ASTRONOMY AND COSMOLOGY WORKSHEET
A-Level Physics 9702

1 **(a)** State Hubble's law. **MJ25/41/Q10**

....

....

.... [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]

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(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]

[Total: 10]

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2 The deuterium nucleus ($^2_1$H) has a mass defect of 0.002 388 u. The helium-4 nucleus ($^4_2$He) has a mass defect of 0.030 377 u. Helium-4 is formed from deuterium in a nuclear reaction that can be represented by the equation

$$3\,^2_1\text{H} \longrightarrow {}^4_2\text{He} + {}^1_1\text{p} + {}^1_0\text{n}.$$

(a) (i) State the name of this type of nuclear reaction.

.... [1]

(ii) Show that the energy released when one nucleus of helium-4 is formed from deuterium is 3.47×10^{-12} J.

[3]

(b) A star has a radius of 6.96×10^8 m. Helium-4 is produced in this star, from deuterium, at a mass rate of 7.34×10^{11} kg s^{-1}. All the energy released from this process is radiated away from the star. All the energy that is radiated from the star is released by this process.

(i) Calculate the luminosity of the star.

luminosity = ... W [3]

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

temperature = ... K [2]

[Total: 9]

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3 **(a)** **(i)** State what is meant by the luminosity of a star. **March25/42/Q10**

....

.... [1]

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

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....

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....

....

.... [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.

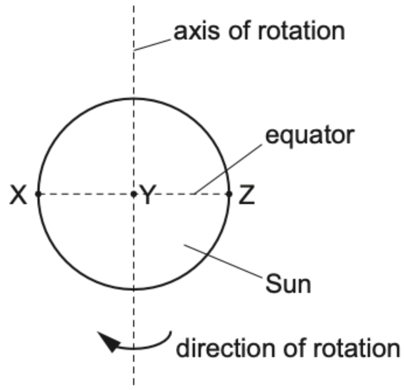

Fig. 10.1

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]

[Total: 11]

4 **(a)** Explain how redshift leads to the idea that the Universe is expanding. **ON24/41/Q10**

....

....

....

....

.... [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:

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

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(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*.

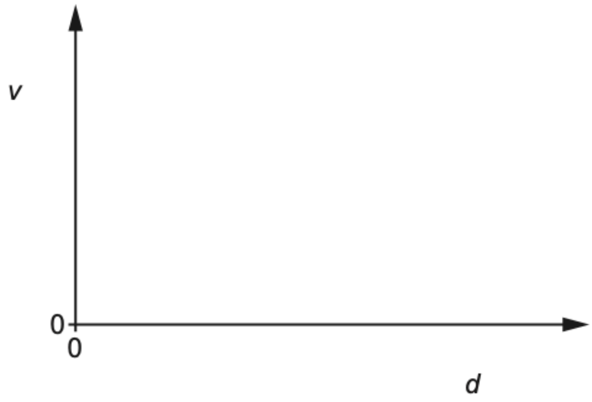

Fig. 10.1

[2]

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

.... [1]

[Total: 10]

MJ24/41/Q10

5 **(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]

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(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]

[Total: 9]

MJ24/42/Q8

6 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 6.2×10^6 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]

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(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]

[Total: 12]

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7 **(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.

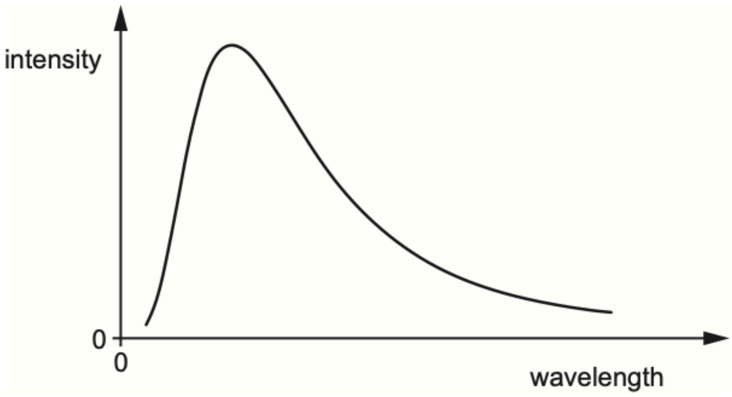

Fig. 10.1

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]

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(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.

