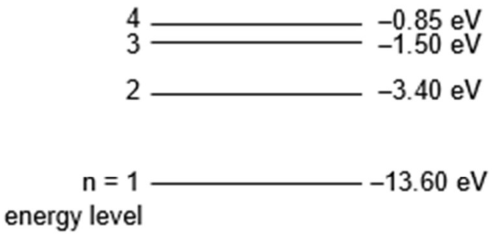

Fig. 8.1

(i) State what happens in the atom when line spectra are produced.

....

....

.... [1]

10

(ii) State the transition and determine the wavelength of one possible **visible** spectral line detected in the **emission** spectrum of atomic hydrogen, due to transitions between these states.

transition = level .... to ....

wavelength = ... μm [3]

(d) Fig. 8.2 below represents a typical X-ray spectrum.

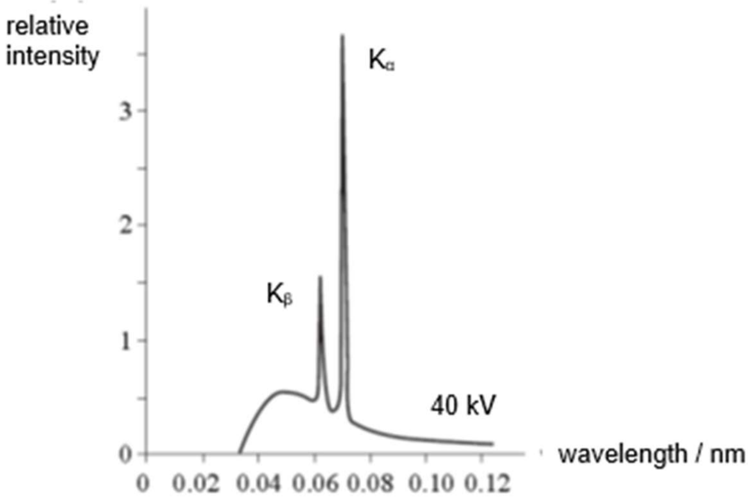

Fig. 8.2

(i) Distinguish between the mechanisms that produce **characteristic** X-ray spectra in Fig. 8.2 and the line spectra in part **(c)(i)**.

....

....

....

....

....

.... [2]

10 **(ii)** Estimate the maximum velocity of the incoming electrons.

maximum velocity ≈ .... m s^{-1} [2]

11 **(a)** A photon of wavelength 940.0×10^{-12} m collides with an isolated stationary electron, as illustrated in Fig. 3.1.

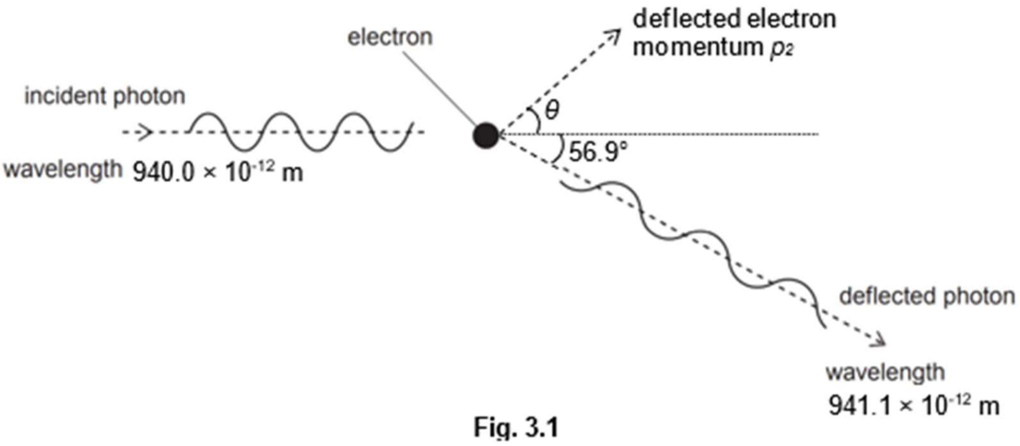

Fig. 3.1

The photon is deflected elastically by the electron.
The wavelength of the deflected photon is 941.1×10^{-12} m.

(i) Without making any calculations, sketch in the space below a vector triangle to show conservation of momentum. Label the triangle with the initial momentum p_1 of incident photon, the final momentum p_2 of electron, and the final momentum p_3 of the deflected photon.

