

OCR A-LEVEL PHYSICS A • H556

PHYSICS



EXAM QUESTION PACK

5.5 ASTROPHYSICS AND COSMOLOGY

SCORE

/225

PERCENTAGE

%

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- 1 Betelgeuse is a star in the constellation of Orion which astronomers think could undergo a supernova explosion.

What could Betelgeuse evolve into following the supernova stage?

- A main sequence star
- B neutron star
- C planetary nebulae
- D red giant star

Your answer

[1]

- 2 Stars emit electromagnetic radiation. A graph of intensity against wavelength λ for a main sequence star is shown.



Which statement is correct as the main sequence star evolves into a red giant?

- A the peak wavelength does not change
- B the peak wavelength moves towards the origin
- C the peak wavelength moves to the left
- D the peak wavelength moves to the right

Your answer

[1]

- 3 When the light from a star is passed through a diffraction grating it forms a spectrum.

Which of the following statements is / are correct?

- 1 Light emitted from the surface of a star would form a continuous spectrum.
- 2 Light received from the Sun has dark lines across its spectrum which correspond to the absorption of certain wavelengths by atoms in the Earth's atmosphere.
- 3 A photon in an emission spectrum occurs when an electron moves from a low to a higher energy level within an atom.

- A 1, 2 and 3
B Only 1 and 2
C Only 2 and 3
D Only 1

Your answer

☐

[1]

- 4 A star has surface temperature $3000\text{ }^{\circ}\text{C}$ and luminosity L . Another star of identical size has a surface temperature of $2500\text{ }^{\circ}\text{C}$.

What is the luminosity of this second star in terms of L ?

- A $0.48L$
B $0.52L$
C $0.83L$
D $0.85L$

Your answer

☐

[1]

5(a) State and explain how *stellar parallax* is used to measure distances in space.

[3]

(b) Fig. 23.1 gives some data on the wavelength of a hydrogen spectral line for light received from the Andromeda galaxy and the Virgo cluster of galaxies.

	wavelength of hydrogen line from galaxy / nm	wavelength of hydrogen line on Earth / nm
Andromeda galaxy	485.6	486.1
Virgo cluster	489.8	486.1

Fig. 23.1

(i) The Virgo cluster is 16.5 Mpc from the Earth.

Estimate the age of the Universe using data from Fig. 23.1.

age = _____ s [3]

(ii) Suggest why hydrogen spectral lines might often be used to measure a star's velocity.

[2]

Explain how the cosmic microwave background radiation supports the Big Bang theory for the start of the Universe. Comment on the relevance of the data in **Fig. 23.1** concerning the Big Bang theory.

[6]

6 A hot metal emits a black-body spectrum. The luminosity of the metal at 800°C is L .

A 1.2L
B 1.3L
C 2.0L
D 2.4L

11

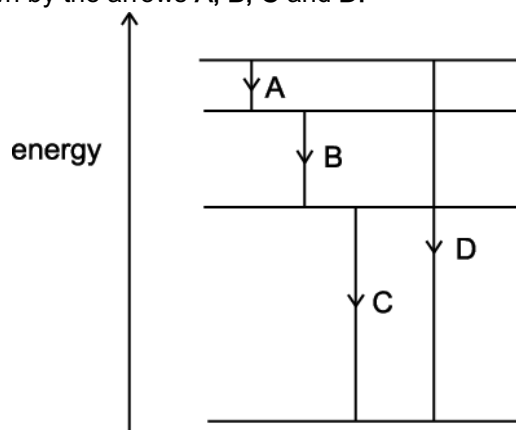
[1]

- 7 Which is the most likely evolution of a star which is 10 times more massive than our Sun?
- | | | | | | | |
|--|---|----------------|---|----------------|---|--------------|
| A. ☐ main sequence star | → | red supergiant | → | white dwarf | → | black dwarf |
| B. main sequence star | → | supernova | → | red supergiant | → | neutron star |
| C. main sequence star | → | red supergiant | → | supernova | → | neutron star |
| D. main sequence star | → | red giant | → | neutron star | → | black hole |

Your answer

[1]

- 8 The four energy levels of an atom are shown below.
Four electron transitions are shown by the arrows A, B, C and D.



Which electron transition will give the longest wavelength of electromagnetic radiation?

Your answer

[1]

- 9 Which of the following is the greatest astronomical distance?

- A 1.0 pc
- B 2.0 ly
- C 3.0×10^5 AU
- D 4.0×10^{13} km

Your answer

[1]

10 Fig. 22 shows the elliptical orbit of a planet around the Sun.

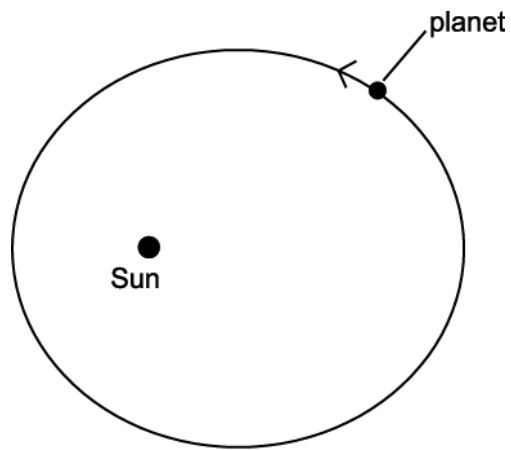


Fig. 22

Draw the gravitational force acting on the planet at the position shown in Fig. 22.

[1]

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

[1]

- (b) Hubble's law can be used to estimate the age of the universe. Fig. 23 shows some of Hubble's early measurements of nearby galaxies plotted on a v against d graph, where v is the recessional speed of a galaxy and d is its distance from us.

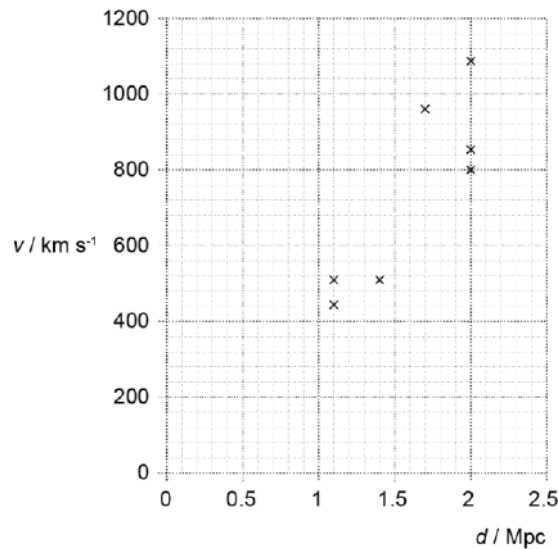


Fig. 23

- (i) State how v was determined.

[1]

- (ii) Use Fig. 23 to estimate a value for the Hubble constant H_0 in $\text{km s}^{-1} \text{Mpc}^{-1}$.

$$H_0 = \text{-----} \text{ km s}^{-1} \text{Mpc}^{-1} \quad [3]$$

- (iii) Use your answer to part (ii) to estimate Hubble's initial value for the age of the universe in years.

age = _____ years [3]

- (c) Hubble's law can be used to estimate the age of the universe. Fig. 23 shows some of Hubble's early measurements of nearby galaxies plotted on a v against d graph, where v is the recessional speed of a galaxy and d is its distance from us. Measurements of more distant galaxies taken over the last 85 years have refined the value of H_0 to be $68 \text{ km s}^{-1} \text{ Mpc}^{-1}$.

- (i) Suggest why measurements for our nearest galaxies can deviate from the current Hubble's law trend line.

----- [1]

- (ii) Suggest why measurements for galaxies at the largest distances deviate from the Hubble's law trend line.

----- [1]

- 12 A light source for an experiment is a discharge lamp containing excited atoms which emit light at several wavelengths. Fig. 8.1 shows the three lowest energy levels of one of these atoms, labelled $n = 1, 2$ and 3 .