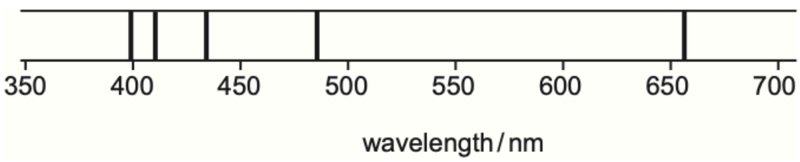

Fig. 10.2

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.

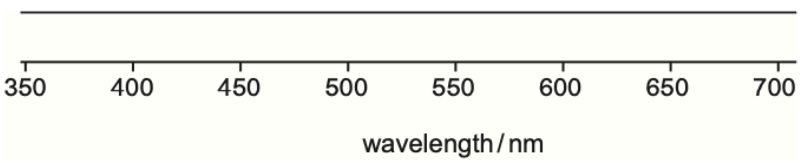

Fig. 10.3

[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]

[Total: 10]

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8 **(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]

[Total: 8]

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9 **(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]

[Total: 9]

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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 $2.1 \times 10^{6}\,\text{m s}^{-1}$.

[1]

(ii) Calculate the distance to the star.

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

distance = ... m [2]

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

....

....

....

....

.... [3]

[Total: 9]

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11 (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]

[Total: 8]

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12 **(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.

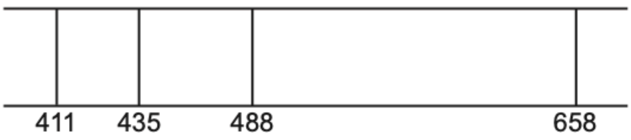

Fig. 9.1

(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.

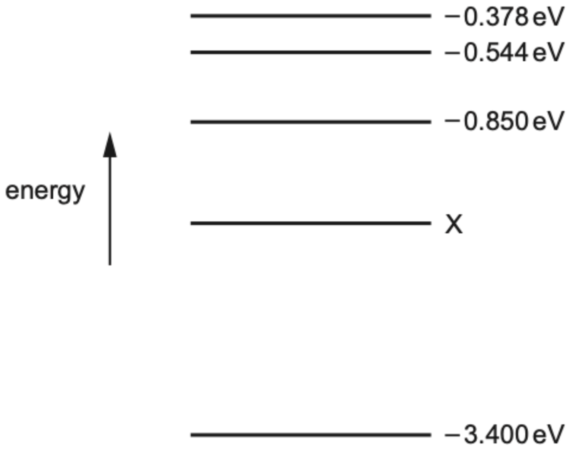

Fig. 9.2 (not to scale)

Show that the energy level X is −1.51 eV.

[3]

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(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.

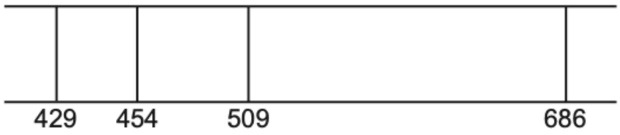

Fig. 9.3

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]

[Total: 13]

13 (a) State Wien's displacement law.

....

.... [1]

(b) Fig. 10.1 shows the wavelength distributions of electromagnetic radiation emitted by two stars A and B.

