1 **(a)** State the de Broglie relation, explaining any symbols you use.

....

....

.... [2]

(b) An electron of mass *m* has kinetic energy *E*. Show that the de Broglie wavelength λ of this electron is given by

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

[2]

(c) Calculate the potential difference through which an electron, initially at rest, must be accelerated so that its de Broglie wavelength is equal to 0.40 nm (the diameter of an atom).

potential difference = ... V [3]

2 The photoelectric effect may be summarised in terms of the word equation

photon energy = work function energy + maximum kinetic energy of emitted electrons.

(a) Explain

(i) what is meant by a *photon*,

....

....

.... [2]

(ii) why most electrons are emitted with kinetic energy less than the maximum.

....

....

.... [2]

(b) Light of constant intensity is incident on a metal surface, causing electrons to be emitted.

State and explain why the rate of emission of electrons changes as the frequency of the incident light is increased.

....

....

.... [2]

3 Electrons are emitted from a metal surface when it is illuminated with suitable electromagnetic radiation.

(a) Name the effect described above.

....[1]

(b) The variation with frequency f of the maximum kinetic energy E_k of the emitted electrons is shown in Fig. 7.1.
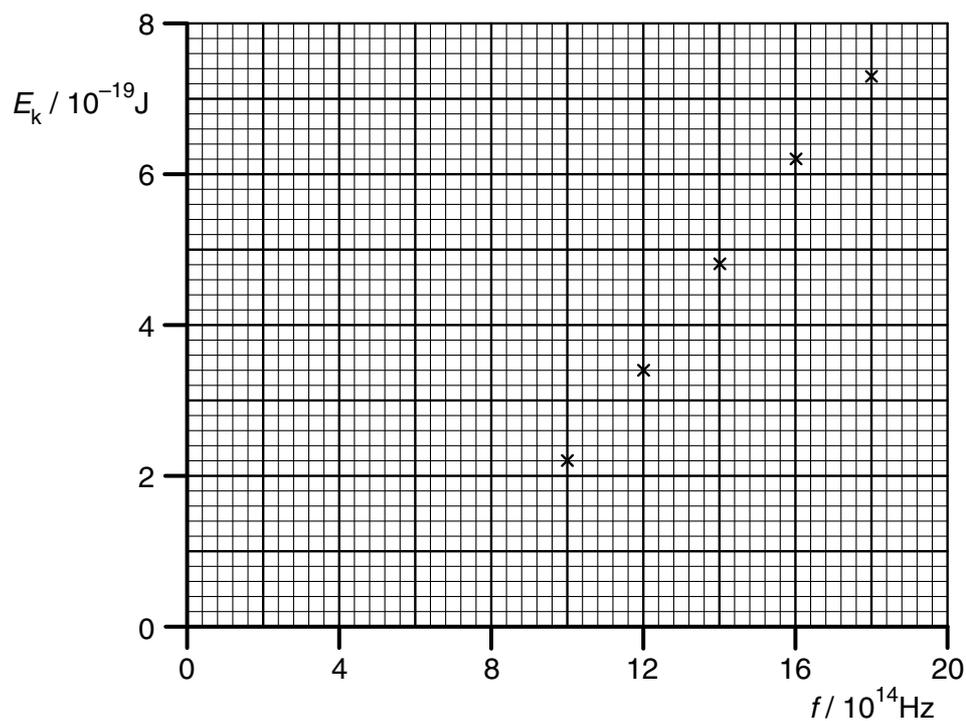

Fig. 7.1

Use Fig. 7.1 to determine

(i) the threshold frequency of the radiation,

threshold frequency = ... Hz

(ii) a value for the Planck constant.

Planck constant = ... J s

[4]

(c) On Fig. 7.1, draw a line to show the variation with frequency f of the maximum kinetic energy E_k of the emitted electrons for a second metal which has a lower work function than that in **(b)**. [2]

(d) The kinetic energy of the electrons is described as the maximum. Suggest why emitted electrons are likely to have a range of values of kinetic energy for any one frequency of the electromagnetic radiation.

....

....

....[2]

