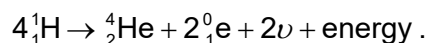**8** Read the passage below and answer the questions that follow.

Stars

Stars are formed from the gravitational collapse of gas clouds called nebulae. Gravitational potential energy is converted to internal energy of hot gases which emit electromagnetic radiation. Thus, the search for new stars usually involves the use of infra-red telescopes in space.

Once the core of a young star is hot enough to initiate hydrogen fusion, it is called a main sequence star. Such stars are stable, lasting for millions or billions of years. One example is our Sun, which produces energy when hydrogen nuclei fuse into stable helium nuclei in the stellar core. The temperature at the core is very high, typically 10^8 K or greater! Here, a process known as the proton-proton cycle begins, releasing energy. This three-stage process can be summarised in a single equation:

$$4{}^{1}_{1}\text{H} \rightarrow {}^{4}_{2}\text{He} + 2{}^{0}_{1}\text{e} + 2\upsilon + \text{energy} .$$

Our Sun is 1.51×10^{11} m from Earth, and it radiates energy uniformly through space with a mean intensity of radiation reaching the Earth's atmosphere of 1.34 kW m^{-2}. Hence, the Sun radiates a power of 3.8×10^{26} W. This is also equal to its luminosity, which is defined as the total power radiated by a star.

While hydrogen fusion supplies the energy stars require to maintain energy balance over its life span, this has little effect to the change in mass of the star. Even after five billion years, the Sun is very nearly the same mass as it is now!

We can estimate the surface temperature of a star from its colour. A body that is at a higher temperature than its surroundings emit electromagnetic radiation. The variation of intensity of the emitted radiation with wavelength λ is shown in Fig. 8.1.
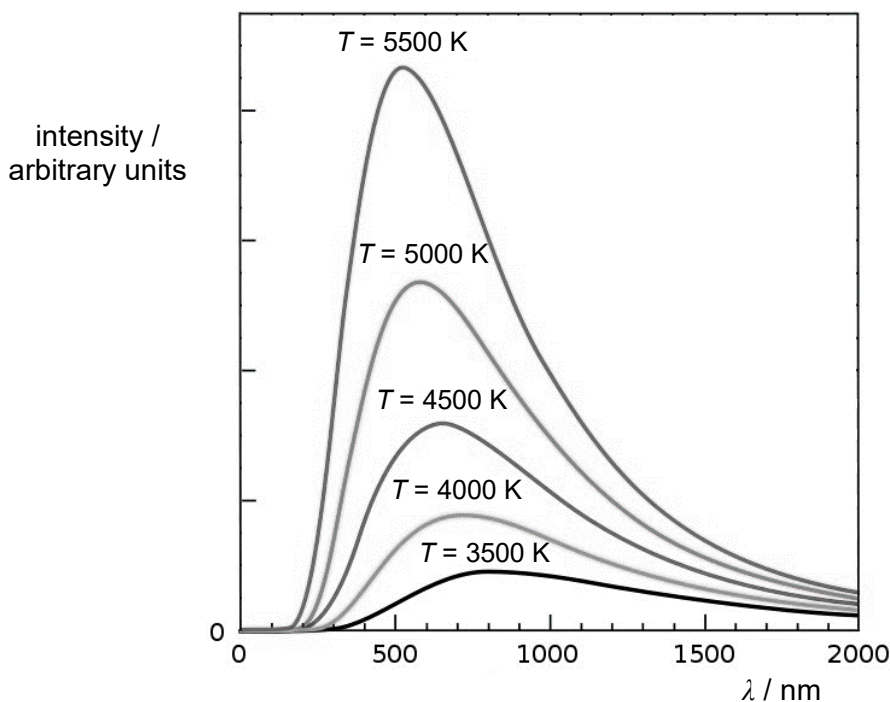
Fig. 8.1

The intensity distribution is different at different surface temperatures. At any temperature T, there is a peak corresponding to a wavelength λ_{max} for maximum intensity.
Theory states that

$$\lambda_{max} T = \text{constant} .$$

For example, at T = 3500 K, the intensity distribution spans the visible and infra-red wavelengths, with λ_{max} occurring at the red end of the visible spectrum. Since our eyes can only see in the visible spectrum, the object appears red-hot.