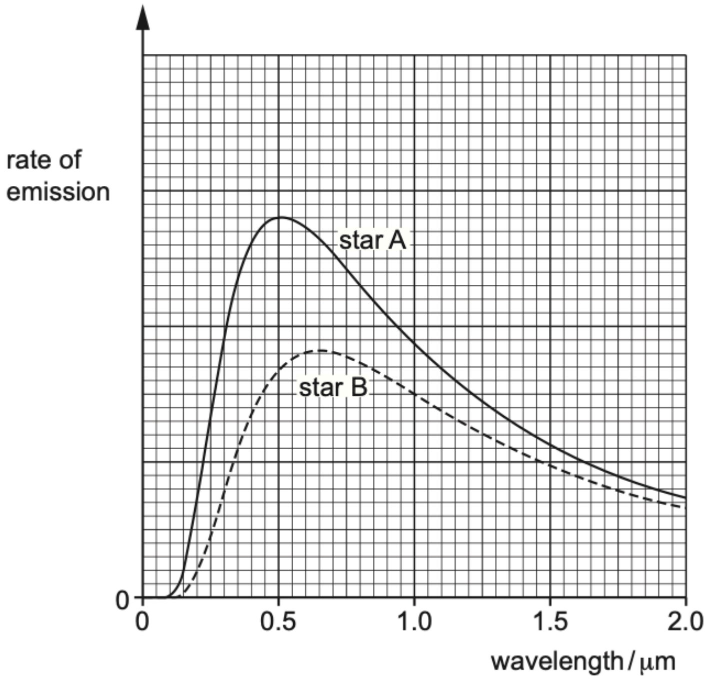

Fig. 10.1

The surface temperature of star A is known to be 5800 K.

(i) Determine the surface temperature of star B.

surface temperature = ... K [2]

(ii) Star B appears less bright than star A when viewed from the Earth.

Use Fig. 10.1 to suggest, with a reason, how else the physical appearance of star B compares with that of star A.

....

....

.... [2]

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

(i) State what is meant by redshift.

....

....

.... [2]

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

....

....

.... [2]

[Total: 9]

MJ22/42/Q9

14 (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.

....

....

....

.... [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.

....

....

....

.... [3]

[Total: 7]

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

....

.... [1]

(b) The luminosity of the Sun is 3.83×10^{26} W. The distance between the Earth and the Sun is 1.51×10^{11} m.

Calculate the radiant flux intensity F of the Sun at the Earth. Give a unit with your answer.

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

(c) Use data from **(b)** to calculate the mass that is converted into energy every second in the Sun.

mass = ... kg [1]

(d) The radius of the Sun is 6.96×10^{8} m.

Show that the temperature T of the surface of the Sun is 5770 K.

[1]

(e) The wavelength λ_{max} of light for which the maximum rate of emission occurs from the Sun is 5.00×10^{-7} m.
The temperature of the surface of the star Sirius is 9940 K.

Use information from **(d)** to determine the wavelength of light for which the maximum rate of emission occurs from Sirius.

wavelength = ... m [2]

[Total: 7]

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16 **(a)** A star has a luminosity that is known to be 4.8×10^{29} W. A scientist observing this star finds that the radiant flux intensity of light received on Earth from the star is $2.6\,\text{nW}\,\text{m}^{-2}$.

(i) Name the term used to describe an astronomical object that has known luminosity.

.... [1]

(ii) Determine the distance of the star from Earth.

distance = ... m [2]

(b) The Sun has a surface temperature of 5800 K. The wavelength λ_{max} of light for which the maximum rate of emission occurs from the Sun is 500 nm.

The scientist observing the star in **(a)** finds that the wavelength for which the maximum rate of emission occurs from the star is 430 nm.

(i) Show that the surface temperature of the star in **(a)** is approximately 6700 K. Explain your reasoning.

[2]

(ii) Use the information in **(a)** and **(b)(i)** to determine the radius of the star.

radius = ... m [2]

[Total: 7]

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17 A star is observed from the Earth. The Earth is a distance of 6.04×10^{18} m away from the star.

(a) State the name of the term used by cosmologists to describe an object of known luminosity that is used to determine distances to galaxies.

....

.... [1]

(b) The light from the star that is observed from Earth is found to be redshifted.

(i) Explain what is meant by *redshift*.

....

.... [1]

(ii) State what can be deduced, from this observation, about the motion of the star.

....

.... [1]

(c) Explain how the observation of redshift in many galaxies has led to the Big Bang theory.

....

....

....

.... [2]

[Total: 5]

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

....

.... [1]

(b) Explain the principles used by observers on Earth to determine the speeds of distant galaxies.

....

....

....

.... [2]

(c) Describe how observations about distant galaxies provide evidence for

(i) the expanding universe,

....

....

.... [2]

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(ii) the Big Bang theory.

....

....

.... [2]

[Total: 7]

19 **(a)** A star known to be at a distance of 3.80×10^{17} m from the Earth provides a spectrum of light as shown in Fig. 7.1.

