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

....

....

.... [2]

(b) A stationary nucleus of uranium-238 ($^{238}_{92}U$) undergoes alpha decay to produce a nucleus of thorium-234 ($^{234}_{90}Th$). The kinetic energy of the emitted alpha particle is 4.200 MeV. A gamma-ray photon is also emitted during the decay.

Assume that the rebound kinetic energy of the thorium nucleus is negligible.

Table 8.1 shows the masses of the nuclides involved in the decay reaction. The mass of the uranium-238 nuclide is missing.

Table 8.1

nuclide	nuclide mass / u
$^{4}_{2}\alpha$	4.000 407
$^{234}_{90}Th$	233.915 174
$^{238}_{92}U$	

The total energy released in the decay of the nucleus of uranium-238 is 4.274 MeV.

(i) Calculate the mass, in u, of the uranium-238 nuclide. Give your answer to five decimal places.

mass = ... u [3]

(ii) Determine a value for the wavelength of the gamma radiation emitted during the decay of the uranium-238 nucleus.

wavelength = ... m [3]

(iii) In practice, the rebound kinetic energy of the thorium nucleus is **not** negligible.

Explain, without further calculation, how your answer in **(b)(ii)** compares with the true wavelength of gamma radiation emitted during the decay of the uranium-238 nucleus.

....

....

.... [1]

(c) Gamma radiation emitted during the decay of a sample of uranium-238 has a single wavelength.

Nuclei of cobalt-60 ($^{60}_{27}Co$) decay by beta emission, and also emit gamma radiation in the process.

Suggest why there is **not** a single wavelength for the gamma radiation emitted during the decay of a sample of cobalt-60.

....

....

.... [2]

[Total: 11]

8 Fig. 8.1 shows the three lowest-frequency lines in the part of the emission spectrum for hydrogen that relates to electron transitions to the ground state (level n = 1).

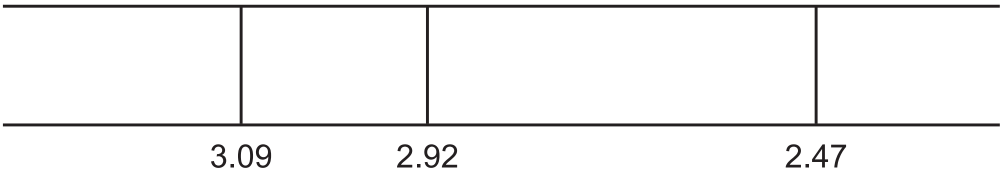

Fig. 8.1 (not to scale)

The numbers represent the frequencies, in 10^{15} Hz, associated with the spectral lines.

(a) Use the photon model of electromagnetic radiation to explain how the existence of spectral lines in the emission spectrum provides evidence for discrete electron energy levels in the hydrogen atom.

....

....

....

....

.... [3]

(b) The energy of the ground state (level n = 1) in a hydrogen atom is –13.6 eV.

(i) Calculate the energy, in J, of the ground state.

energy = ... J [1]

(ii) Show that the energy difference between levels n = 1 and n = 2 is 10.2 eV.

[2]

(iii) Complete Table 8.1 to show the energy differences from the ground state, and the energies of the levels up to $n = 4$, in the hydrogen atom. Use the space for any working.

Table 8.1

level	(energy difference from $n = 1$) / eV	energy / eV
$n = 4$		
$n = 3$		
$n = 2$	10.2	
$n = 1$	0.0	–13.6

[4]

[Total: 10]

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

....

....

.... [2]

(b) The photoelectric effect is investigated using two clean metal plates. One plate is made from metal X and the other is made from metal Y.

Metal X has work function energy Φ. Metal Y has work function energy 2Φ.
Metal X has threshold frequency F.

State expressions, in terms of either or both of Φ and F, for

(i) the threshold frequency of metal Y

threshold frequency = ... [1]

(ii) the Planck constant.

Planck constant = ... [1]

(c) The maximum kinetic energy E_K of photoelectrons is determined for each of the plates in **(b)** for different frequencies f of incident radiation.

On Fig. 9.1, sketch the variation of E_K with f for each plate. Label your lines X and Y to identify which line relates to which plate.

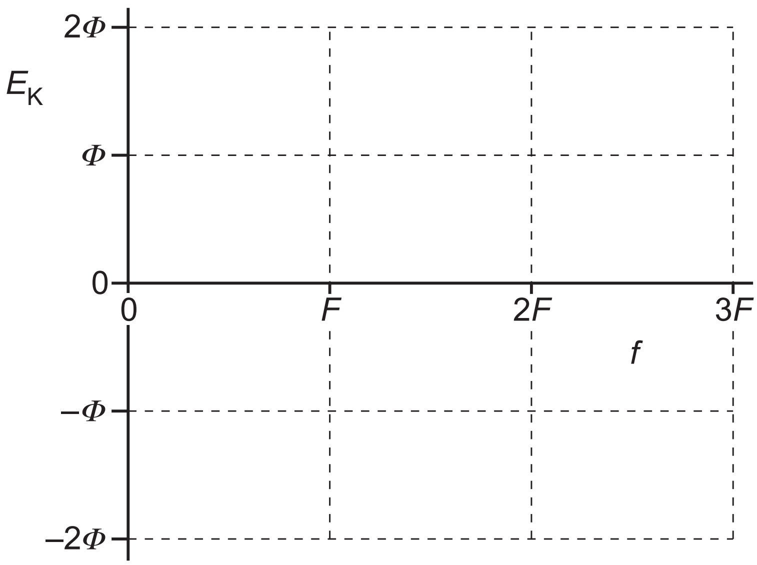

Fig. 9.1

[4]

[Total: 8]

9 **(a)** **(i)** Describe what is meant by wave–particle duality.

