10 **(a)** State what is meant by redshift.

....

....

.... [2]

(b) Explain how observations of redshift lead to the idea that the universe is expanding.

....

....

.... [2]

(c) Explain how Hubble's law leads to the Big Bang theory of the origin of the universe.

....

....

....

....

.... [3]

9 **(a)** State what is meant by the mass defect of a nucleus.

....

....

.... [2]

(b) The nuclear fusion reaction for the formation of helium-4 from deuterium is represented by

$$^{2}_{1}\text{H} + ^{2}_{1}\text{H} \rightarrow ^{4}_{2}\text{He}.$$

Table 9.1 shows the masses of the nuclides involved in this reaction.

Table 9.1

nuclide	nuclide mass / u
$^{2}_{1}\text{H}$	2.013 553
$^{4}_{2}\text{He}$	4.001 505

Calculate the energy released in the formation of 1.00 mol of helium-4.

energy = ... J [4]

(c) The star Sirius has a radius of 1.19×10^{9} m and loses mass due to nuclear fusion at a rate of 1.09×10^{11} kg s^{-1}. Assume that the power of the radiation emitted by the star is equal to the power released by this process.

(i) Determine a value for the luminosity of Sirius. Give a unit with your answer.

luminosity = ... unit .... [2]

(ii) Use your answer in **(c)(i)** to determine the surface temperature of Sirius.

surface temperature = ... K [2]

(d) Explain how cosmologists use standard candles to estimate the distance of a galaxy from the Earth.

....

....

....

....

.... [3]

9 **(a)** State Wien's displacement law.

....

....

.... [2]

(b) Fig. 9.1 shows the variation with d^{-2} of the radiant flux intensity F observed from a star X, where d is the distance of the observer from the star. Fig. 9.2 shows the variation with wavelength λ of the rates of emission P of radiation by star X and the Sun.

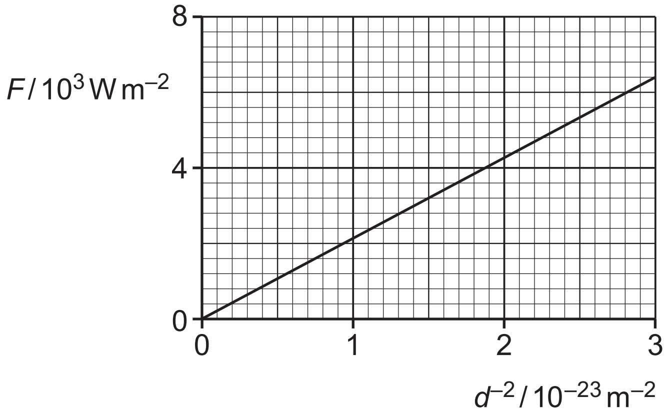

Fig. 9.1

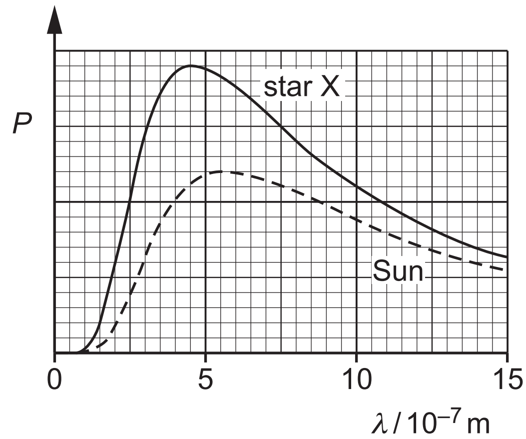

Fig. 9.2

The surface temperature of the Sun is 5770 K.

State **three** conclusions about star X that can be drawn from this data. The conclusions may be qualitative or quantitative. Use the space for any working.

1 ....

....

2 ....

....

3 ....

....

[3]

(c) Star X is in a galaxy that is moving away from the Earth.

Suggest, with a reason, how the line for star X in Fig. 9.2 would appear differently if it had been obtained from data measured on the Earth.