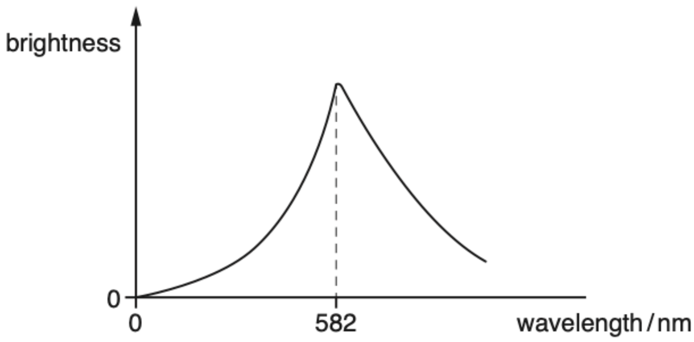

Fig. 7.1

(i) Use Wien's displacement law to determine the surface temperature of the star. The constant of proportionality in Wien's displacement law is 2.90×10^{-3} m K.

temperature = ... K [2]

(ii) This star provides an intensity of radiation at the Earth of 2.38×10^{-8} W m^{-2}.

Calculate the radius of the star.

radius = ... m [4]

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(b) Describe how the wavelength of a spectral line from a light source could be measured in a school laboratory.

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....

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....[5]

[Total: 11]

20 **(a)** Sketch a graph showing how the relative intensity of light from a hot body varies with the wavelength of the light.

[1]

(b) **(i)** The Sun has a surface temperature of 5800 K and the wavelength of light of maximum intensity occurs at a wavelength of 520 nm. A distant star has its wavelength of maximum intensity at a wavelength of 210 nm.

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Calculate the surface temperature of the distant star.

temperature = ... K [1]

(ii) Using data from similar stars it is estimated that the surface area of the distant star is $6.3 \times 10^{17}\,m^2$. From your answer in **(b)(i)** calculate the approximate luminosity of the star.

luminosity = ... W [2]

(iii) The intensity of radiation incident on the Earth from the distant star is $1.60 \times 10^{-9}\,W\,m^{-2}$. Estimate the distance of the star from the Earth.

distance = ... m [2]

[Total: 6]

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1 (a)	speed is (directly) proportional to distance speed is speed of recession of galaxy from an observer, and distance is the distance of the galaxy from the observer	M1 A1	**Ignore** symbols unless defined. **Ignore** references to units.
10(b)(i)	star is receding from the Earth observed wavelength is redshifted from emitted wavelength	B1 B1	**Allow** 'moving away' for 'receding'. **Allow** 'observer' for 'Earth'.
10(b)(ii)	$\Delta\lambda / \lambda = v / c$ $(4.91 - 4.62) / 4.62 = v / (3.00 \times 10^8)$ v = $\mathbf{1.9 \times 10^7}$ **m s⁻¹**	 C1 A1	 Use of 4.91 in denominator (gives $v = 1.8 \times 10^7$) is XP. Correct to at least 2 significant figures. AFC. (1.88)
10(b)(iii)	wavelength (of maximum intensity) is inversely proportional to temperature observed wavelength too high, so determined temperature too low	B1 B1	
10(c)	$v = H_0 d$ $d = (1.9 \times 10^7) / (2.3 \times 10^{-18})$ $= \mathbf{8.3 \times 10^{24}}$ **m**	C1 A1	 Possible ECF from **(b)(ii)**. Correct to at least 2 significant figures. AFC. (8.26) Use of unrounded v gives $\mathbf{8.2 \times 10^{24}}$ (8.17) m, AFC.