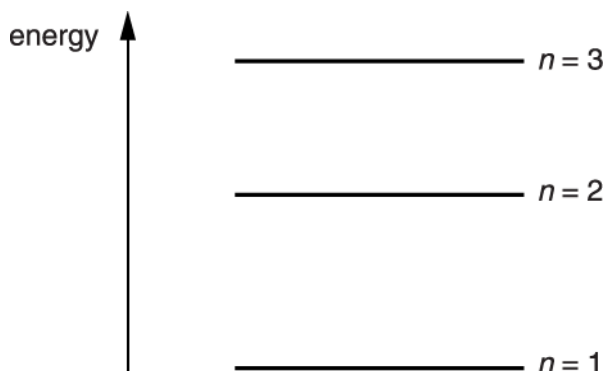


Fig. 8.1

Electron transitions between these energy levels can produce three different wavelengths of radiation. The transition between $n = 2$ and $n = 1$ causes the 440 nm photons.

- (i) Photons at 590 nm are also emitted. Which transition causes these photons?

----- [1]

- (ii) Hence calculate the wavelength of the photons emitted by the third transition.

wavelength = ----- m [3]

13 X-rays are produced in an X-ray tube when fast moving electrons hit a metal target.

Fig. 7.1 shows a typical graph of intensity I against wavelength λ of X-rays emitted by an X-ray tube.

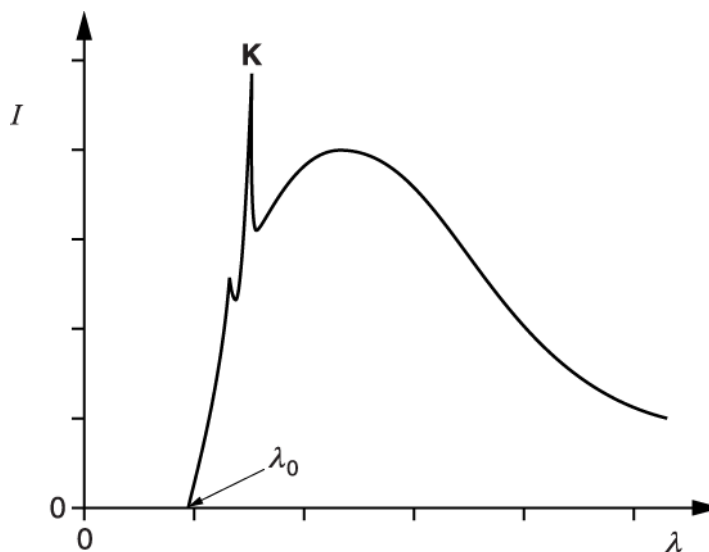


Fig. 7.1

High-speed electrons colliding with the atoms in the target metal can remove electrons from these atoms. The removal of such electrons creates 'gaps' in the lower energy levels of these atoms. These gaps are quickly filled by electrons in the higher energy levels making transitions to these lower energy levels. The electrons lose energy which is released as photons with particular wavelengths. These emission spectral lines are shown by the high intensity peaks such as **K** shown in Fig. 7.1.

Fig. 7.2 shows three of the energy levels, **A**, **B** and **C**, for the metal atoms of the target. The electron transition shown produces the peak **K**.

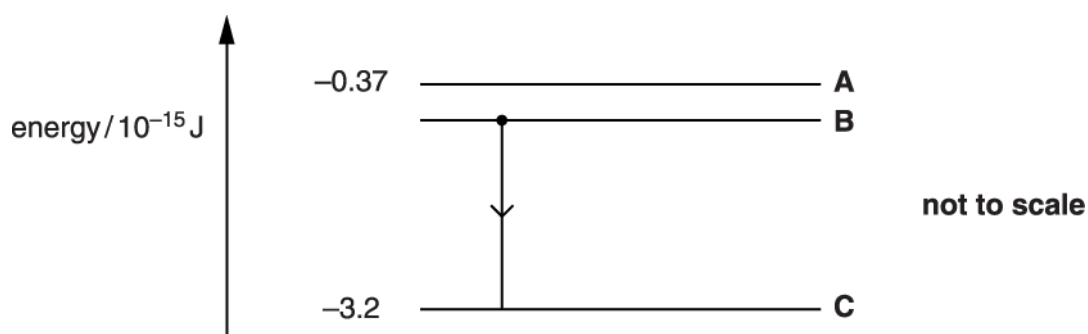


Fig. 7.2

(i) Explain what is meant by an *energy level* of an atom.

----- [1]

(ii) The peak K occurs at a wavelength of 7.2×10^{-11} m. Calculate the value of the energy level B.

value of energy level = ----- J [3]

(iii) In Fig. 7.1, the shortest wavelength λ_0 produced from an X-ray tube depends on the accelerating potential difference V . The maximum kinetic energy of a single accelerated electron is equal to the energy of a single X-ray photon of wavelength λ_0 . Explain how λ_0 from the X-ray tube changes when the accelerating potential difference of the X-ray tube is **doubled**.

----- [2]

14(a) Sirius A and B are binary stars in our galaxy at a distance of 8.6 ly from the Sun. Sirius B is a white dwarf of diameter 12 km and mass 2.0×10^{30} kg.

Calculate the parallax angle in arc seconds for Sirius B.

$$1 \text{ pc} = 3.1 \times 10^{16} \text{ m}$$

parallax angle = _____ arc seconds [2]

- (b) Sirius A is moving towards the Earth at a relative velocity of 7600 ms^{-1} . Calculate the percentage change in the wavelength of a spectral line observed from this star compared with an identical spectral line observed in the laboratory.

percentage change = _____ % [2]

- (c) A student suggests that the distance of Sirius A can be calculated using Hubble's law and the speed given in the previous part. Discuss whether this suggestion is correct or incorrect.

----- [1]

15(a) State the *cosmological principle*.

----- [2]

(b) State some of the properties of the microwave background radiation observed from the Earth. Discuss how the background microwave radiation is linked to the big bang model of the universe.

----- [3]

(c) Calculate the age of our universe in years based on a critical density of the universe of $9.7 \times 10^{-27} \text{ kgm}^{-3}$.

age = ----- y [3]

16(a) Explain what is meant by a *white dwarf* when describing the evolution of a star.

----- [1]

- (b) Antares is a red giant and one of the brightest stars in the night sky. The parallax angle for this star is 0.0059 arc seconds.

Calculate its distance in light years from us.

1 pc = 3.26 ly

distance = ----- ly [2]

- (c)

Sirius-B is a white dwarf. In comparison with Sirius-B, Antares has 12 times greater mass and has 1.1×10^5 times greater radius. The surface temperatures of Sirius-B and Antares are 25000 K and 4300 K respectively.

The intensity I of electromagnetic radiation emitted from the surface of a star is related to its temperature T in kelvin as follows:

$$I \propto T^4.$$

- (i) Explain what is meant by *intensity*.

----- [1]

- (ii) Calculate the ratio

1

$$\frac{\text{mean density of Antares}}{\text{mean density of Sirius-B}}$$

ratio = ... [2]

2

$$\frac{\text{total power emitted from Antares}}{\text{total power emitted from Sirius-B}}$$

ratio = ... [3]

17(a) State Hubble's law.

[1]

(b) The redshift of a specific spectral line in the spectrum of a galaxy can be used to determine its recession velocity v . The fractional change z in the wavelength of a spectral line is given by the equation

$$z = \frac{v}{c}$$

where c is the speed of light in a vacuum.

The table of Fig. 11.1 shows data for some of our closest galaxies. The distance of the galaxy from the Earth is d .

Galaxy	$z / 10^{-3}$	$v / 10^3 \text{ ms}^{-1}$	$d / 10^{23} \text{ m}$
A	1.12	336	1.50
B	1.61	483	2.14
C	1.85	555	2.46
D	2.26	678	3.00
Messier 109	3.38		

Fig. 11.1

(i) Complete the table by determining v and d for the galaxy Messier 109.

[2]

(ii) Fig. 11.2 shows the data for the first four galaxies plotted on a v against d graph.