4 A parallel beam of electrons, all travelling at the same speed, is incident normally on a carbon film. The scattering of the electrons by the film is observed on a fluorescent screen, as illustrated in Fig. 7.1.
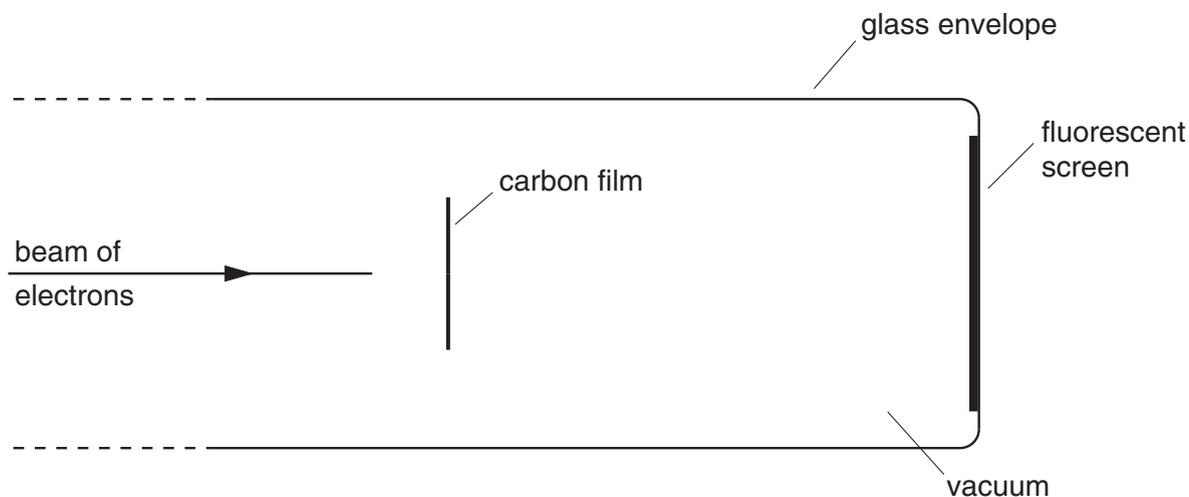

Fig. 7.1

(a) Assuming that the electrons behave as **particles**, predict what would be seen on the screen.

....

.... [1]

(b) In this experiment, the electrons do **not** behave as particles.

Describe briefly the pattern that is actually observed on the screen. You may draw a sketch if you wish.

....

.... [1]

(c) The speed of the electrons is gradually increased.

State and explain what change, if any, is observed in the pattern on the screen.

....

....

....

.... [3]

5 **(a)** State three pieces of evidence provided by the photoelectric effect for a particulate nature of electromagnetic radiation.

1. ....

....

2. ....

....

3. ....

....

[3]

(b) **(i)** Briefly describe the concept of a photon.

....

....

....[2]

(ii) Explain how lines in the emission spectrum of gases at low pressure provide evidence for discrete electron energy levels in atoms.

....

....

....[2]

(c) Three electron energy levels in atomic hydrogen are represented in Fig. 7.1.
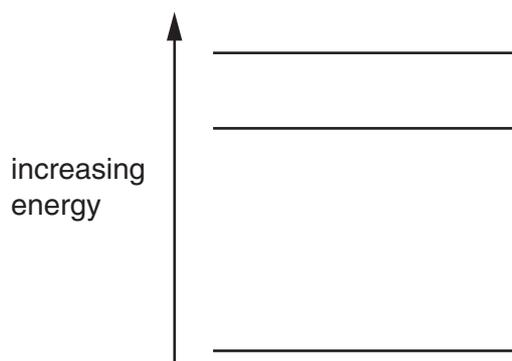
increasing
energy

Fig. 7.1

The wavelengths of the spectral lines produced by electron transitions between these three energy levels are 486 nm, 656 nm and 1880 nm.

(i) On Fig. 7.1, draw arrows to show the electron transitions between the energy levels that would give rise to these wavelengths.
Label each arrow with the wavelength of the emitted photon. [3]

(ii) Calculate the maximum change in energy of an electron when making transitions between these levels.

energy = ...J [3]

6 A parallel beam of electrons, all travelling at the same speed, is incident normally on a carbon film. The scattering of the electrons by the film is observed on a fluorescent screen, as illustrated in Fig. 7.1.
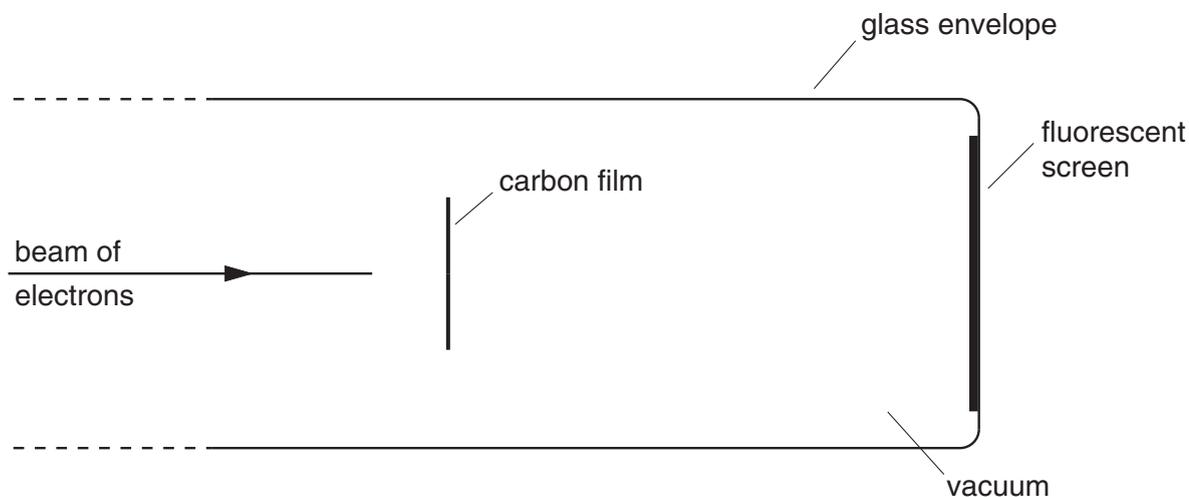
glass envelope