....

....

.... [2]

(ii) State the relationship between the de Broglie wavelength λ of a particle and its momentum p. State the meaning of any other symbols that you use.

....

.... [2]

(b) A narrow beam of electrons, all with the same speed, is incident normally on a carbon film. The electrons then move on to a fluorescent screen, as illustrated in Fig. 9.1.

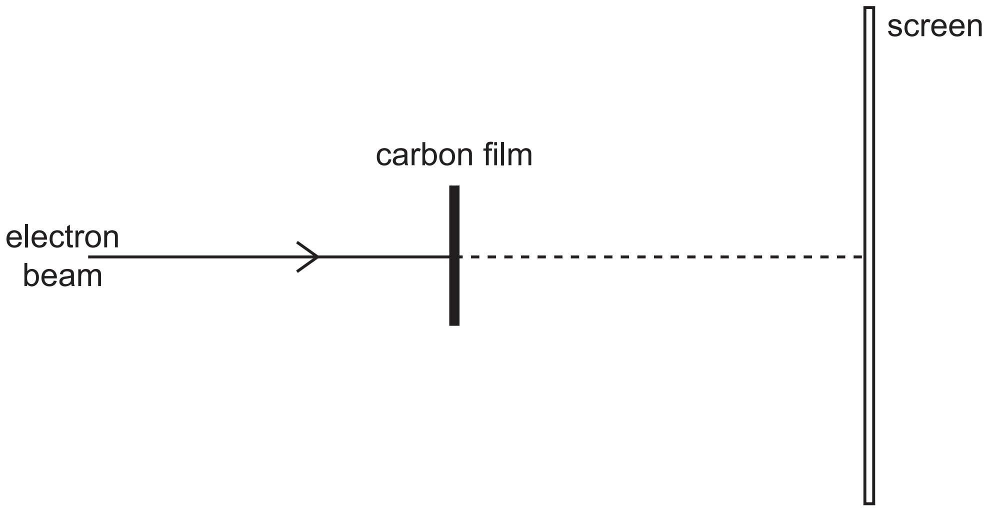

Fig. 9.1

The apparatus is in a vacuum.
The pattern produced on the screen is shown in Fig. 9.2.

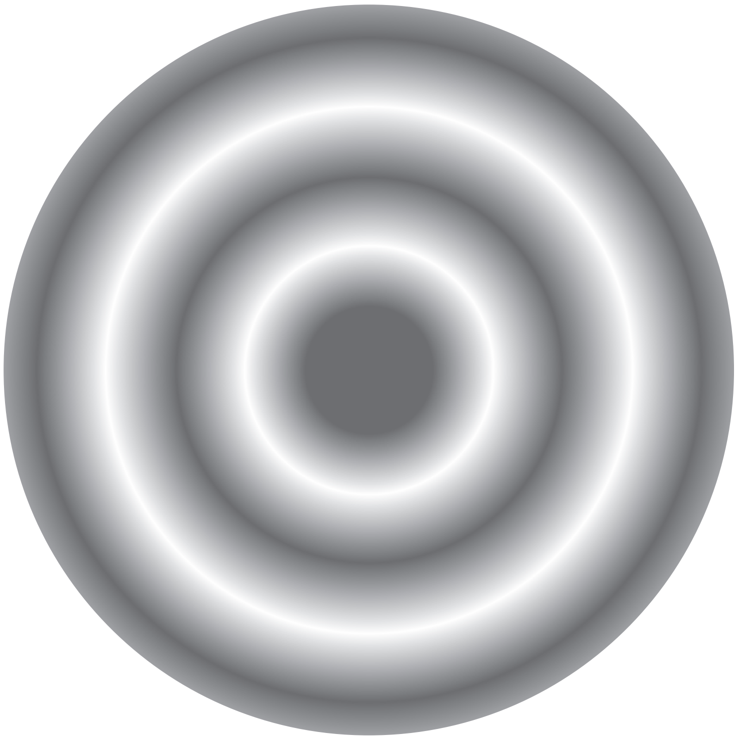

Fig. 9.2 (not to scale)

(i) Explain why the pattern in Fig. 9.2 provides experimental evidence to indicate a wave nature for the electrons.

....

....

.... [2]

(ii) The speed of the electrons is increased.

Suggest, with a reason, how this change affects the pattern observed on the screen.

....

....

.... [2]

[Total: 8]