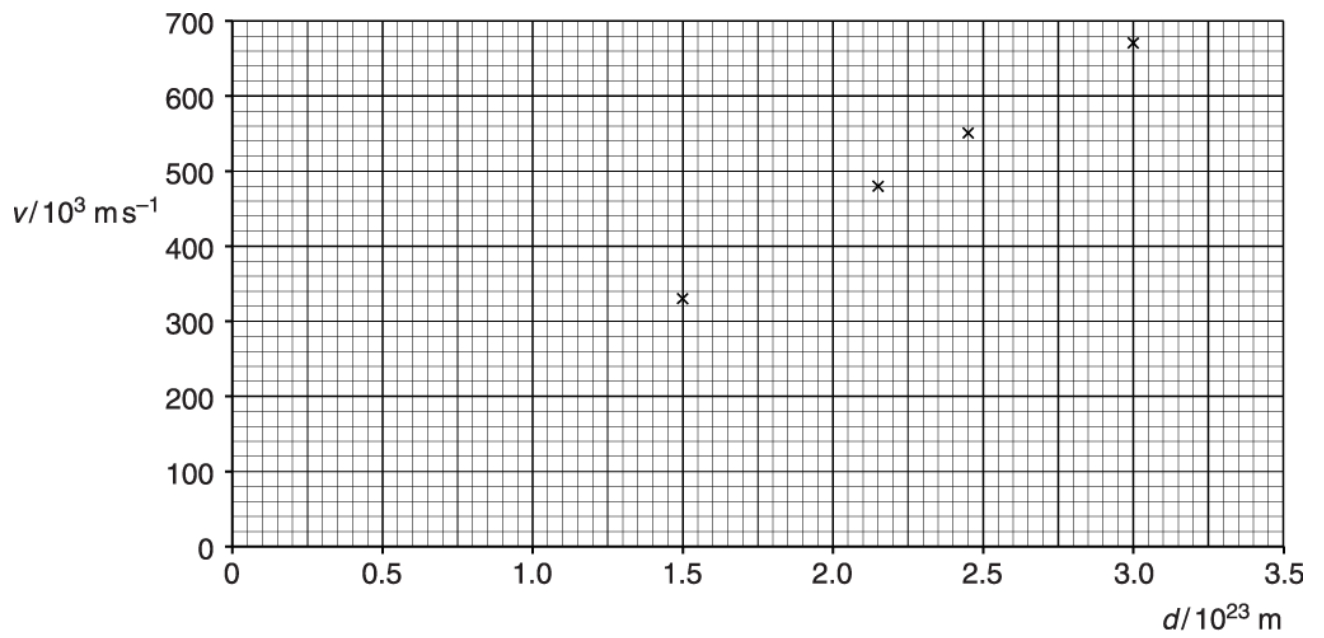


Fig. 11.2

Use Fig. 11.2 to determine the age of the Universe in years.

$$1 \text{ y} = 3.16 \times 10^7 \text{ s}$$

age = _____ years [3]

- (c) One piece of observational evidence for the big bang is that galaxies are receding from each other.
Explain what is meant by the big bang and suggest **two** other observations that support the big bang model of the Universe.

[3]

- 18(a) An astronomer uses a spectrometer and diffraction grating to view a hydrogen emission spectrum from a star.
The light is incident normally on the grating.

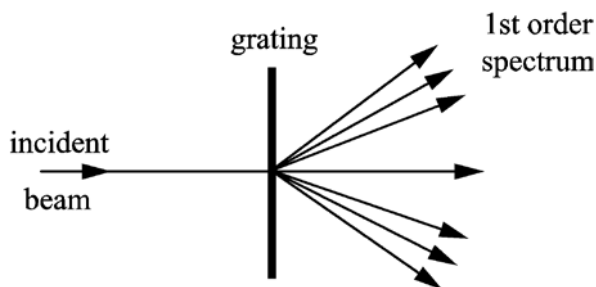


Fig. 6.1

First order diffraction maxima are observed at angles of 12.5° , 14.0° and 19.0° to the direction of the incident light as shown in Fig. 6.1.

Two of the wavelengths are $4.33 \times 10^{-7} \text{ m}$ and $4.84 \times 10^{-7} \text{ m}$.

Calculate the wavelength of the third line.

wavelength = _____ m [2]

- (b) In order to increase the accuracy of the values for wavelength, the student decides to look for higher order diffraction maxima.

- (i) State how this increases the accuracy.

_____ [1]

- (ii) Calculate how many orders n can be observed for the shorter wavelength given in (a).

$n =$ _____ [2]

- (c) These three emission lines all arise from transitions to the same final energy level. The part of the energy level diagram of hydrogen relevant to these transitions is shown in Fig. 6.2.

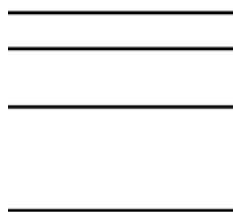


Fig. 6.2

- (i) Draw lines between the energy levels to indicate the transitions which cause the three emission lines and label them with their wavelengths.

[1]

- (ii) There are other possible transitions between the energy levels shown in Fig. 6.2. The least energetic of these produces photons of 4.8×10^{-20} J.

Calculate the wavelength of these photons.

State in which region of the electromagnetic spectrum this wavelength is found.

wavelength _____ m

region: _____

[3]

19(a) Fig. 11.1 shows a diagram of Andromeda, our nearest galaxy.



Fig. 11.1

Andromeda is 2.4×10^{22} m from the Earth. It has a diameter of 1.3×10^{20} m.

Calculate the maximum angle in degrees subtended by Andromeda at the Earth.

angle = _____ ° [1]

- (b) All the stars in Andromeda rotate about its centre. Some stars in Andromeda are moving towards us and some are moving away from us. The outermost stars in Andromeda have a rotational speed of $2.5 \times 10^5 \text{ m s}^{-1}$. The wavelength of the hydrogen-alpha spectral line in the laboratory is 656.3 nm. The wavelength of this spectral line from the outermost stars is Doppler shifted when observed from the Earth. Calculate the change in wavelength of this spectral line due to this rotation.

change in wavelength = _____ nm [2]

- (c) The circular motion of the outermost stars is due to the gravitational attraction of all the stars in Andromeda. Assume that the mass of Andromeda providing the gravitational force on these outermost stars is all at the centre of this galaxy. The average mass of a star is $2.0 \times 10^{30} \text{ kg}$. Estimate the total number of stars in Andromeda.

number of stars = _____ [4]



[5]

[1]

(c) Some cosmologists have estimated the critical density of the Universe to be equivalent to about 8 protons per cubic metre.

(i) Calculate the Hubble constant H_0 in s^{-1} .

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

(ii) Estimate the age of the Universe in years.

$$1 \text{ y} = 3.2 \times 10^7 \text{ s}$$

$$\text{age} = \text{-----} \text{ y [2]}$$

21(a) The Big Bang theory explains the origin and the evolution of the early Universe.
The table below shows the distance d and recession velocity v of some galaxies close to our own galaxy.

Galaxy	d / Mpc	$v / \text{km s}^{-1}$
NGC-5357	0.45	200
NGC-3627	0.90	650
NGC-4151	1.7	960
NGC-4472	2.0	850

*Discuss the evidence for the Big Bang theory of the Universe. Use data in the table and your knowledge of electromagnetic radiation in your answer.

$1 \text{ pc} = 3.1 \times 10^{16} \text{ m}$

[6]

- (b) The chemical composition of the stars in our galaxy can be determined by analysing in the laboratory the absorption spectral lines for these stars.
The closest star to us is the Sun. The wavelength of the hydrogen-beta spectral line from the Sun is 486 nm.

- (i) Use the information from the table to calculate the **observed** wavelength λ of the hydrogen-beta spectral line from a star in the galaxy NGC-4151.

$\lambda =$ _____ nm [3]

- (ii) A diffraction grating with 800 lines per mm is used to observe and analyse the light from the Sun in the laboratory.

A narrow beam of light from the Sun is incident normally at the diffraction grating.

Calculate the angle θ between the central beam of light through the grating and the hydrogen-beta spectral line in the **second** order spectrum.

$\theta =$ _____ ° [2]

(c) Other than matter, state what else may be present in the Universe that may affect its density.

-----[1]

22(a) A group of students have gathered data on four stars from the Internet. The information is shown in the table below.

Star	T / K	$\lambda_{\text{max}} / \mu\text{m}$
Antares	3.1×10^3	9.4×10^{-1}
Zeta	3.0×10^4	9.7×10^{-2}
Vega	9.3×10^3	3.1×10^{-1}
OTS-44	2.3×10^3	1.3×10^0

The surface temperature of the star in kelvin is T and λ_{max} is the wavelength of the emitted electromagnetic radiation at which the intensity is maximum.