As the temperature of a body increases, the total emitted power also increases. It is known that the luminosity L of a star is related to its surface area A and its temperature T (in kelvins) as follows:

$$L \propto AT^4 .$$

When observing stars, astronomers rely on a phenomenon called the Doppler effect of light. The Doppler effect is more relatable to us with sound waves. Whenever there is relative motion between a wave source and an observer, the frequency noted by the observer is different from the actual frequency of the waves. We would have experienced the Doppler effect, such as when the frequency of the sirens change from higher pitch to lower pitch as an ambulance passes by. The higher pitch heard in front of the moving source is due to the 'bunching up' of wave crests as shown in Fig. 8.2. The reverse occurs for the observer behind the source.

observer behind   observer in front

Fig. 8.2

When light emitted from a distant star is passed through a diffraction grating, it is found that each line in the absorption spectrum from hydrogen gas occurs at a different wavelength from that of the corresponding line in the spectrum obtained in the laboratory. The Doppler effect is evident in Fig. 8.3. With some stars, all the spectral lines are shifted to longer wavelengths (red shifted), while with other stars, the lines are shifted to shorter wavelengths (blue shifted). Thus, hydrogen spectral lines provide important information about the motion of a star.
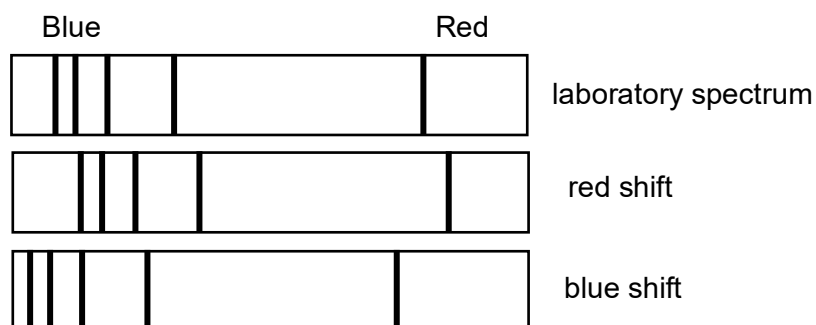

Blue   Red

laboratory spectrum

red shift

blue shift

Fig. 8.3

Using the Doppler effect together with the hydrogen spectral lines is extremely important in the detection of binary stars. This method of detection is known as spectroscopic binary. Over four-fifths of the single spots of light we see in the night sky are two or more stars revolving around each other. Binary stars, which consist of only two stars, are the most common star systems. An example would be Sirius-A and Sirius-B. However, when two stars are close together, they appear visually as a single star when viewed with a telescope.

Since binary stars rotate about their common centre of mass, when one star is approaching Earth, the other must be moving away. Analysis of the spectral lines could reveal information that there are, in fact, two stars.

(a) Suggest one advantage of placing telescopes in space to observe new stars.

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....[1]

(b) Explain why very high temperatures are necessary for fusion reactions to occur in stars.

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....[2]

(c) (i) Show that the total power radiated by the Sun is 3.8×10^{26} W.

[1]

(ii) Use the data below to calculate the number of fusion reactions occurring in the Sun each second. Assume all the radiated energy from the Sun comes from the fusion reaction.

mass of electron = 0.000549 u

mass of proton = 1.007276 u

mass of helium-4 nucleus = 4.001506 u

number of reactions per second = ... [3]

(iii) The present mass of the Sun is 2.0 × 10^{30} kg. In about another five billion years, the core of the Sun will be depleted of hydrogen.

Calculate the percentage decrease in the mass of the Sun when the core is depleted of hydrogen. Justify whether your calculation agrees with the claim in the passage.

percentage decrease = ... %

....
....

