25. Astronomy and Cosmology

25.3 Hubble's law and the Big Bang theory

Paper 4

Question Paper

1 Fig. 8.1 shows part of the emission spectrum of visible radiation emitted by hydrogen gas in a star in a distant galaxy.

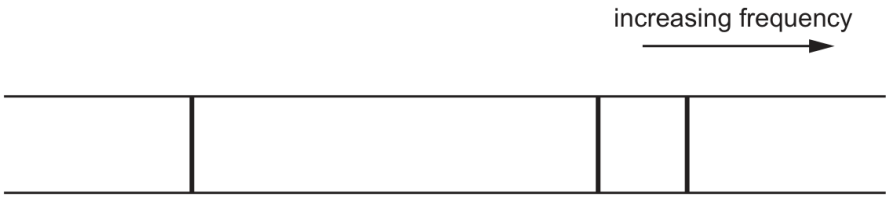


Fig. 8.1

The galaxy is moving away from the Earth at a speed of $6.2 \times 10^6\,\text{m s}^{-1}$.

(a) (i) Explain how the positions of the lines in the emission spectrum seen by an observer on the Earth differ from the positions shown in Fig. 8.1.

.....

.....

..... [2]

(ii) On Fig. 8.1, draw the three lines in possible positions in the spectrum seen by the observer. [2]

(b) The lines in Fig. 8.1 correspond to electron transitions down to the energy level –3.40 eV. One of the lines represents emitted radiation of wavelength 488 nm.

(iii) Determine the wavelength, in nm, of this radiation as detected by the observer on the Earth.

wavelength = ... nm [2]

(c) A value for the Hubble constant is $2.3 \times 10^{-18}\,s^{-1}$.

Determine the distance of the galaxy from the Earth.

distance = ... m [2]

2 **(a)** Explain how redshift leads to the idea that the Universe is expanding.

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.....

..... [3]

(b) Stars in a distant galaxy emit radiation. The total luminosity of the stars in the galaxy is 1.90×10^{36} W.
The emission spectrum of the radiation contains a line X at a wavelength of 658 nm.

Radiation from the galaxy is observed on the Earth. The observed radiation has a radiant flux intensity of 8.42×10^{-16} W m^{-2}. In the observed emission spectrum, line X is at a wavelength of 726 nm.

Determine:

(ii) the speed v of the galaxy relative to the Earth.

v = ... m s^{-1} [2]

(c) Observations of many galaxies, such as the one in **(b)**, lead to many pairs of values of d and v. Plotting these values reveals a trend.

(i) On Fig. 10.1, sketch the variation of v with d.

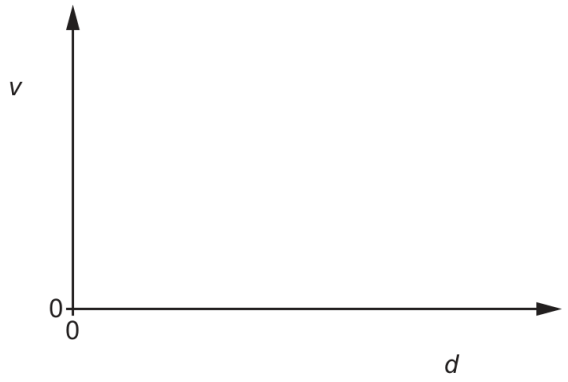


Fig. 10.1

[2]

(ii) State the name of the quantity represented by the gradient of the line in Fig. 10.1.

..... [1]

3 **(a)** State Hubble's law. Identify any symbols that you use.

.....

.....

.....

..... [2]

(c) The star in **(b)** is in a distant galaxy. A spectral line in the light from this galaxy is known to have a wavelength of 486 nm. This spectral line in the light from the galaxy observed on the Earth has a wavelength of 492 nm.

(i) Explain why the wavelength observed on the Earth is different from the wavelength that the galaxy is known to have emitted.

.....

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..... [2]

(ii) Determine a value for the Hubble constant H_0.

H_0 = ... s^{-1} [3]

4 **(b)** A cosmology student observes the electromagnetic radiation received from a star in a galaxy. The student uses Wien's law to estimate the surface temperature of the star, a standard candle to estimate the distance to the galaxy, and the Stefan–Boltzmann law to estimate the radius of the star.

The student observes that the radiation from the star is redshifted.

(ii) State the reason why the radiation from the star is redshifted.

..... [1]

5 **(c)** The lines in Fig. 10.1 have been corrected for redshift.

(i) State what is meant by redshift.

.....

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..... [2]

(ii) Explain how cosmologists are able to determine that light from a distant star has undergone redshift.

.....

.....

..... [2]

6 **(a)** **(i)** State Hubble's law.

.....

.....

..... [2]

(ii) Explain how cosmologists use observations of emission spectra from stars in distant galaxies to determine that the Universe is expanding.

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..... [2]

(b) Explain how Hubble's law and the idea of the expanding Universe lead to the Big Bang theory of the origin of the Universe.

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..... [3]

7 **(a)** Fig. 9.1 shows the visible part of the emission spectrum from hydrogen gas in a laboratory on the Earth. The numbers indicate the wavelength, in nm, represented by each line.

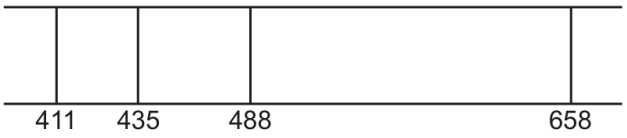


Fig. 9.1

(b) The same part of the emission spectrum from hydrogen as in **(a)**, observed in light from stars in a distant galaxy, is shown in Fig. 9.3. The numbers indicate the wavelengths in nm.

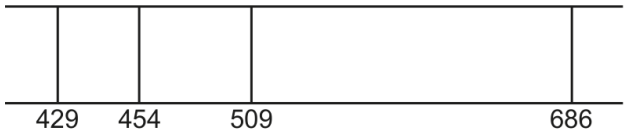


Fig. 9.3

The spectrum shows the same pattern as Fig. 9.1 but with different wavelengths.

(i) State the name of the phenomenon that gives rise to the change in the wavelengths.

..... [1]

(ii) State what this phenomenon shows about the motion of the galaxy.

..... [1]

(iii) Use one of the lines in Fig. 9.1, and the corresponding line in Fig. 9.3, to determine the speed of the distant galaxy relative to the observer.

speed = ... $m\,s^{-1}$ [3]

(c) The galaxy in **(b)** is known to be a distance of 5.7×10^{24} m from the Earth.

Use your answer in **(b)(iii)** to determine a value for the Hubble constant H_0.

H_0 = ... s^{-1} [2]