Analyse and evaluate this data to show whether or not Wien's displacement law is obeyed.

[2]

- (b) A sensor of cross-sectional area $4.0 \times 10^{-4} \text{ m}^2$ mounted on a satellite orbiting the Earth is used to gather the electromagnetic radiation from the star Antares.

Antares is 550 light years from the Earth. The radiant power entering the sensor from Antares is $2.6 \times 10^{-11} \text{ W}$.

- (i) Calculate the luminosity L of Antares.

$L = \text{-----} \text{ W}$ [3]

- (ii) Use your answer in (i) and the data in the table to calculate the radius r of Antares.

$$r = \text{-----} \text{ m [2]}$$

(iii) The mean density of Antares is $4.4 \times 10^{-5} \text{ kg m}^{-3}$.

Calculate the gravitational field strength g at the surface of Antares.

$$g = \text{-----} \text{ N kg}^{-1} \text{ [2]}$$

23 This question is about the brightest wavelength (590 nm) of light from a sodium lamp.

Analysis of the light from the sodium lamp using a diffraction grating shows that there are photons of two different energies at wavelengths 589.0 nm and 589.6 nm.

(i) Calculate the energy difference ΔE between these two photons.

$\Delta E =$ _____ J [3]

(ii) The light at these wavelengths can be seen as two separate lines when viewed through a diffraction grating. In order to be distinguishable from each other, the angular separation between the lines must be at least 0.02° .

Show that the lines will appear separated in the **second order** spectrum when the sodium lamp is viewed through a grating with 300 lines per millimetre.

[3]

24 The intensity against wavelength graph of an object at 750°C peaks at a wavelength of λ . The temperature of the object is raised to 960°C .

What is the wavelength now at the new peak intensity in terms of λ ?

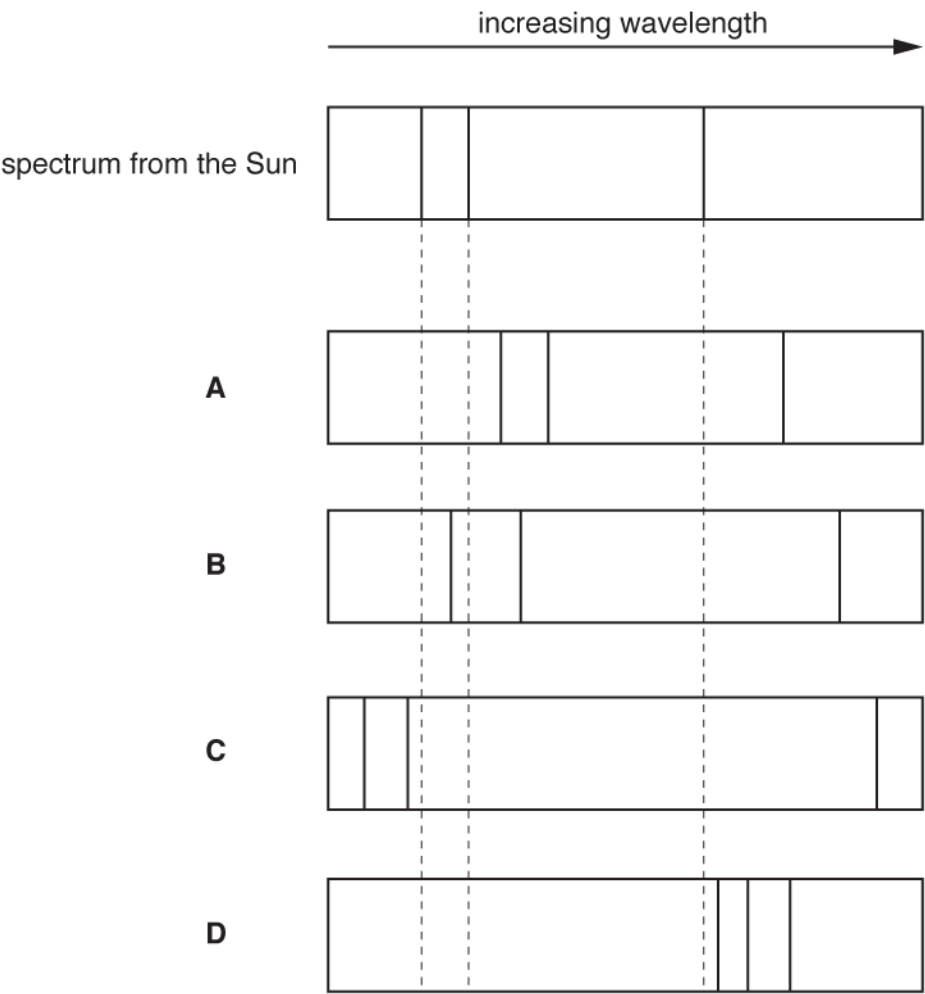
- A 0.78λ
- B 0.83λ
- C 1.2λ
- D 1.3λ

Your answer

[1]

25 Part of the line spectrum for light from the Sun is shown below.

Which spectrum best shows light from a similar star to the Sun?



Your answer

[1]

26 Which two quantities are related in Hubble's law?

- A Distance and mass of galaxies.
- B Velocity and intensity of galaxies.
- C Distance and velocity of galaxies.
- D Distance and red shift of stars in our galaxy.

Your answer

[1]

27(a)

Fig. 21.1 shows some of the energy levels of electrons in hydrogen gas atoms.
The energy levels are labelled A, B, C and D.

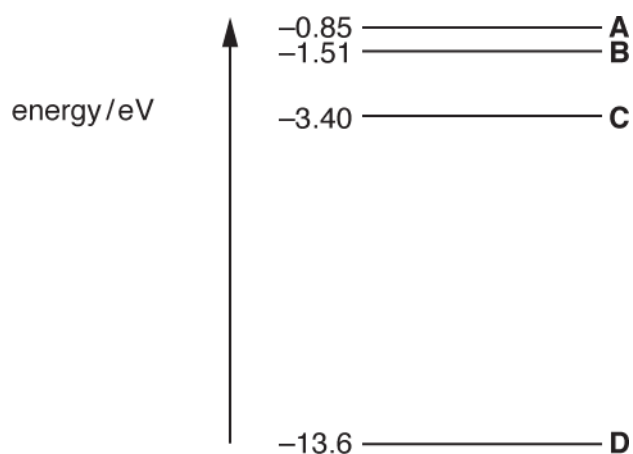


Fig. 21.1 (not to scale)

(i) Explain why the energy levels are negative.

----- [1]

(ii) An electron makes a transition (jump) from level C to level A.

1 Calculate the energy gained by this electron.

energy = ----- eV [1]

1 Calculate the wavelength in nm of the photon absorbed by this electron.

wavelength = _____ nm [3]

- (b) Light from a distant galaxy is passed through a diffraction grating. Fig. 21.2 shows the part of the spectrum of light that shows a strong hydrogen-alpha emission line.

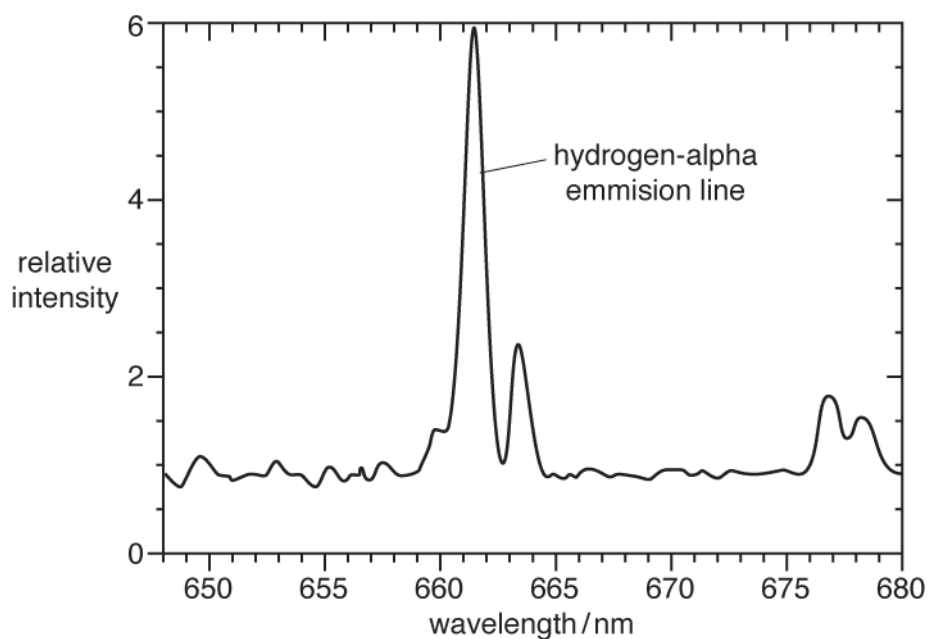


Fig. 21.2

- (i) State how an emission line is produced.