....

....

.... [2]

10 **(a)** State Hubble's law.

....

....

.... [2]

(b) A star in a distant galaxy emits radiation that has a maximum intensity of emission at a wavelength of 4.62×10^{-7} m.

Observations of the galaxy made on the Earth detect the maximum intensity of emission from the star at a wavelength of 4.91×10^{-7} m.

(i) Explain why the observed wavelength and the emitted wavelength have different values.

....

....

.... [2]

(ii) Calculate the speed of the star relative to the Earth.

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

(iii) The wavelength of maximum intensity of emission is used to determine a value for the surface temperature of the star.

Explain how the temperature determined using the observed wavelength compares with the true value of temperature determined using the emitted wavelength.

....

....

.... [2]

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

Use your answer in **(b)(ii)** to determine the distance of the star in **(b)** from the Earth.

distance = ... m [2]

10 **(a)** **(i)** State what is meant by the luminosity of a star.

....

.... [1]

(ii) Explain how standard candles are used to determine the distance to a galaxy.

....

....

....

....

....

.... [3]

(b) The Sun rotates on its axis. Points X, Y and Z are on the equator of the Sun as shown in Fig. 10.1.

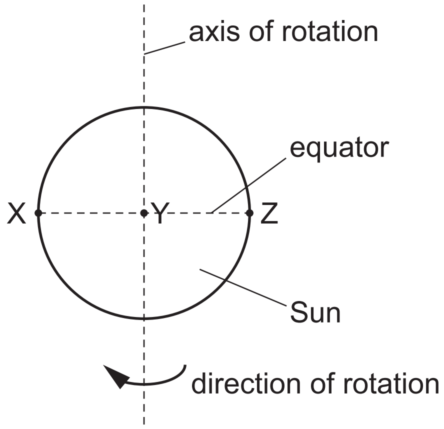

Fig. 10.1

The wavelengths of light from points X and Y are observed and recorded in Table 10.1.

Table 10.1

observed wavelength from X / nm	observed wavelength from Y / nm
656.2877	656.2831

(i) The Sun rotates with a period of 2.07×10^{6} s.

Show that the radius of the Sun is 6.93×10^{8} m.

[3]

(ii) State and explain how the expected wavelength of the light observed from Z compares with the emitted wavelength.

....

....

.... [2]

(iii) The luminosity of the Sun is 3.8×10^{26} W.

Use the information in **(b)(i)** to calculate the surface temperature of the Sun.

temperature = ... K [2]

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

....

....

....

....

.... [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 $8.42 \times 10^{-16}\,\mathrm{W\,m^{-2}}$. In the observed emission spectrum, line X is at a wavelength of 726 nm.

Determine:

(i) the distance *d* of the galaxy from the Earth

d = ... m [2]

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

v = ... $\mathrm{m\,s^{-1}}$ [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*.

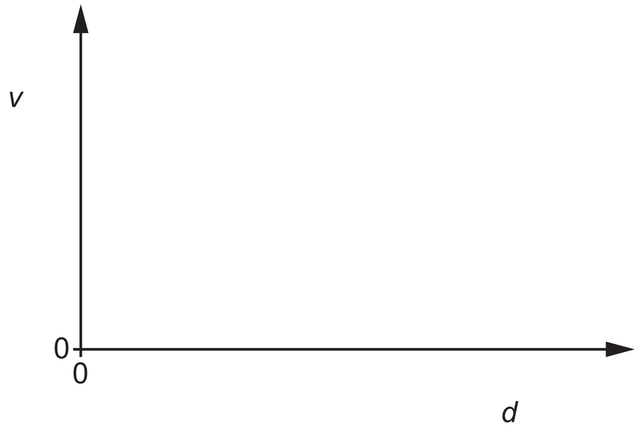

Fig. 10.1

[2]

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

.... [1]

