8 In the late 17th century, scientists were embroiled in a debate about the fundamental nature of light – whether it was a wave or a particle. In the 1860, the Scottish physicist James Clerk Maxwell described light as a propagating wave of electric and magnetic fields. This Wave Theory of light is successful in explaining the laws of reflection and refraction of light, as well as the diffraction and interference effects of light in the Thomas Young double slit experiment. According to the Wave Theory, energy is emitted continuously.

However, the Wave Theory of light cannot explain the concept of blackbody radiation. Fig 8.1 shows how the intensity *I* of the emitted radiation varies with its wavelength λ at the different temperatures. In 1900, the German physicist Max Planck, introduced the idea that energy is quantised to explain the observation that with increasing temperature of the body, the peak of the radiation curve shifts to shorter wavelength with higher intensity.

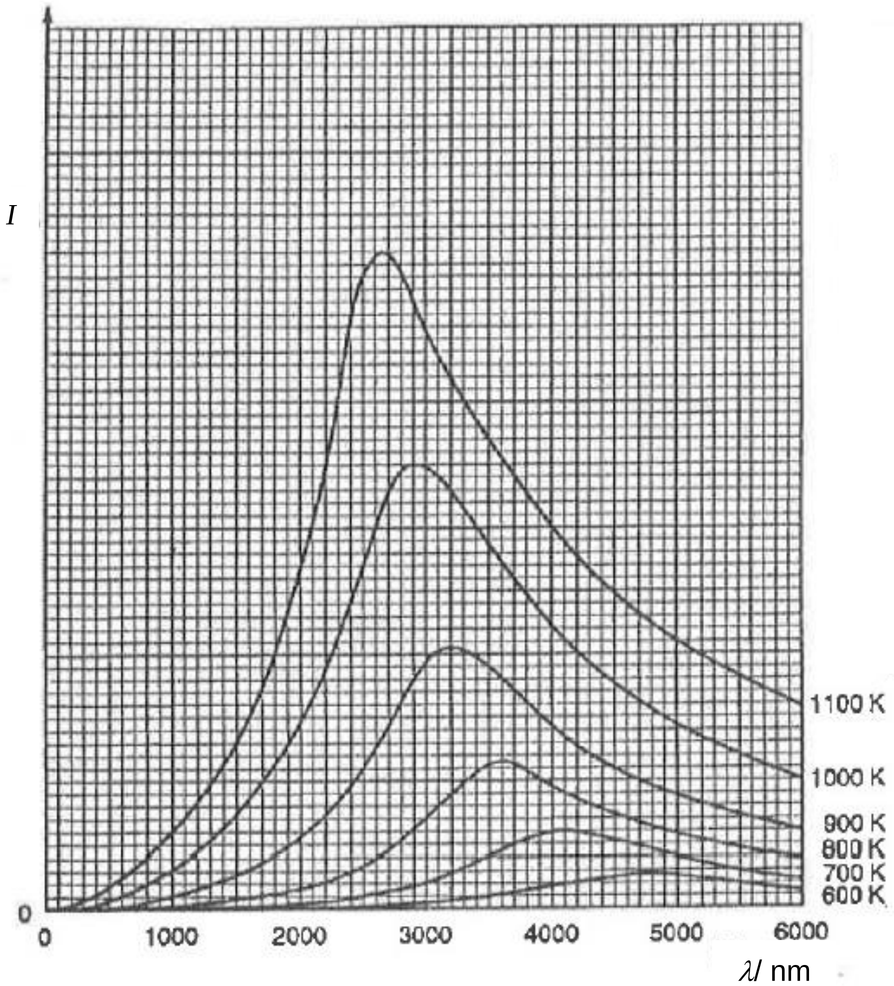

Fig. 8.1

(a) Explain what is meant by energy is *quantised*.