[1]

- (ii) State an adjustment that could be made to the experimental arrangement that would space the emission lines more widely.

----- [1]

- (iii) In the laboratory, the wavelength of the hydrogen-alpha emission line is 656.3 nm. Use Fig. 21.2 to determine the recession velocity of the galaxy.

recession velocity = _____ m s^{-1} [3]

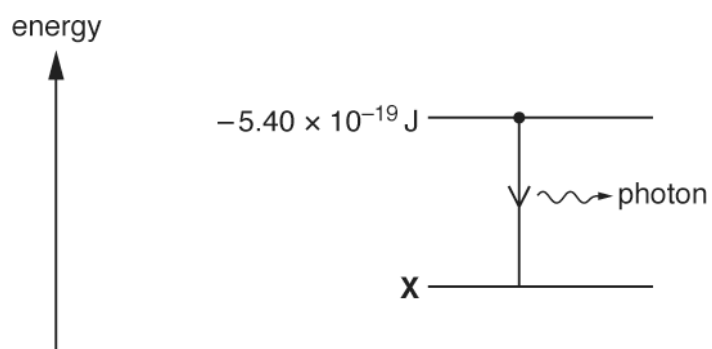
- (iv) Suggest why hydrogen spectral lines play an important role in determining red shift of galaxies.

----- [1]

- Describe and explain how the equivalent spectrum might appear.

[3]

28 An electron makes a transition between the two energy levels shown below.



This transition produces a photon of frequency $4.10 \times 10^{14} \text{ Hz}$.

What is the value of the energy level X?

- A $-2.68 \times 10^{-19} \text{ J}$
- B $-2.72 \times 10^{-19} \text{ J}$
- C $-5.40 \times 10^{-19} \text{ J}$
- D $-8.12 \times 10^{-19} \text{ J}$

Your answer

[1]

29(a) Fig. 19 is an incomplete Hertzsprung–Russell (HR) diagram of stars in our galaxy.

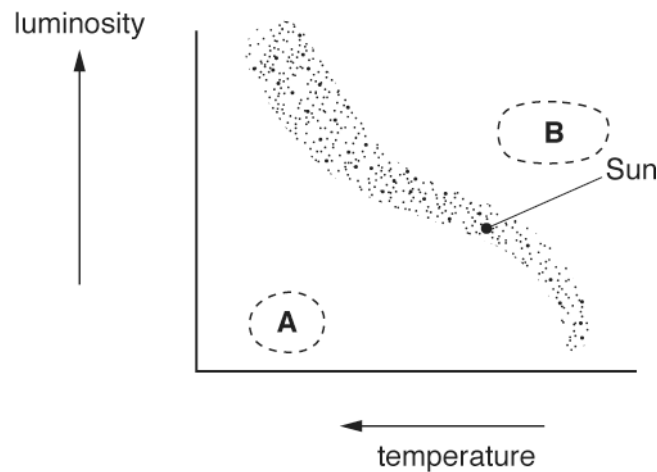


Fig. 19

The position of the Sun on the HR diagram is shown in Fig. 19.

State the type of stars found in regions A and B.

A ----- B ----- [1]

(b) The Sun is a main sequence star. Its surface temperature is 5800 K. The wavelength of the emitted light at maximum intensity is 550 nm.

Beta Pictoris is also a main sequence star. The wavelength of the emitted light at maximum intensity from this star is 370 nm.

(i) Calculate the surface temperature of Beta Pictoris.

temperature = ----- K [2]

(ii) On Fig. 19, mark the likely position of Beta Pictoris with a letter P. [1]

30(a)

According to the Cosmological principle, the Universe is isotropic, homogeneous and the laws of physics are universal.

State what is meant by the term *homogeneous*.

----- [1]

- (b) Astronomers often use absorption spectral lines to determine the relative velocity of distant galaxies. The wavelength of a specific absorption spectral line observed in the laboratory is 280 nm.

The galaxy RXJ1242-11 is 200 Mpc away from the Earth and it has a massive black hole at its centre.

- (i) Calculate in nm the wavelength λ of the same spectral line from RXJ1242-11 when **observed** from the Earth. Assume the Hubble constant is $68 \text{ km s}^{-1} \text{ Mpc}^{-1}$.

$\lambda =$ ----- nm [3]

- (ii) State one of the characteristics of a black hole.

----- [1]

Describe the evolution of the Universe up to the formation of the first nuclei.

[4]

31(a) A group of students are conducting an experiment to determine the wavelength of monochromatic light from a laser.

Fig. 24.1 shows the laser beam incident normally at a diffraction grating.

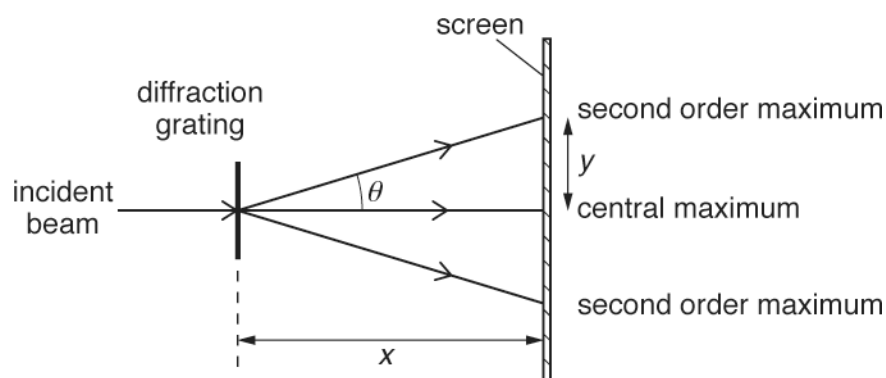


Fig. 24.1

The students use a diffraction grating with $600 \text{ lines mm}^{-1}$. They vary the distance x between the grating and the screen from 1.000 m to 2.000 m. They measure the distance y from the *central* maximum to the *second order* maximum.

The students decide to plot a graph of y against $\sqrt{x^2 + y^2}$.

Show that the gradient of the graph is equal to $\sin \theta$, where θ is the angle between the central maximum and the *second order* maximum.

[1]

(b) Fig. 24.2 shows the graph plotted by the students.

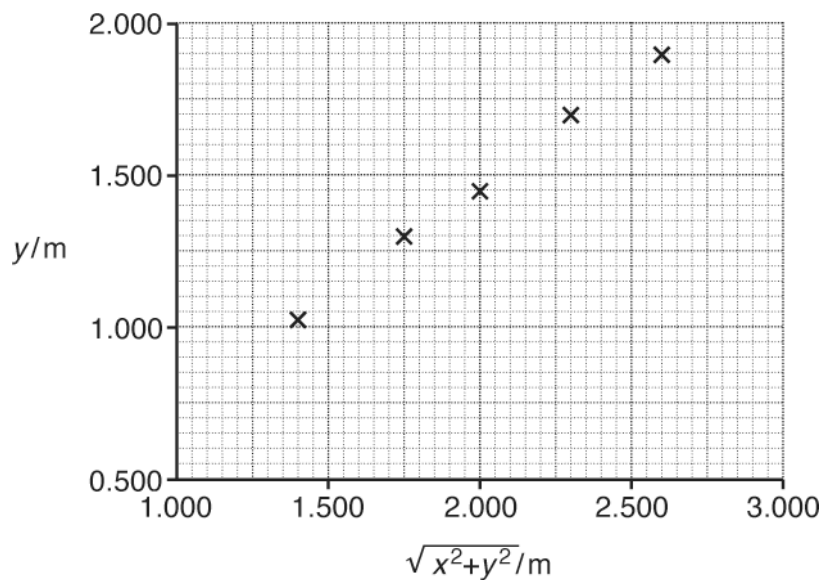


Fig. 24.2

(i) Use Fig. 24.2 to determine an accurate value of the wavelength λ of the light from the laser.