....
....[2]

(d) Fig. 8.4 shows some data about our Sun and Sirius-A, one of the binary stars mentioned.

	Sun	Sirius-A
Radius / m	R	$1.7R$
Luminosity / W	L	$25L$
Surface temperature / K	5800	
Wavelength λ_{max} at maximum intensity / nm	500	

Fig. 8.4

(i) Calculate the surface temperature T of Sirius-A.

T = ... K [2]

(ii) Use data from Fig. 8.1 to verify the theory that

$$\lambda_{max}T = \text{constant} .$$

[2]

(iii) Use information from Fig. 8.4 and your answer in **(d)(i)** to determine the wavelength λ_{max} for which maximum intensity occurs from Sirius-A.

$$\lambda_{max} = \text{.................................... nm [2]}$$

(iv) By considering your answer in **(d)(iii)**, suggest why Sirius-A appears as a bluish star to an astronomer using an optical telescope.

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....[1]

(e) Fig. 8.5 shows the visible part of the absorption spectrum from hydrogen gas in a laboratory on the Earth and the same part of the absorption spectrum observed in light from a star in a distant galaxy. The numbers indicate the wavelengths in nanometres (nm).

Blue   Red

spectrum from lab

434 486   656

Blue   Red
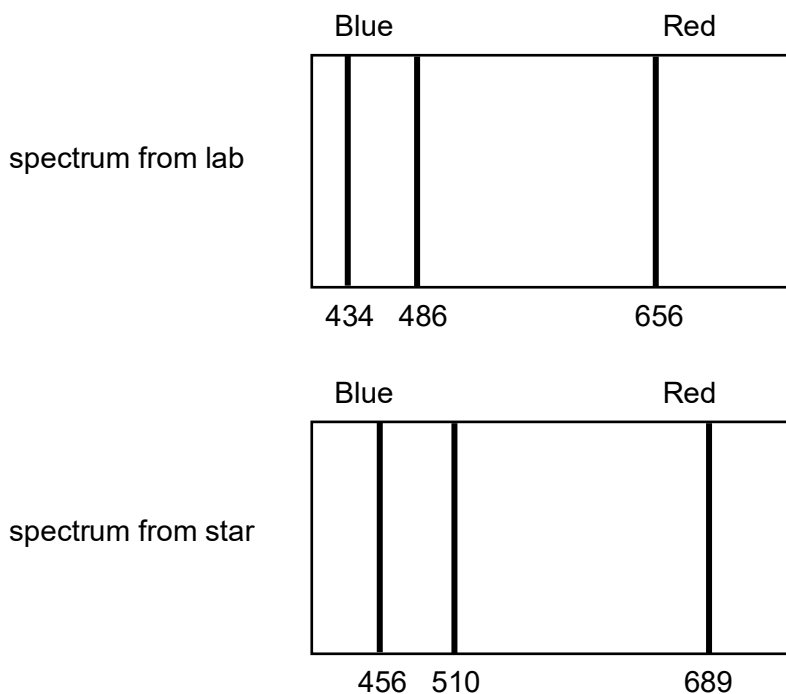
spectrum from star

456 510   689

Fig. 8.5 (not to scale)

(i) Compare the line spectra and state what this shows about the motion of the star.

....
....

....
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....[2]

(ii) Use Fig. 8.5 to calculate the percentage change in the wavelength of a spectral line observed with light from the star compared with a corresponding spectral line observed in the laboratory.

percentage change = ... % [1]

(f) (i) Apart from two binary stars being too close together, use Rayleigh's criterion to state another reason why the stars could appear as a single image as seen with a telescope.

....
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....[1]

(ii) Suggest how hydrogen spectral lines might provide astronomers with information that a star is part of a binary star system.

Assume that the observed star has similar brightness as its binary counterpart and viewed from Earth in the plane of their orbits.

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....[2]

[Total: 22]

End of Paper