2 (a)(i)	(nuclear) fusion	B1	**Do not allow** any mis-spelling that creates ambiguity with 'fission'.
11(a)(ii)	$\Delta m = [0.030377 - (3 \times 0.002388)]$ u $= 0.023213$ u $E = \Delta m c^2$ $= 0.023213 \times 1.66 \times 10^{-27} \times (3.00 \times 10^8)^2 = 3.47 \times 10^{-12}$ J	B1 C1 A1	B1 mark does not require the value 0.023213 to be calculated; it is for the working leading to it. Full substitution and answer needed for the A1 mark. The 0.023213 figure can be left in terms of the B1 mark working. **Allow** '3' for '3.00'. **Do not allow** '1.67' for '1.66'.
11(b)(i)	*either*: mass of 1 mol of helium 4 = 4 g *or*: mass of 1 helium atom = 4u *either*: N rate $= (6.02 \times 10^{23} \times 7.34 \times 10^{11}) / (4 \times 10^{-3})$ *or*: N rate $= (7.34 \times 10^{11}) / (4 \times 1.66 \times 10^{-27})$ $= 1.10 \times 10^{38}$ s⁻¹ luminosity $= 1.10 \times 10^{38} \times 3.47 \times 10^{-12}$ $= \mathbf{3.83 \times 10^{26}}$ **W**	C1 C1 A1	 This C1 mark implies the first one as well. This C1 mark is for the working leading to the N rate of 1.10×10^{35}. This value implies both C1 marks. No ECF from **(a)(ii)**. Correct to at least 3 significant figures. AFC. (3.833).
11(b)(ii)	$L = 4\pi\sigma r^2 T^4$ $3.83 \times 10^{26} = 4\pi \times 5.67 \times 10^{-8} \times (6.96 \times 10^8)^2 \times T^4$ T = **5770 K**	 C1 A1	 Possible ECF from **(b)(i)**. Correct to at least 3 significant figures. AFC. (5772).

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3 10(a)(i)	total power of radiation emitted (by the star)	**B1**
10(a)(ii)	standard candle has known luminosity	**B1**
	measure the radiant flux intensity	**B1**
	use $F = L / (4\pi d^2)$ to calculate d	**B1**
10(b)(i)	$v = 2\pi R / T$	**C1**
	$v = 3.00 \times 10^8 \times (656.2877 - 656.2831) / 656.2831$	**C1**
	$R = [3.00 \times 10^8 \times (656.2877 - 656.2831) / 656.2831] \times (2.07 \times 10^6) / 2\pi = 6.93 \times 10^8$ m	**A1**
10(b)(ii)	Z is moving towards Earth	**M1**
	so observed wavelength is less than the emitted wavelength	**A1**
10(b)(iii)	$L = 4\pi\sigma r^2 T^4$ $3.8 \times 10^{26} = 4\pi \times 5.67 \times 10^{-8} \times (6.93 \times 10^8)^2 \times T^4$	**C1**
	T = 5800 K	**A1**

4 a)	• <u>redshift</u> is the increase in observed wavelength / decrease in observed frequency (caused by Doppler effect) • radiation from distant galaxies is observed to be redshifted • redshift provides evidence that galaxies are moving apart • <u>galaxies</u> moving apart means Universe must be expanding *Any three points, 1 mark each*	**B3**
10(b)(i)	$F = L / 4\pi d^2$	**C1**
	$d = \sqrt{(1.90 \times 10^{36} / [4\pi \times 8.42 \times 10^{-16}])}$ $= 1.34 \times 10^{25}$ m	**A1**
10(b)(ii)	$\Delta\lambda / \lambda = v / c$ $(726 - 658) / 658 = v / (3.00 \times 10^8)$	**C1**
	$v = 3.1 \times 10^7$ m s^{-1}	**A1**
10(c)(i)	line with positive gradient passing through the origin	**B1**
	straight line with positive gradient	**B1**
10(c)(ii)	Hubble constant	**B1**

5 (a)(i)	<u>total</u> power	**B1**
	power radiated (by the star)	**B1**
10(a)(ii)	standard candle has known luminosity	**B1**
	radiant flux intensity measured by observer	**B1**
	(distance calculated using) $F = L / 4\pi d^2$	**B1**
10(b)(i)	luminosity $= 4\pi\sigma r^2 T^4$ $= 4\pi \times 5.67 \times 10^{-8} \times (6.96 \times 10^8)^2 \times 5780^4$	**C1**
	$= 3.85 \times 10^{26}$ W	**A1**
10(b)(ii)	$\lambda_{MAX} T$ = constant	**C1**
	temperature $= (5780 \times 501) / 624$ $= 4640$ K	**A1**