$\lambda =$ _____ m [2]

(ii) Suggest why there are no error bars shown in Fig. 24.2.

 _____ [1]

(iii) Suggest how the precision of this experiment may be affected by using a protractor to measure the angle θ .

32(a) Hydrogen atoms excited in a discharge tube only emit four different discrete wavelengths of visible photons.

*In a semi-darkened room, a single slit is placed in front of the discharge tube. A student holds a diffraction grating which has 300 lines per millimetre.

The student looks through the grating at a 15 cm plastic ruler placed 0.50 m away, as shown in Fig. 5.1.

The paths of the different colours of light from the slit to the student's eye are shown in Fig. 5.2.

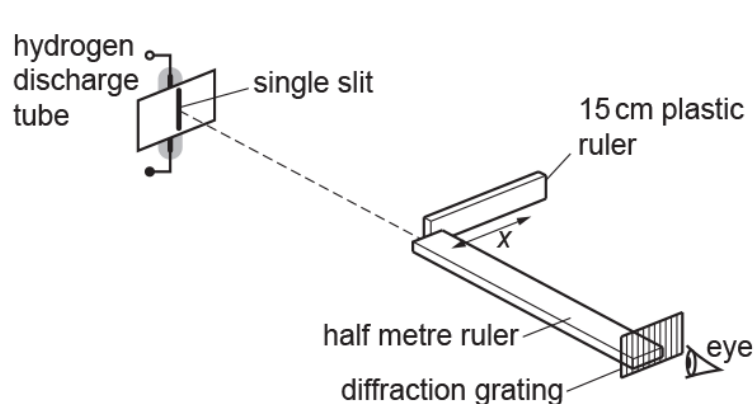


Fig. 5.1 (not to scale)

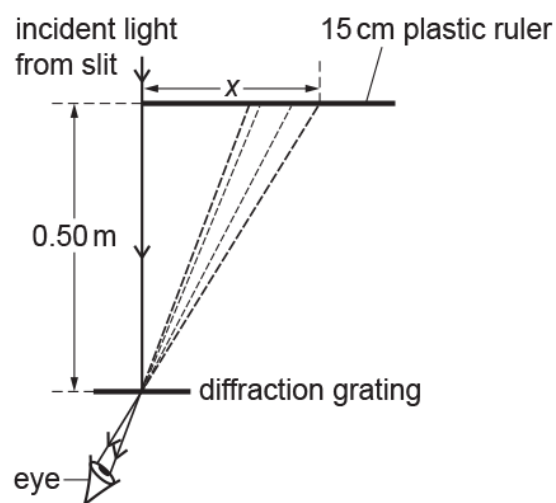


Fig. 5.2 (not to scale)

Four **first** order images of the slit, one at each photon wavelength, are observed as vertical lines against the background of the plastic ruler, as shown in Fig. 5.3.

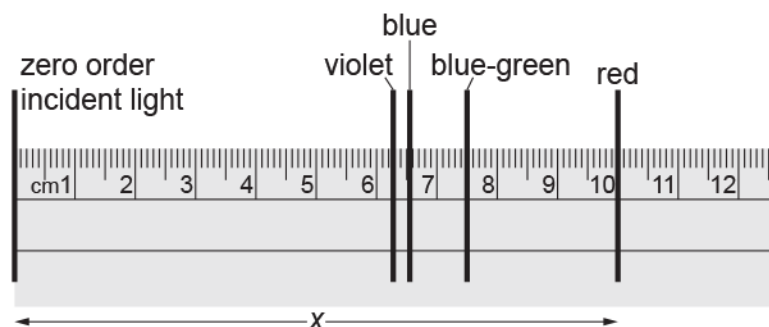


Fig. 5.3

The student decides to determine the wavelength of the photons which form the red line observed at $x = 10$ cm on the ruler.

- Describe how the information that has been given can be used to determine the wavelength of the red photons.
- Estimate the percentage uncertainty in the measured value of the wavelength.

Blank lined paper for writing.

(b)

- (i) Show that the energy of a photon of wavelength 486 nm is 4.09×10^{-19} J.

[1]

- (ii) Fig. 5.4 shows some of the energy levels of an electron in a hydrogen atom.

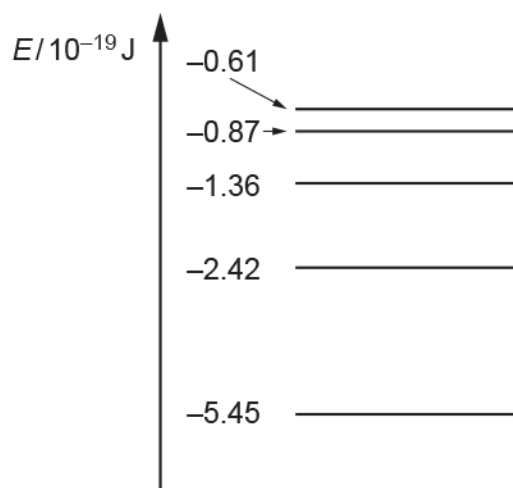


Fig. 5.4 (not to scale)

Draw an arrow on Fig. 5.4 to show an electron transition which would cause the **emission** of a photon of wavelength 486 nm.

[2]

[1]

- (b) In cosmology, the Doppler effect can be observed with light from distant galaxies. The Doppler effect can also be observed with sound waves.

Two students use sound waves to investigate the Doppler effect.
 In an open space, one student swings a loudspeaker at constant speed in a horizontal circle of radius 0.60 m.
 The other student stands a large distance away and holds a microphone. The microphone is connected to a data logger and computer.

Fig. 6.1 shows the situation, viewed from above.

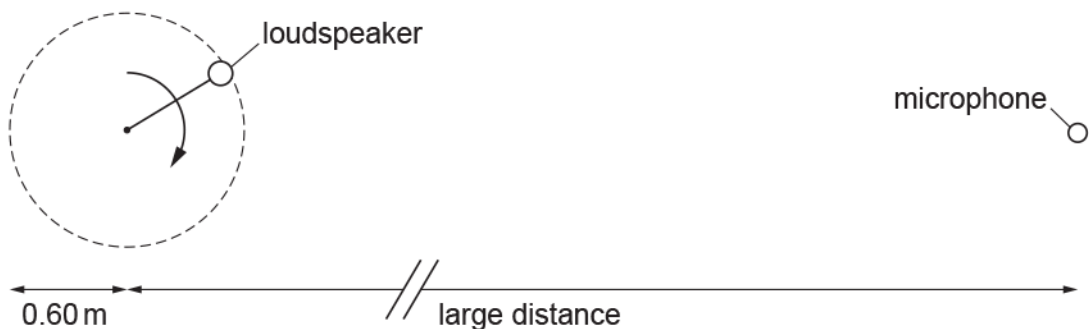


Fig. 6.1

The loudspeaker emits sound in all directions at a single frequency $f_0 = 1700\text{ Hz}$.

Fig. 6.2 shows the variation with time t of the frequency f received by the microphone.

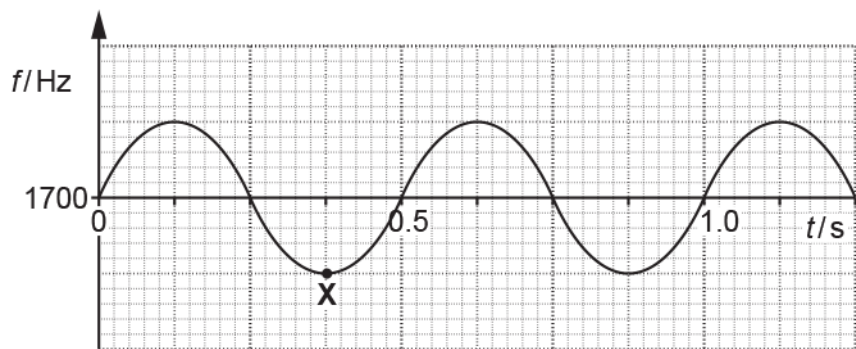


Fig. 6.2

- (i) Use Fig. 6.2 to show that the speed of the loudspeaker is 7.5 m s^{-1} .

