8 **(a)** A photomultiplier tube (PMT) can be used to detect high-energy charged particles. Fig. 8.1 shows a diagram of a particular photomultiplier tube.

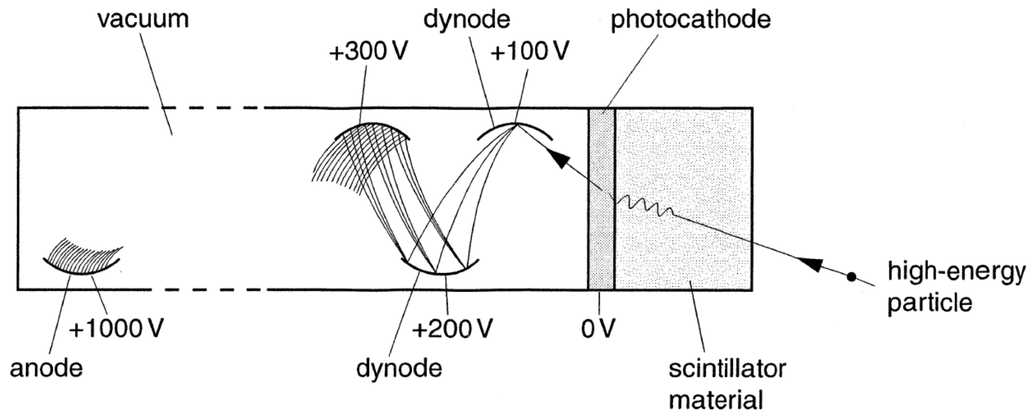

Fig. 8.1

The incoming charged particle strikes the scintillator material and produces a short burst of visible light. When this light reaches the photocathode, it removes some of the surface electrons due to the *photoelectric effect*. These electrons are then accelerated towards the first positive dynode because of the 100 V potential difference between it and the cathode.

The kinetic energy of one such electron is sufficient to liberate, on average, 3 'secondary' electrons from a dynode. These electrons are then accelerated towards the next dynode and the whole process is repeated. Eventually a tiny pulse of charge is detected at the anode.

In one particular case, a proton of kinetic energy 0.70 MeV produces 550 photons of light of wavelength 410 nm in the scintillator material. For a PMT with 9 dynodes, a single electron emitted from the photocathode produces a pulse of charge lasting 2.3×10^{-8} s at the anode. The work function energy of the material of the photocathode is 3.5×10^{-19} J.

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

....

.... [1]

(ii) For a single electron emitted from the photocathode, determine the number of electrons striking the anode.

number of electrons = ………………. [1]

(iii) If the current at the anode is 7.2 μA, deduce the rate of electrons emitted at the photocathode.

rate of photoelectrons = ……..………………… s^{-1} [4]

(iv) Calculate the energy of a single photon of light of wavelength 410 nm.

energy of photon = ………………………… J [2]

(v) Hence, calculate the maximum kinetic energy of the electrons emitted from the photocathode.

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

(vi) Hence, calculate the maximum possible speed of the electrons arriving at the first dynode (+100 V as shown in Fig. 8.1)

maximum possible speed = ………………………………. m s^{-1} [2]

(b) Fig. 8.2 shows a cooler region of hydrogen gas surrounding a hot gas cloud emitting white light.

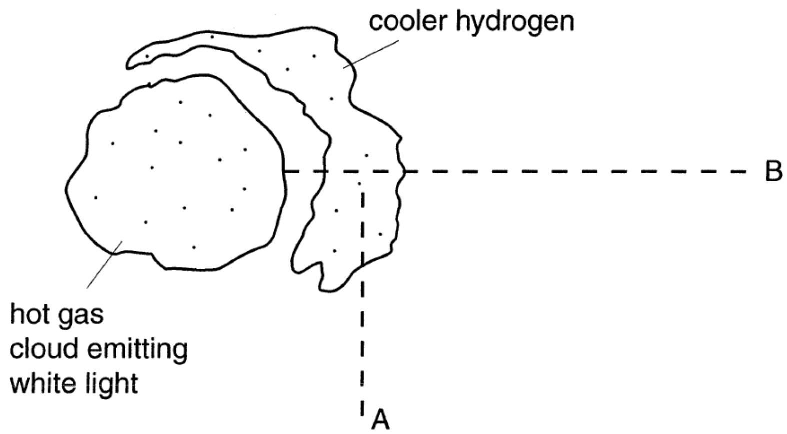

Fig. 8.2

(i) State the type of hydrogen spectrum observed from

1. point A

.... [1]

2. point B

.... [1]

(ii) Fig. 8.3 shows some of the energy levels of a hydrogen atom.

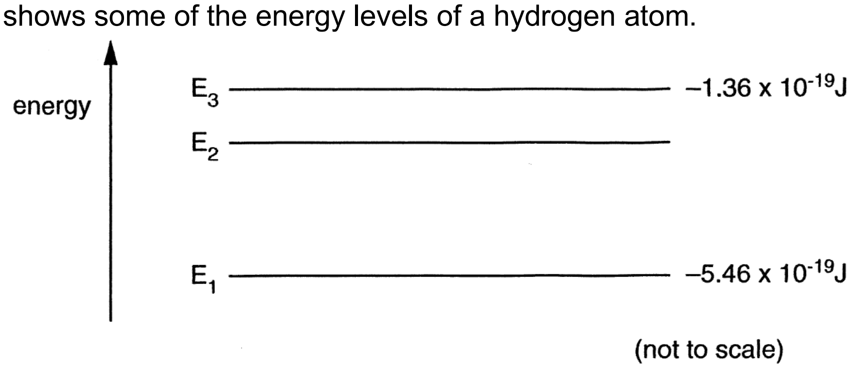

Fig. 8.3

1. The frequency of radiation emitted when an electron makes a transition between energy levels E_3 to E_2 is 1.60×10^{14} Hz.

Determine the wavelength of the electromagnetic radiation when an electron makes a transition between energy levels E_2 and E_1.

wavelength = ……………………….. nm [3]

2. Determine the shortest wavelength of the electromagnetic spectrum that can be emitted when an electron makes a transition between any two energy levels shown in Fig. 8.3.

shortest wavelength = ……………………. nm [2]

3. State the colour of this shortest wavelength.

……………………………………………………………………………… [1]

END OF PAPER