…………………………………………………………………………………………………

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

(b) **(i)** On the horizontal axis of Fig. 8.1, indicate with the letter V, a wavelength that is in the visible region of the electromagnetic spectrum. [1]

(ii) Use Fig. 8.1 to suggest why, at a temperature of 1100 K, the object would glow with a red colour.

…………………………………………………………………………………………

…………………………………………………………………………………………

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

(c) The radiation emitted by a body may be used as a means to determine the temperature of the body.

(i) Suggest and explain a property of the radiation that could be used for this purpose.

....

.... [1]

(ii) Suggest one advantage and one disadvantage of this method of measuring temperature.

advantage: ....

.... [1]

disadvantage: ....

.... [1]

The Wave Theory also does not explain the line spectra of hydrogen. In 1913, a Danish physicist, Neils Bohr successfully matched the wavelength of the emission line spectra to the discrete energy levels in hydrogen, again using quantisation. In the Bohr model, the hydrogen atom is pictured as a heavy, positively charged nucleus orbited by a light, negatively charged electron. According to Bohr, the angular momentum, which is the product of the linear momentum of the electron and its radius of orbit around the nucleus, is quantised. He further added that the electron with linear momentum p can only move in those orbits with radius r provided the angular momentum of the electron is an integer multiple of $\frac{h}{2\pi}$

$$\text{angular momentum} = pr = \frac{nh}{2\pi}$$

where n is a positive integer and h is the Planck constant.

At the ground state, the electron is in the smallest orbit, with the lowest energy, and has an orbital radius known as the Bohr radius.

(d) **(i)** Show that the linear speed v, in m s^{-1}, of the electron in the hydrogen atom is related to its orbital radius r, in m, by

$$v = \frac{15.9}{\sqrt{r}}$$

[3]

(ii) Using your expression in **(d)(i)** to calculate the Bohr radius r_o.

r_o = ………………….. nm [2]

(iii) Hence, by considering the potential and kinetic energies of the electron, show that the total energy of the electron in the ground state is –13.6 eV.

[2]

(e) The measured wavelength, λ, of selected lines in the hydrogen spectrum are given empirically by

$$\frac{1}{\lambda} = 1.097 \times 10^{7}\left(1 - \frac{1}{n^2}\right)$$

where n is an integer greater than or equal to one.

Fig. 8.2 represents part of the emission spectrum of atomic hydrogen. It contains a series of lines, the wavelengths of some of which are marked.

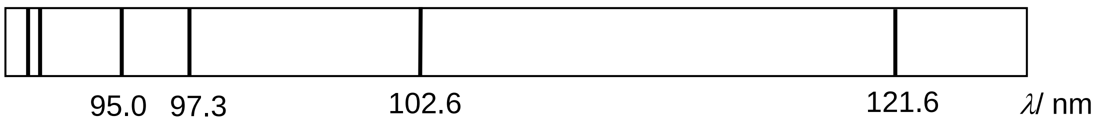

Fig. 8.2

These lines are part of the Lyman series due to electron transitions from higher energy levels to the ground state.

(i) Calculate the minimum wavelength given by this equation.

wavelength = ……………….. nm [1]

(ii) Show that the energy E of a photon and its wavelength λ are related by

$$E\lambda = 1.99 \times 10^{-16} \text{ J nm}$$

[2]

(iii) Use the relation given in **(e)(ii)**, complete Fig. 8.3 to determine the photon energies equivalent to all the wavelengths marked in Fig. 8.2.

wavelength λ / nm	$E = \dfrac{hc}{\lambda}$ / eV
121.6	
102.6	
97.3	
95.0	

Fig. 8.3

[1]

(iv) Use your answers in **(e)(iii)** to map a partial energy level diagram for hydrogen. You can leave your energy levels to 3 significant figures.
Show and label clearly, the electron transitions responsible for the emission lines with labelled wavelengths in Fig. 8.2.

[3]

(v) Another emission line in the hydrogen spectrum occurs at a wavelength of 434.1 nm. Identify and label on your answer in **(e)(iv)** the electron transition responsible for this line. [1]

[Total: 22]