[2]

(ii) Calculate the final momentum p_3 of the deflected photon.

p_3 = ... N s [1]

11 **(iii)** Calculate the kinetic energy of the deflected electron.

kinetic energy = ... J [2]

(iv) Using your answer in **(a)(i)**, or otherwise, determine p_2 and θ.

p_2 = ... N s

θ = ... ° [3]

12 **(a)** Electrons are accelerated through a potential difference of 15 kV. The electrons collide with a metal target and a spectrum of X-rays is produced. The variation with wavelength λ of the intensity I of the emitted X-ray radiation is shown in Fig. 5.1.

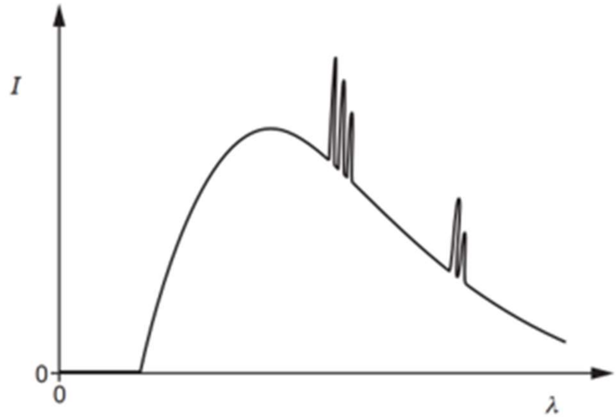

Fig. 5.1

(i) Explain why there is a continuous distribution of wavelengths.

....

....

....

....

.... [2]

(ii) Explain why at certain wavelengths, there are narrow peaks of increased intensity.

....

....

....

....

.... [2]

(iii) Calculate the wavelength of the highest energy X-ray photon produced.

wavelength = ... m [2]

12 **(iv)** Draw, on Fig. 5.1, the spectrum of X-ray produced if the potential difference is increased. [2]

(b) An electron of mass 9.11×10^{-31} kg travelling at 3.00×10^{7} m s^{-1} passes through a narrow slit of width 1.00×10^{-10} m (comparable to the spacing of atoms in a crystal).

(i) Calculate the uncertainty in momentum of the electron along the slit as it passes through the slit.

uncertainty in momentum = ………………………… kg m s^{-1} [2]

(ii) Suggest the significance of this uncertainty.

……………………………………………………………………………………………

…………………………………………………………………………………………… [1]

(c) Explain how Einstein's photon model of light differs from the classical description of light as an electromagnetic wave in the way it explains

(i) light intensity,

classical explanation: ……………………………………………………………………

……………………………………………………………………………………………

quantum explanation: ……………………………………………………………………

…………………………………………………………………………………………… [2]

(ii) the absorption of light energy by a metal surface.

classical explanation: ……………………………………………………………………

……………………………………………………………………………………………

quantum explanation: ……………………………………………………………………

…………………………………………………………………………………………… [2]

12

(d) The maximum kinetic energy E_{MAX} of electrons emitted from a metal surface is determined for different wavelengths λ of the electromagnetic radiation incident on the surface.

The variation with $\frac{1}{\lambda}$ of E_{MAX} is shown in Fig. 5.2.

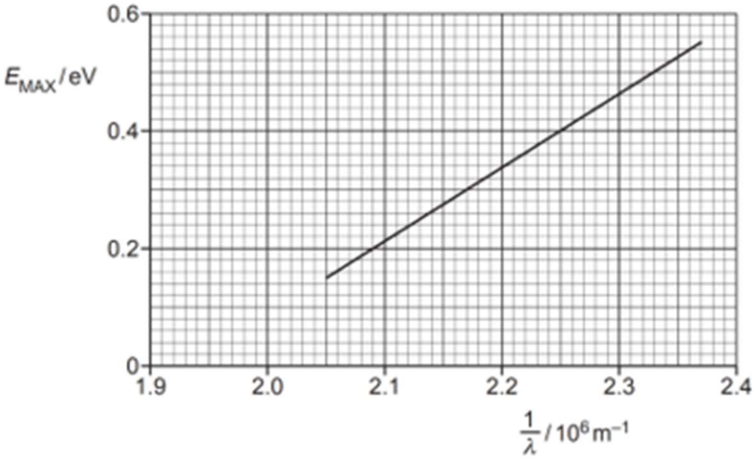

Fig. 5.2

(i) Use Fig. 5.2 to determine the threshold frequency f_0.

f_0 = ………………………… Hz [2]

(ii) The electromagnetic radiation is now incident on a metal with a larger work function energy than the metal in (d)(i).