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6 a)(i)	movement of star causes change in (observed) frequency **or** movement of star causes redshift	**B1**
	observed frequency is lower (than emitted frequency)	**B1**
8(a)(ii)	all three lines shown to left of corresponding printed lines	**B1**
	distance between drawn line and corresponding printed line approximately the same for all three lines	**B1**
8(b)(i)	$E = hf$ **and** $\lambda = c / f$	**C1**
	$E = (6.63 \times 10^{-34} \times 3.00 \times 10^{8}) / (488 \times 10^{-9})$ $= 4.08 \times 10^{-19}$ J	**A1**
8(b)(ii)	photon energy = $(4.08 \times 10^{-19}) / (1.60 \times 10^{-19})$ = 2.55 eV	**C1**
	energy level = –3.40 + 2.55 = –0.85 eV	**A1**
8(b)(iii)	$\Delta\lambda = \lambda \times (v / c)$ $= (488 \times 6.2 \times 10^{6}) / (3.00 \times 10^{8})$ (= 10 nm)	**C1**
	observed wavelength = 488 + $\Delta\lambda$ = 488 + 10 = 498 nm	**A1**
8(c)	$v = H_0 d$	**C1**
	$d = (6.2 \times 10^{6}) / (2.3 \times 10^{-18})$ $= 2.7 \times 10^{24}$ m	**A1**

7 (a)(i)	$L = 4\pi\sigma r^2 T^4$ $3.85 \times 10^{26} = 4\pi \times 5.67 \times 10^{-8} \times r^2 \times 5780^4$	**C1**
	$r = 6.96 \times 10^{8}$ m	**A1**
10(a)(ii)	$F = L / 4\pi d^2$ $= (3.85 \times 10^{26}) / (4\pi \times (1.50 \times 10^{11})^2)$	**C1**
	$= 1.36 \times 10^{3}$ W m^{-2}	**A1**
10(a)(iii)	line of same shape showing peak intensity at greater wavelength	**B1**
	line of same shape showing lower peak intensity	**B1**
10(b)(i)	5 lines in same pattern shifted to longer wavelengths	**B1**
10(b)(ii)	$\Delta\lambda / \lambda = v / c$ $\Delta\lambda = (21400 / 300000) \times 656$ = 46.8 nm	**C1**
	wavelength = 656 + 46.8 = 703 nm	**A1**
10(b)(iii)	(peak) wavelength too high so temperature too low	**B1**

8 a)	temperature inversely proportional to wavelength	**M1**
	temperature is thermodynamic temperature of surface, and wavelength is the wavelength at which maximum emission rate occurs	**A1**
10(b)(i)	(astronomical) object of known luminosity	**B1**
10(b)(ii)	star / galaxy is moving away from the student	**B1**
10(b)(iii)	one tick placed in correct column in each row: wavelength: too high	**B1**
	surface temperature: too low	**B1**
	distance: unchanged	**B1**
	radius: too high	**B1**

9 (a)	speed is (directly) proportional to distance	**M1**
	speed is speed of recession of galaxy from an observer, and distance is the distance of the galaxy from the observer	**A1**
10(b)	$F = L / (4\pi d^2)$	**C1**
	$= (3.8 \times 10^{31}) / [4\pi \times (1.8 \times 10^{24})^2]$ $= 9.3 \times 10^{-19}$ W m^{-2}	**A1**
10(c)(i)	galaxy is moving away (from the Earth)	**B1**
	wavelength (of light from the galaxy) increased by the Doppler effect / due to redshift	**B1**
10(c)(ii)	$\Delta\lambda / \lambda = v / c$ $v = [(492 - 486) \times 3.00 \times 10^8] / 486$ ($v = 3.7 \times 10^6$ m s^{-1})	**C1**
	$H_0 = v / d$	**C1**
	$= (3.7 \times 10^6) / (1.8 \times 10^{24})$ $= 2.1 \times 10^{-18}$ s^{-1}	**A1**

10 a)	brighter star could be closer (to Earth)	**B1**
	brighter star could have a greater luminosity (in the visible wavelengths)	**B1**
10(b)	object with known luminosity	**B1**
10(c)(i)	$\frac{660.9 - 656.3}{656.3} \approx \frac{v}{3.0 \times 10^8}$ leading to 2.1×10^6 m s^{-1}	**B1**
10(c)(ii)	$v = H_o d$	**C1**
	$d = 2.1 \times 10^6 / 2.3 \times 10^{-18}$ $= 9.1 \times 1023$ m	**A1**
10(c)(iii)	wavelength has increased / light is redshifted	**B1**
	star within galaxy is moving away / receding (from Earth)	**B1**
	Universe is expanding	**B1**