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

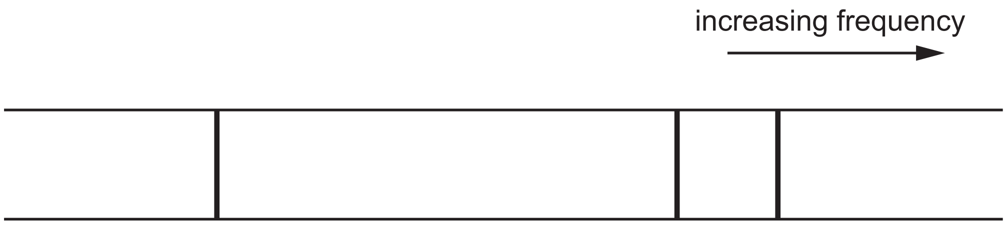

Fig. 8.1

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

(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.

(i) Calculate the energy of a photon of this radiation.

photon energy = ... J [2]

(ii) Determine the energy, in eV, of the energy level from which the electron transition originates to cause the emission of this radiation.

energy level = ... eV [2]

(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]

10 (a) (i) State what is meant by the luminosity of a star.

....

....

.... [2]

(ii) Explain how a standard candle in a distant galaxy can be used to determine the distance of the galaxy from an observer.

....

....

....

....

.... [3]

(b) The Sun has a radius of 6.96×10^8 m and a surface temperature of 5780 K.
Light from the Sun is observed to have a peak intensity at a wavelength of 501 nm.

(i) Calculate the luminosity of the Sun. Give a unit with your answer.

luminosity = ... unit .... [2]

(ii) Another star emits radiation that has a peak intensity at a wavelength of 624 nm.

Determine the surface temperature of this star.

surface temperature = ...K [2]

10 **(a)** The Sun has a surface temperature of 5780 K. The luminosity of the Sun is 3.85×10^{26} W.

(i) Calculate the radius of the Sun.

radius = ... m [2]

(ii) The Earth is a distance of 1.50×10^{11} m from the Sun.

Calculate the radiant flux intensity F of the radiation from the Sun at a distance of 1.50×10^{11} m. Give a unit with your answer.

F = ... unit .... [2]

(iii) The variation with wavelength of the intensity of radiation emitted from the Sun is shown in Fig. 10.1.

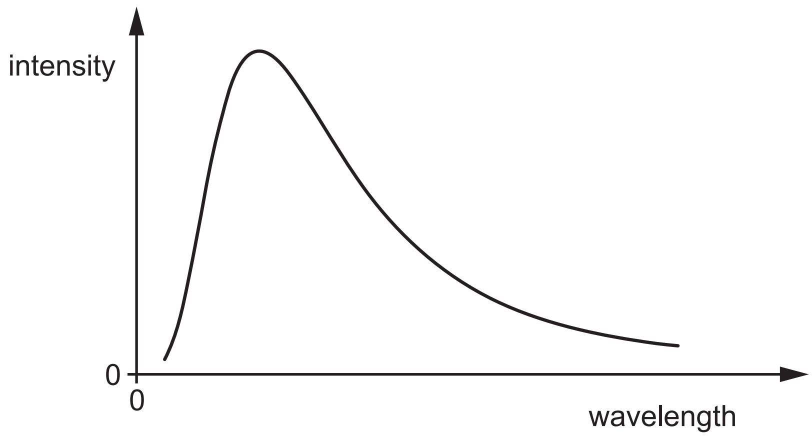

Fig. 10.1

Another star has the same radius as the Sun but has a lower surface temperature.

On Fig. 10.1, sketch a line to show the variation with wavelength of the intensity of the radiation emitted for this star. [2]

(b) A galaxy in the constellation Corona Borealis is moving away from the Earth.

(i) The visible emission spectrum for the Sun is shown in Fig. 10.2.