On Fig. 5.2, sketch the variation with $\frac{1}{\lambda}$ of E_{MAX}. [1]

13 **(a)** The wave properties of electrons can be demonstrated using electron diffraction. The arrangement used includes a parallel beam of electrons accelerated by a potential difference in a glass envelope as shown in Fig. 6.1. A graphite film is placed perpendicularly to the path of the electron beam.

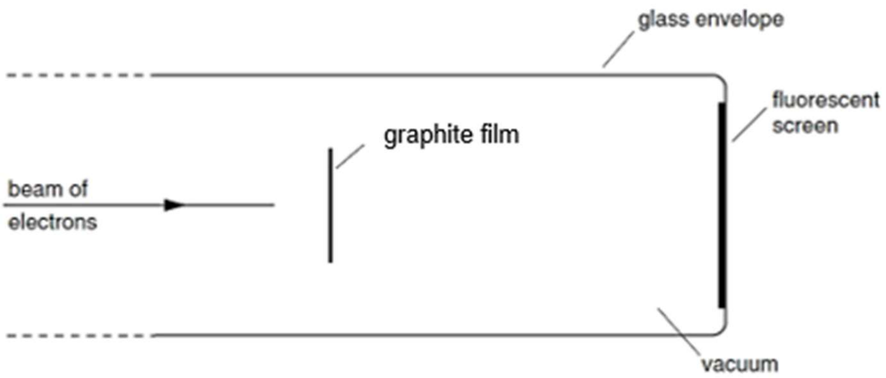

Fig. 6.1

The electrons incident on a fluorescent screen create a pattern consisting of bright and dark rings, as shown in Fig. 6.2.

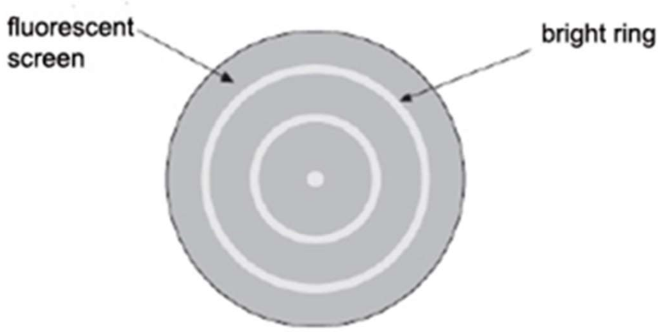

Fig. 6.2

(i) Identify two key features in Fig. 6.2 and explain how they provide evidence for the wave nature of electrons.

....

....

....

....

....

.... [2]

13

(ii) Electrons of mass m are accelerated in a vacuum through a potential difference V of 250 V.

1. Show that the associated wavelength λ of the electrons can be expressed as

$$\lambda = \frac{h}{\sqrt{2meV}}.$$

[2]

2. Hence, calculate the wavelength λ of the electrons.

λ = ... m [2]

(iii) Describe and explain how the observed pattern in Fig. 6.2 changes as the potential difference V is increased.

....

....

....

....

.... [2]

13 **(b)** The wave properties of matter do not seem to affect us noticeably in everyday life.

When a 80 kg man walks in a straight line at 2.0 m s^{-1} and passes through a doorway of width 1.2 m, he is not obviously deflected from his path.

Show, using Heisenberg's Uncertainty Principle and some appropriate workings, that the deflection of the man is negligible. You may take the width of the doorway as the uncertainty in position of the man.

....

....

.... [2]

[Total: 10]

14 A circuit used to investigate the photoelectric effect is shown in **Fig. 5.1**.

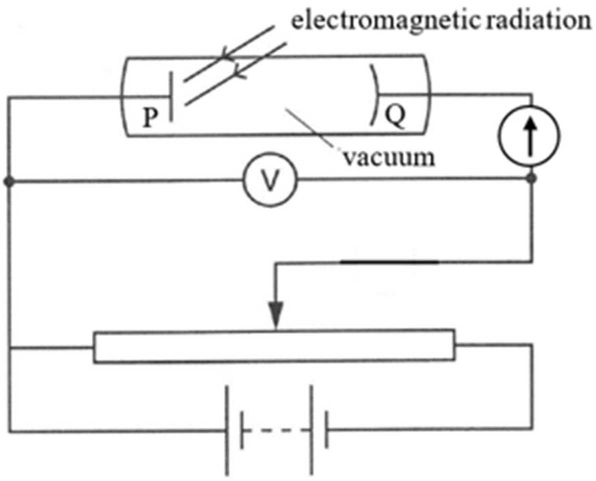

Fig. 5.1

A potential divider circuit is connected to two metal electrodes P and Q enclosed in an evacuated glass tube.
The electromagnetic radiation incident on P is of a single frequency and constant intensity.
The voltmeter measures the potential difference V between the electrodes and a sensitive meter measures the current I between the electrodes. The potential difference applied across P and Q can be changed from positive to negative by reversing the battery terminals.

