9 **(a)** State what is meant by a *photon*.

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[2]

(b) It has been observed that, where photoelectric emission of electrons takes place, there is negligible time delay between illumination of the surface and emission of an electron.

State three other pieces of evidence provided by the photoelectric effect for the particulate nature of electromagnetic radiation.

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2. ....

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3.

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[3]

(c) The work function energy of a metal surface is 3.5 eV. Light of wavelength 450 nm is incident on the surface.

Determine whether electrons will be emitted, by the photoelectric effect, from the surface.

[3]

(d) When free electrons collide with atoms in their ground state, the atoms can be excited or ionised.

(i) State what is meant by *ground state*.

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[1]

(ii) Explain the difference between *excitation* and *ionisation*.

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[2]

(e) An atom can also become excited by the absorption of photons. Explain why only photons of certain frequencies can cause excitation in a particular atom.

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[3]

(f) Fig. 9.1 shows five electron energy levels in an atom and some transitions between them.
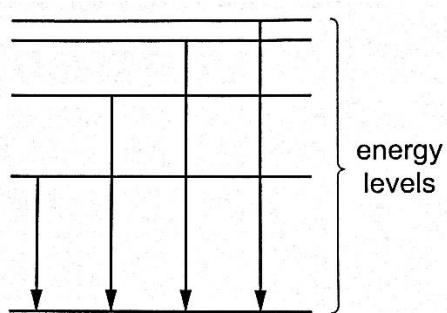
energy levels

Fig. 9.1

The line spectrum produced is in the visible region of the electromagnetic spectrum.

Sketch, on Fig. 9.2, the line emission spectrum that corresponds to the four energy level changes, assuming that the energy levels are drawn roughly to scale.

increasing frequency
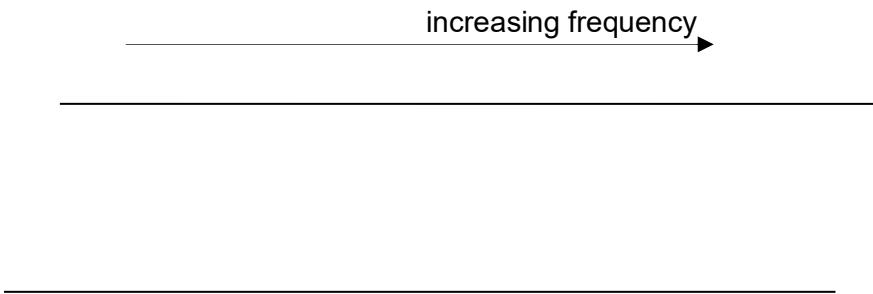
Fig. 9.2

[2]

(g) Ernest Rutherford proposed a planetary model for the hydrogen atom. In the model, a single electron is treated as a point-like charged particle, moving in a circular orbit around a stationary proton (the nucleus) as shown in Fig. 9.3.

electron

proton
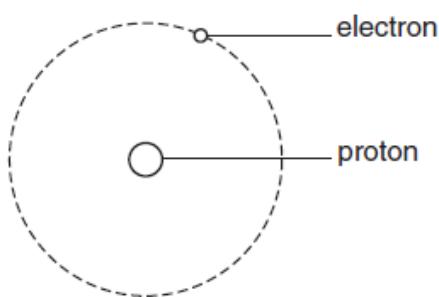
Fig. 9.3

Rutherford's planetary model allows any size for the electron orbits, but quantum theory puts a lower limit on the size of the hydrogen atom. To understand why this is the case, we can use the Heisenberg uncertainty principle for position and momentum.

$$\Delta p \Delta x \geq h$$

Δp is the uncertainty in the (*x*-component) of momentum of the electron, and Δx is the uncertainty in the (*x*-component) of the position of the electron.

(i) State the changes in Δp and Δx when the atom is made smaller by reducing the radius of the electron orbit.

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[1]

(ii) Explain how the change in Δp affects the kinetic energy of the orbiting electron.

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[2]

(iii) By considering your answers to **(g) (ii)**, explain why there is a minimum radius for an electron orbit in the hydrogen atom.

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[1]

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