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11 (a)	total power of radiation emitted (by the star)	**B1**
9(b)(i)	$F = L / (4\pi d^2)$	**C1**
	$= 9.86 \times 10^{27} / [4\pi \times (8.14 \times 10^{16})^2]$ $= 1.18 \times 10^{-7}$ W m^{-2}	**A1**
9(b)(ii)	$L = 4\pi\sigma r^2 T^4$ $9.86 \times 10^{27} = 4 \times \pi \times 5.67 \times 10^{-8} \times r^2 \times 9830^4$	**C1**
	radius = 1.22×10^9 m	**A1**
9(c)	wavelength of peak intensity determined (from spectrum of star)	**B1**
	wavelength of peak intensity from object of known temperature determined	**B1**
	Wien's displacement law used **or** wavelength of peak intensity inversely proportional to temperature	**B1**

12 (a)(i)	• energy of photon has a corresponding frequency • change in electron energy level emits a single photon • photon energy = difference in energy levels • discrete frequencies must have come from discrete energy gaps • discrete energy changes imply discrete energy levels *Any three points, 1 mark each*	**B3**
9(a)(ii)	transition (to – 3.400 eV) from X corresponds to 658 nm line	**C1**
	$E_1 - E_2 = hc / \lambda$	**C1**
	$E_1 - (-3.400) = (6.63 \times 10^{-34} \times 3.00 \times 10^8) / (658 \times 10^{-9} \times 1.60 \times 10^{-19})$ and so $E_1 = -1.51$ eV (*full substitution and answer needed*)	**A1**
9(b)(i)	redshift	**B1**
9(b)(ii)	moving away (from observer)	**B1**
9(b)(iii)	$\Delta\lambda / \lambda = v / c$ e.g. for 658 nm line: $\Delta\lambda = 686 - 658$ (= 28 nm) (*other lines may be used*)	**C1**
	$28 / 658 = v / (3.00 \times 10^8)$ (*other lines may be used*)	**C1**
	$v = 1.3 \times 10^7$ m s^{-1}	**A1**
9(c)	$v = H_0 d$	**C1**
	$H_0 = (1.3 \times 10^7) / (5.7 \times 10^{24})$ $= 2.3 \times 10^{-18}$ s^{-1}	**A1**

13 (a)	wavelength of maximum intensity is inversely proportional to (thermodynamic) temperature	**B1**
10(b)(i)	$\lambda_{MAX} = 0.50$ µm for A **and** 0.65 µm for B	**C1**
	$T = 5800 \times (0.50 / 0.65)$ $= 4500$ K	**A1**
10(b)(ii)	(star B has) greater peak / average wavelength	**B1**
	(star B looks) redder	**B1**
10(c)(i)	apparent wavelength is greater **or** wavelength is greater than known value	**B1**
	(due to) movement of star away (from observer)	**B1**
10(c)(ii)	by examining the (lines in the) spectrum (of light from the star)	**B1**
	and comparing with known spectrum	**B1**

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14 (a)(i)	speed is (directly) proportional to distance	M1
	where speed is speed of recession of galaxy (from observer) and distance is distance of galaxy away from observer	A1
9(a)(ii)	wavelengths (of spectral lines) are greater (than their known values)	B1
	redshift shows stars (in distant galaxies) moving away from Earth	B1
9(b)	(all) parts of Universe moving away from each other	B1
	more distant objects are moving away faster	B1
	matter must have been close together / very dense in the past	B1

15 (a)	total power of radiation emitted (by the star)	B1
12(b)	$F = \frac{L}{4\pi d^2}$ $= \frac{3.83\times10^{26}}{4\times\pi\times1.51\times10^{112}}$	C1
	$= 1340\ \text{W m}^{-2}$	A1
12(c)	$m = \frac{E}{c^2}$ $= \frac{3.83\times10^{26}}{3.00\times10^{82}}$ $= 4.26\times10^{9}$ kg	A1
12(d)	$L = 4\pi\sigma r^2 T^4$ $3.83\times10^{26} = 4\times\pi\times5.67\times10^{-8}\times6.96\times10^{82}\times T^4$ leading to T = 5770 K	B1
12(e)	$\lambda_{(max)} \propto \frac{1}{T}$ $\frac{5.00\times10^{-7}}{\lambda} = \frac{9940}{5770}$	C1
	$\lambda = 2.90\times 10^{-7}$m	A1