(a) Explain the energy transformation that occurs during photoelectric emission.

....

....

....

.... [2]

14 The variation with potential difference V of current I is shown in **Fig. 5.2**.

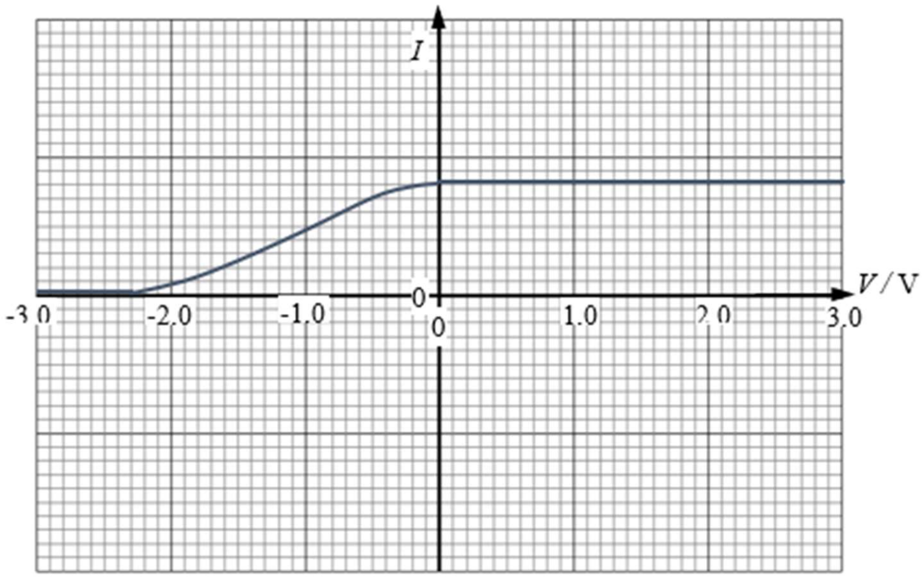

Fig. 5.2

(b) The work function of metal P is 2.0 eV. Use **Fig. 5.2** to calculate

(i) the maximum kinetic energy of the photoelectrons.

Maximum KE = ……………………. J[2]

(ii) the frequency of the electromagnetic radiation.

frequency =…………..……. Hz [2]

(c) The frequency of the electromagnetic radiation is kept constant as its intensity is doubled. Sketch on **Fig. 5.2** the variation with V of I for this increased intensity. Label this graph A. [2]

(d) The same electromagnetic radiation in **(c)** is now incident on Q in **Fig. 5.1**. Given that the stopping potential for photoelectric emission from metal Q is 1.8 V, sketch on **Fig. 5.2** the variation with V of I when the electromagnetic radiation is incident on Q. Label this graph B. [2]

15 **(a)** **Fig. 6.1** shows the famous Orion Nebula, which is a large gas cloud in the Milky Way. It contains many young stars being formed. The gas cloud produces vast quantities of energetic UV rays that ionise the surrounding gas. The ions eventually recombine, leaving the gas atoms in an excited state. The excited atoms subsequently return to their ground state.