[2]

(ii) The speed of sound in this experiment is 330 m s^{-1} .

Calculate the maximum change in frequency Δf of the sound detected by the microphone.

$\Delta f = \dots\dots\dots \text{ Hz}$ [2]

(iii) Hence complete the scale on the y-axis of Fig. 6.2.

[1]

(iv) Mark with an X on Fig. 6.1 the position of the loudspeaker which corresponds to the point X on Fig. 6.2.

[1]

- 34 Which column **A**, **B**, **C** or **D**, shows the correct sequence for the evolution of the Universe between the Big Bang and the formation of stars?

A	B	C	D
Universe starts to expand ↓ quarks and leptons form ↓ hadrons form ↓ nuclei form ↓ atoms form	Universe starts to expand ↓ hadrons form ↓ quarks and leptons form ↓ nuclei form ↓ atoms form	quarks and leptons form ↓ nuclei form ↓ Universe starts to expand ↓ atoms form ↓ hadrons form	quarks and leptons form ↓ hadrons form ↓ Universe starts to expand ↓ nuclei form ↓ atoms form

Your answer

[1]

- 35 Some stars will evolve into white dwarfs.
The mass of the Sun is 2.0×10^{30} kg.

Which of the following **cannot** be the mass of a white dwarf?

- A 1.2×10^{30} kg
- B 2.0×10^{30} kg
- C 2.7×10^{30} kg
- D 3.2×10^{30} kg

Your answer

[1]

- 36 An astronomer analyses the light from a distant galaxy.
One of the spectral lines in the spectrum observed from the galaxy has wavelength 610 nm.
The same spectral line has a wavelength of 590 nm when measured in the laboratory.

What is the speed of this galaxy?

- A $9.8 \times 10^6 \text{ ms}^{-1}$
- B $1.0 \times 10^7 \text{ ms}^{-1}$
- C $2.9 \times 10^8 \text{ ms}^{-1}$
- D $3.0 \times 10^8 \text{ ms}^{-1}$

Your answer

[1]

37 * In 2017, an ultra-cool star TRAPPIST-1 was discovered with at least five of its own orbiting planets. Astronomers are interested about the possibility of finding life on some of the planets orbiting TRAPPIST-1.

The table below shows some data.

	TRAPPIST-1	Sun
Luminosity L / W	2.0×10^{23}	3.8×10^{26}
Surface temperature T / K	2500	5800
Radius of star / m	R	7.0×10^8
Distance between Earth and Sun / m		1.5×10^{11}
Distance between planets and TRAPPIST-1 / m	1.6×10^9 to 9.0×10^9	

The temperature T in kelvin of a planet, its distance d from the star and the luminosity L of the star are related by the expression

$$\frac{T^4 d^2}{L} = \text{constant.}$$

- The average temperature of the Earth is about 290 K. Explain how life may be possible on some of the planets orbiting TRAPPIST-1.
- Use your knowledge of luminosity to show that the radius R of TRAPPIST-1 is smaller than the Sun.
- Support your answers by calculations.

Blank lined paper for writing.

38(a) Proxima Centauri is the closest star to Earth.

Fig. 24.1 shows the apparent positions of this star against the background of very distant stars as seen from the Earth over a period of exactly 6 months.

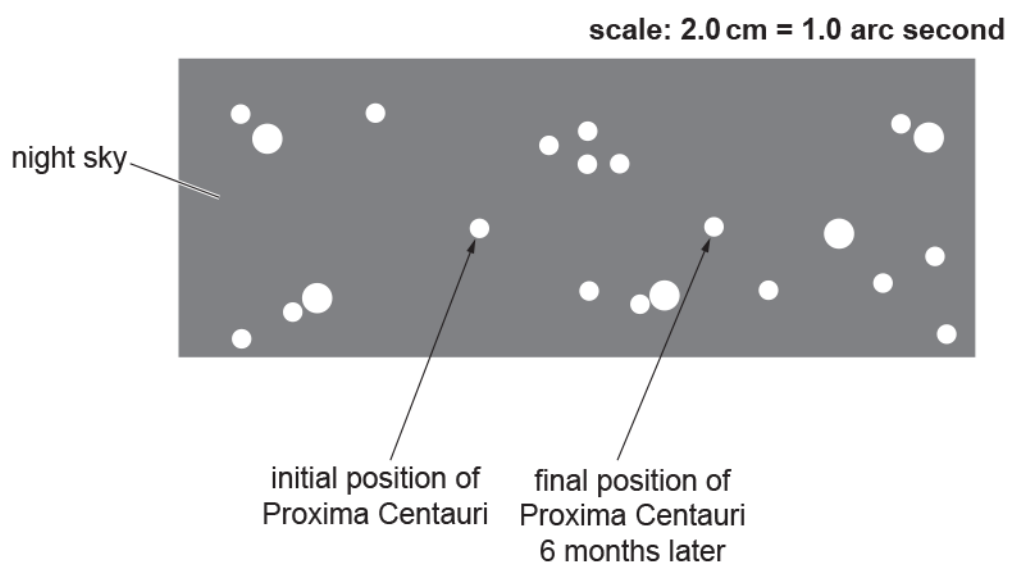


Fig. 24.1

The parallax angle for Proxima Centauri can be determined from Fig. 24.1 using the scale provided.

- (i) Show that the parallax angle p for Proxima Centauri is about 0.8 arc second.

[2]

(ii) Use your answer in (i) to calculate the distance d of Proxima Centauri from the Earth in light-years (ly).

$$1 \text{ pc} = 3.26 \text{ ly}$$

$$d = \dots\dots\dots \text{ ly [2]}$$

(b) The galaxies in the Universe may be assumed to be distributed uniformly through space.

In this model, the separation between two neighbouring galaxies is $1.4 \times 10^{23} \text{ m}$ and each galaxy occupies a cube of space of volume $2.7 \times 10^{69} \text{ m}^3$ as shown in Fig. 24.2.

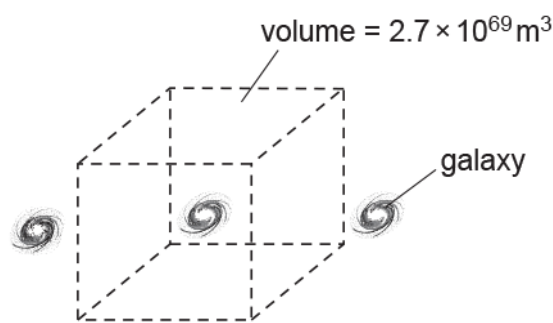


Fig. 24.2

There are on average 10^{11} stars in each galaxy and the mass of an average star is about $2.0 \times 10^{30} \text{ kg}$.

(i) Estimate the gravitational force between two neighbouring galaxies.

$$\text{force} = \dots\dots\dots \text{ N [2]}$$

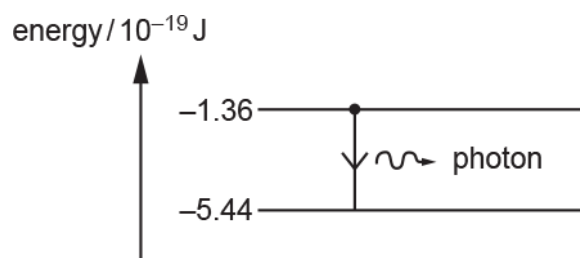
(ii) Show that the mean density of the Universe is about $7 \times 10^{-29} \text{ kg m}^{-3}$.

[1]

(iii) Suggest why the actual mean density of the Universe is different from the value calculated in (ii).

[1]

39 The diagram below shows two energy levels for the electron in the hydrogen atom.



The electron makes the transition shown by the arrow.

What is the wavelength of the photon emitted?

- A 293 nm
- B 366 nm
- C 488 nm
- D 1460 nm

Your answer

[1]

- 40 Recent analysis of the data collected from the Hubble and Gaia telescopes gave the Hubble constant a value of $73.5 \text{ km s}^{-1} \text{ Mpc}^{-1}$.