fluorescent
screen

carbon film

beam of
electrons

vacuum

Fig. 7.1

(a) Assuming that the electrons behave as **particles**, predict what would be seen on the screen.

....

.... [1]

(b) In this experiment, the electrons do **not** behave as particles.

Describe briefly the pattern that is actually observed on the screen. You may draw a sketch if you wish.

....

.... [1]

(c) The speed of the electrons is gradually increased.

State and explain what change, if any, is observed in the pattern on the screen.

....

....

....

.... [3]

7 A proton is moving with constant velocity *v*. It enters a uniform magnetic field that is normal to the initial direction of motion of the proton, as shown in Fig. 8.1.
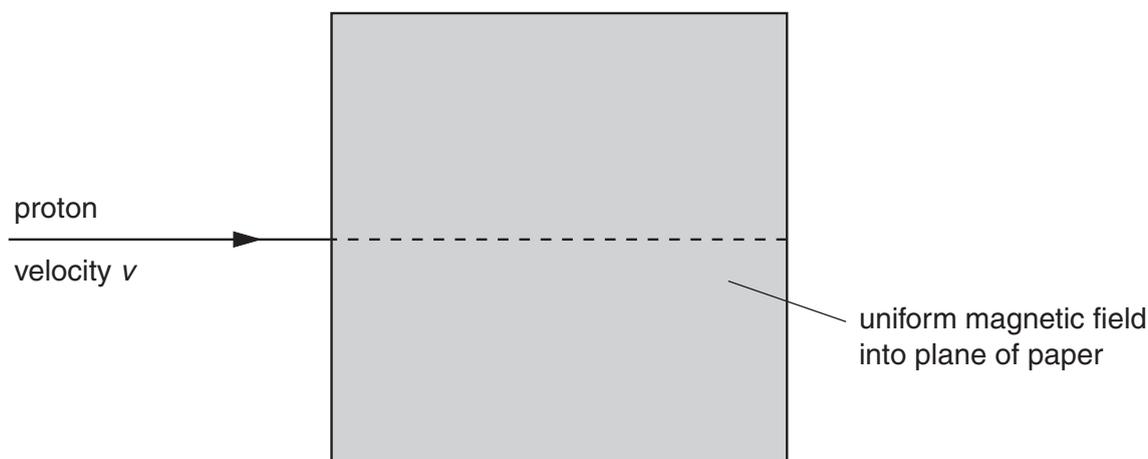
proton

velocity *v*

uniform magnetic field into plane of paper

Fig. 8.1

A uniform electric field is applied in the same region as the magnetic field so that the proton passes undeviated through the fields.

(a) On Fig. 8.1, draw an arrow labelled E to show the direction of the electric field. [1]

(b) The proton is replaced by other particles. The electric and magnetic fields remain unchanged.

State and explain the deviation, if any, of the following particles in the region of the fields.

(i) an α-particle with initial velocity *v*

....

....

....

.... [3]

(ii) an electron with initial velocity 2*v*

....

....

....

.... [3]

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

....

.... [1]

(ii) Show that the photon energy of light of wavelength 350 nm is 5.68×10^{-19} J. [1]

(iii) State the value of the ratio

$$\frac{\text{energy of photon of light of wavelength 700 nm}}{\text{energy of photon of light of wavelength 350 nm}}.$$

ratio = …………….. [1]

(b) Two beams of monochromatic light have similar intensities. The light in one beam has wavelength 350 nm and the light in the other beam has wavelength 700 nm.

The two beams are incident separately on three different metal surfaces. The work function of each of these surfaces is shown in Fig. 5.1.

metal	work function / eV
tungsten	4.49
magnesium	3.68
potassium	2.26

Fig. 5.1

(i) Explain what is meant by the *work function* of the surface.

....

....

.... [2]

(ii) State which combination, if any, of monochromatic light and metal surface could give rise to photo-electric emission. Give a quantitative explanation of your answer.

....

....

....

....

....

.... [3]