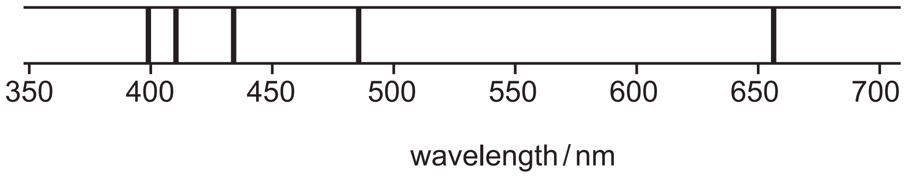

Fig. 10.2

The lines are at wavelengths of 397 nm, 410 nm, 434 nm, 486 nm and 656 nm. The compositions of the Sun and a star in the Corona Borealis galaxy are similar.

On Fig. 10.3, sketch the emission spectrum for the star in the Corona Borealis galaxy as observed from the Earth. No calculations are required.

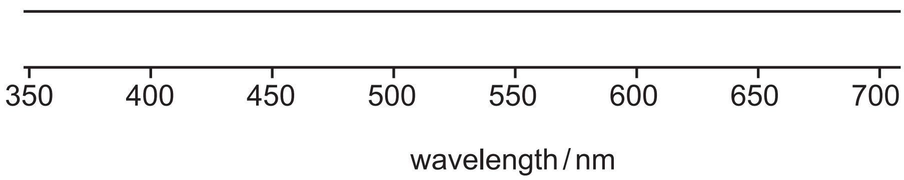

Fig. 10.3

[1]

(ii) The galaxy in Corona Borealis is moving away from the Earth at a speed of 21 400 km s^{-1}.

Use information from **(b)(i)** to calculate, in nm, the observed wavelength of the lowest visible energy emission for the star in the Corona Borealis galaxy.

wavelength = ... nm [2]

(iii) The wavelength in **(b)(ii)** is used to calculate a value for the surface temperature of the star in the Corona Borealis galaxy. The calculation does not give an accurate value.

State and explain whether this value of temperature is too high or too low.

....

....

.... [1]

10 **(a)** State Wien's displacement law. Identify any symbols that you use.

....

....

.... [2]

(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.

(i) State what is meant by a standard candle.

.... [1]

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

.... [1]

(iii) The true values of the quantities observed or estimated are those that are corrected to allow for redshift. However, the student does not correct for redshift.

By placing one tick (✓) in each row, complete Table 10.1 to indicate how the observations and estimates made by the student compare with the true values.

Table 10.1

	student's uncorrected value		
	too low	the same	too high
wavelength of radiation			
surface temperature of star			
distance to star			
radius of star			

[4]

9 **(a)** Define mass defect.

....

....

.... [2]

(b) Table 9.1 shows the mass defects of three nuclei.

Table 9.1

nucleus	mass defect / u
${}^{2}_{1}H$	0.002 388
${}^{3}_{1}H$	0.009 105
${}^{4}_{2}He$	0.030 377

The nuclear fusion process in a particular star is described by

$$ {}^{2}_{1}H + {}^{3}_{1}H \rightarrow {}^{4}_{2}He + X $$

where X is a particle that has no mass defect.

(i) State the name of particle X.

.... [1]

(ii) Show that the energy released when one nucleus of ${}^{4}_{2}He$ is formed in this fusion reaction is 2.8×10^{-12} J.

[3]

(c) The star in **(b)** has a radius of 2.3×10^9 m and a luminosity of 1.4×10^{28} W.
All the energy released from the formation of ${}^4_2He$ is radiated away from the star.
All the energy that is radiated from the star has been released in the formation of ${}^4_2He$.

Determine:

(i) the mass of ${}^4_2He$ produced per unit time by the fusion process

mass per unit time = ... $kg\,s^{-1}$ [3]

(ii) the surface temperature of the star.

temperature = ... K [2]

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

....

....

....

.... [2]

(b) A star of luminosity 3.8×10^{31} W is a distance of 1.8×10^{24} m from the Earth.

Calculate the radiant flux intensity at the Earth of the radiation emitted by the star.

radiant flux intensity = ... $\mathrm{W\,m^{-2}}$ [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.