16 (a)(i)	standard candle	B1
12(a)(ii)	$F = L / 4\pi d^2$	C1
	$2.6 \times 10^{-9} = 4.8 \times 10^{29} / 4\pi d^2$ distance = 3.8×10^{18} m	A1
12(b)(i)	(Wien's displacement law states) $\lambda_{max} \propto 1 / T$	B1
	so $T = (5800 \times 500) / 430 = 6700$ K (6740 K)	A1
12(b)(ii)	$L = 4\pi\sigma r^2 T^4$ $4.8 \times 10^{29} = 4\pi \times 5.67 \times 10^{-8} \times 6700^4 \times r^2$	C1
	radius = 1.8×10^{10} m	A1

17 (a)	standard candle	1
7(b)(i)	increase in observed wavelength	1
7(b)(ii)	star is moving away from Earth	1
7(c)	the red shift observed / the speed of recession is greater for galaxies that are further away **or** speed is proportional to distance	1
	This implies that, at some point in the past, all galaxies were initially at the same point	1

18 (a)	speed of galaxies is directly proportional to their distance from Earth	1
7(b)	measure/observe wavelengths of spectral lines/light	1
	velocity can be determined from the shift in wavelength or $v \propto \Delta\lambda/\lambda$	1
7(c)(i)	**either** the observed light has an increased wavelength **or** the light observed is redshifted	1
	this tells us that galaxies are moving away from Earth	1
7(c)(ii)	galaxies all moving away from a point implies that they all originated from that point	1
	(since speed $\propto$ distance) all galaxies have been travelling for same time so were at that single point at the same moment in time	1

19 7(a)(i)	wavelength at peak × temperature = 2.90×10^{-3}		1
	temperature (= $2.90 \times 10^{-3} / 582 \times 10^{-9}$) = 5000 (K)		1
7(a)(ii)	(surface area of sphere of radius 3.80×10^{17}) = $4\pi \times (3.80 \times 10^{17})^2$ OR 1.81×10^{36}		1
	L = 2.38×10^{-8} × their surface area ($4\pi r^2$) OR 4.32×10^{28} (W)		1
	$r^2 = L/4\pi\sigma T^4$ OR r^2 = their $L / 4\pi \times 5.67 \times 10^{-8} \times 4983^4$		1
	$r = 9.9 \times 10^9$ [m]		1
7(b)	use of a diffraction grating	use of a double slit	1
	measurement of angle of deflection θ	measurement of angle of deflection θ or fringe separation	1
	$n\lambda = d \sin\theta$	$n\lambda = d \sin\theta$ or $\lambda = ax / D$	1
	plus any two from: • suitable source e.g. sodium lamp OR bright source of monochromatic light • diagram / description for arrangement of set up (must include source, grating, and screen) • method for measuring angle e.g. use of a spectrometer or protractor • method for improving accuracy of result	plus any two from: • suitable source e.g. sodium lamp OR bright source of monochromatic light • diagram / description for arrangement of set up (must include source, grating, and screen) • method for measuring angle e.g. use of a spectrometer or protractor • method for improving accuracy of result	2

20 **(a)** rising from zero at 0 to a peak then falling away [1] [1]

(b) **(i)** $\lambda_{max} T = 520 \times 5800 = 210 \times T$ so $T = 14400$ (K) [1] [1]

(ii) luminosity = area × s × $T^4 = 6.3 \times 10^{17} \times 5.67 \times 10^{-8} \times 14400^4$ [1]
= 1.5×10^{27} (W) with estimate only to 1, 2 or 3 significant figures [1] [2]

(iii) $1.5359 \times 10^{27}/4\pi R^2 = 1.6 \times 10^{-9}$ W m^{-2} [1]
$R = \sqrt{(1.5359 \times 10^{27}/4\pi \times 1.6 \times 10^{-9})} = 2.75 \times 10^{17}$ (m) [1] [2]

[6]

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