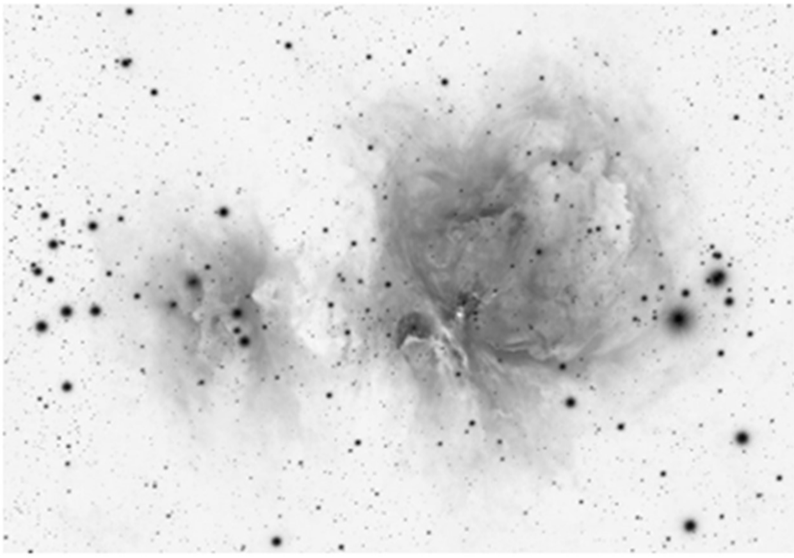

Fig 6.1

A simplified model of gas clouds is shown in **Fig. 6.2** below which depicts two different gas clouds. Cloud A is a hydrogen gas cloud in an excited state due to its proximity to a young star. Cloud B is a cool hydrogen cloud situated at a greater distance away and is not in an excited state.

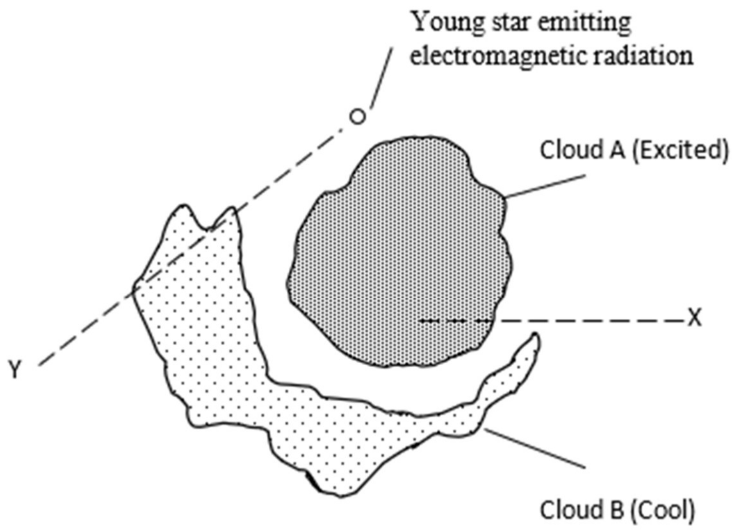

Fig. 6.2

15

(i) State and explain the type of hydrogen spectrum observed from point X along the dotted line.

....

....

....

.... [2]

(ii) State and explain the type of hydrogen spectrum observed from point Y along the dotted line.

....

....

....

.... [2]

(iii) Suggest how these observations provide evidence for discrete energy levels in atoms.

....

....

....

.... [2]

15

(b) A metal target is bombarded by high-speed electrons. The spectrum of the emitted radiation is shown in **Fig. 6.3.**

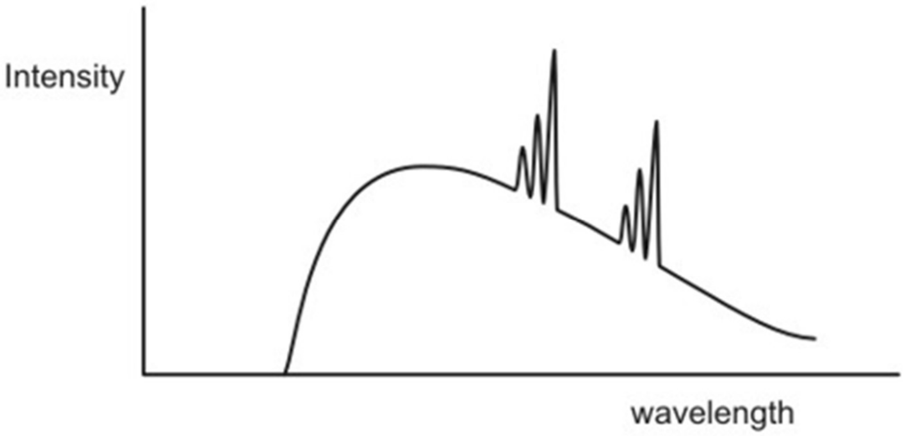

Fig. 6.3

(i) Explain why there is a continuous distribution of wavelengths.

....

....

....

.... [2]

(ii) Consider now incoming electrons that have half as much kinetic energy as before. Sketch a curve on **Fig. 6.3** showing the new spectrum of the emitted radiation. [2]