....

....

.... [2]

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

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

10 **(a)** A student observes different stars from the Earth.
Give **two** reasons why some stars appear brighter than others.

1 ....

....

2 ....

.... [2]

(b) State what is meant by a standard candle.

....

.... [1]

(c) A spectral line from a star within a galaxy is observed to have a wavelength of 660.9 nm. The same spectral line measured in the laboratory is observed to have a wavelength of 656.3 nm.

(i) Show that the speed of the star relative to the Earth is $2.1 \times 10^6\,\mathrm{m\,s^{-1}}$.

[1]

(ii) Calculate the distance to the star.

(ii) Calculate the distance to the star.

The Hubble constant is $2.3 \times 10^{-18}\,\mathrm{s^{-1}}$.

distance = ... m [2]

(iii) State and explain what can be concluded about the Universe based on this change in observed wavelength.

....

....

....

....

.... [3]

9 **(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.

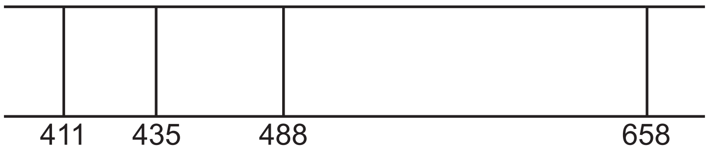

Fig. 9.1

(i) Explain how the emission spectrum provides evidence for the existence of discrete energy levels for the electron in a hydrogen atom.

....

....

....

.... [3]

(ii) Fig. 9.2 shows five of the energy levels in the hydrogen atom. The wavelengths of radiation shown in Fig. 9.1 relate to transitions to the –3.400 eV level in Fig. 9.2.

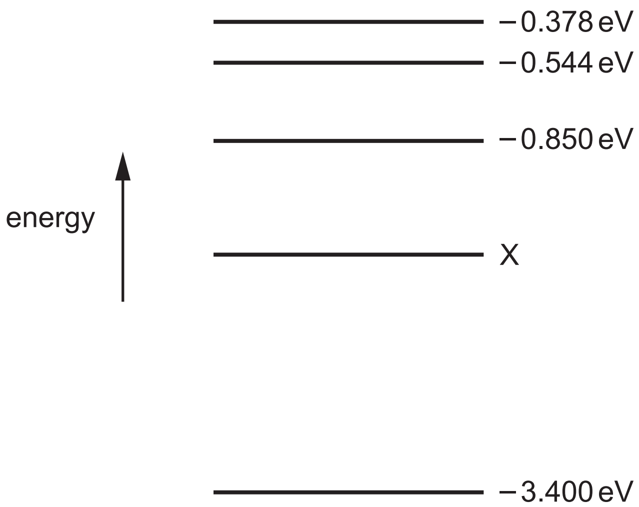

Fig. 9.2 (not to scale)

Show that the energy level X is –1.51 eV.

[3]

(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.

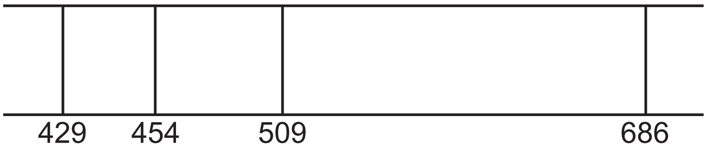

Fig. 9.3

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]

9 **(a)** State what is meant by the luminosity of a star.

.... [1]

(b) A star in the constellation Canis Major is a distance of 8.14×10^{16} m from the Earth and has a luminosity of 9.86×10^{27} W. The surface temperature of the star is 9830 K.

(i) Calculate the radiant flux intensity of the radiation from the star observed from the Earth. Give a unit with your answer.

radiant flux intensity = ... unit .... [2]

(ii) Determine the radius of the star.

radius = ... m [2]

(c) Explain how the surface temperature of a distant star may be determined from the wavelength spectrum of the light from the star.

....

....

....

.... [3]