What is this value, written to 2 significant figures, in s^{-1} ?

- A $2.4 \times 10^{-21} \text{ s}^{-1}$
- B $2.4 \times 10^{-18} \text{ s}^{-1}$
- C $2.4 \times 10^{-12} \text{ s}^{-1}$
- D $2.4 \times 10^{21} \text{ s}^{-1}$

Your answer

[1]

- 41 Laser light of wavelength of 640 nm is incident normally at a diffraction grating. The separation between adjacent lines (slits) is $3.3 \times 10^{-6} \text{ m}$.

What is the **total** number of bright spots that can be observed in the diffraction pattern?

- A 5
- B 6
- C 10
- D 11

Your answer

[1]

- 42 In astronomy, distance can be measured in different units.

Which one of the following distances is the **largest**?

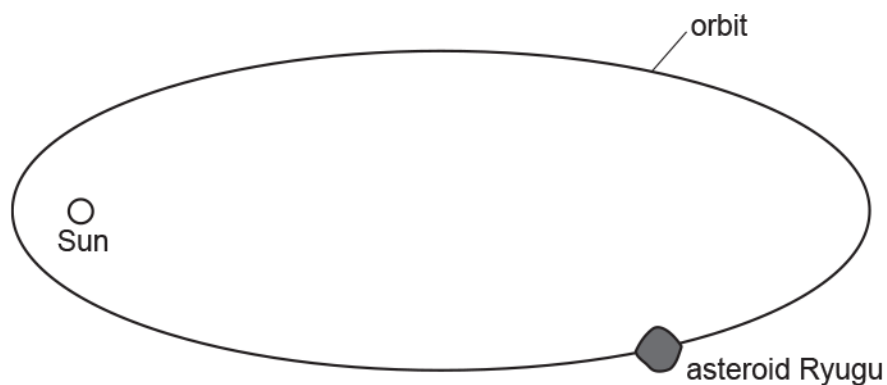
- A $4.22 \times 10^{16} \text{ m}$
- B 1.91 pc
- C 3.42 ly
- D 593AU

Your answer

[1]

43(a) In June 2018, the spacecraft Hayabusa2 arrived at an asteroid called Ryugu.

The asteroid orbits the Sun in an elliptical orbit as shown below.



The diagram is **not** drawn to scale.

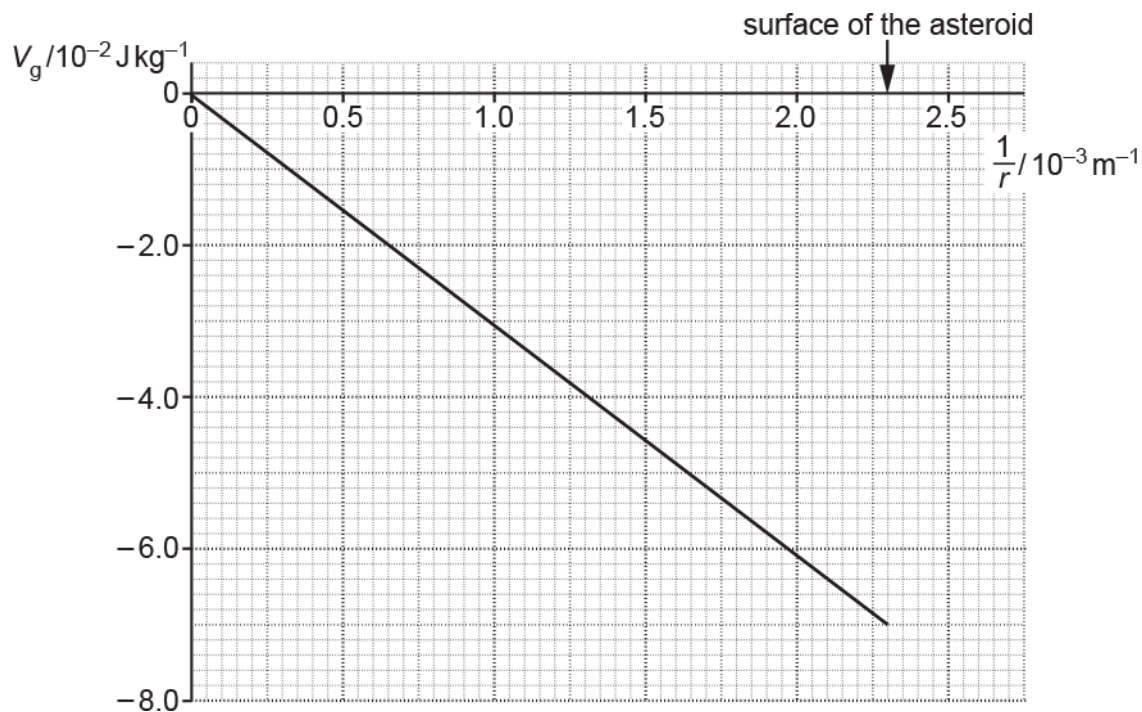
- (i) Indicate with a letter **X** on the orbit where the asteroid would be moving at maximum speed.

[1]

1 Use Kepler's **second law** to explain your answer to (a)(i) .

[2]

- (b) The gravitational potential at a distance r from the centre of the asteroid Ryugu is V_g . The graph of V_g against $\frac{1}{r}$ for the asteroid is shown below.



(i) Define gravitational potential .

[1]

(ii) Show that the magnitude of the gradient of the graph is equal to GM , where M is the mass of the asteroid and G is the gravitational constant.

[1]

(iii) Use the gradient of the graph to show that the mass M of the asteroid is about 4.6×10^{11} kg.

$M = \dots\dots\dots$ kg [2]

- (c) In October 2018, the probe Mobile Asteroid Surface Scout (MASCOT) was released from **rest** from the Hayabusa2 spacecraft from a distance of 600 m from the centre of the asteroid.

Assume that the spacecraft was stationary relative to the asteroid when MASCOT was dropped.

Use information from **(b)** to calculate the speed of the impact v when MASCOT landed on the surface of the asteroid.

$v = \dots\dots\dots \text{ m s}^{-1}$ [3]

44(a) Our Sun will eventually become a red giant.
Describe and explain the next stages of evolution of our Sun.

[4]

(b) Rigel is a blue giant star in the constellation of Orion.
 The table below shows some data about Rigel and about our Sun.

	Rigel	Sun
Surface temperature / K		5.8×10^3
Luminosity / W	4.62×10^{31}	3.85×10^{26}
Wavelength of emitted light at peak intensity / nm	240	500

(i) Show that the surface temperature of Rigel is 12 000 K.

[2]

(ii) Calculate the radius of Rigel.

radius = ... m [2]

(c) An astronomer claims to have discovered a white dwarf with a mass twice that of our Sun.
 Suggest why this claim must be incorrect.

[1]

(i) Use the data below to show that the luminosity of the Sun is about 4×10^{26} W.

- radius of Sun = 7.0×10^8 m
- surface temperature of Sun = 5800 K

[1]

(ii) Sirius, the brightest star in the night sky, has a luminosity 25 times greater than that of the Sun. It has diameter 1.7 times greater than that of the Sun.

Calculate the surface temperature T of Sirius.

$T = \dots\dots\dots$ K [3]

END OF QUESTION PAPER

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
1			B	1	
			Total	1	
2			D	1	
			Total	1	
3			D	1	
			Total	1	
4			B	1	
			Total	1	
5	a		Apparent motion or displacement of a star relative to the position of more distant stars. Caused by the Earth's orbit around the Sun. An angle of parallax of 1 arcsecond when displacement of Earth is 1AU corresponds to distance 1 pc	B1 B1 B1	
	b	i	$v = \frac{(489.8 - 486.1) \times 3 \times 10^8}{486.1} \quad (= 2.28 \times 10^6 \text{ m s}^{-1})$ $\text{age} = 1/H_0 = \frac{16.5 \times 10^6 \times 3.1 \times 10^{16}}{2.28 \times 10^6}$ $\text{age} = 2.2 \times 10^{17} \text{ (s)}$	C1	
		i		C1	
		i		A1	
		ii	Hydrogen is most common element in stars or Hydrogen has most intense (spectral) lines.	B1	
		ii	Intensity of light from other elements may be too low for accurate measurement.	B1	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
	c		*Level 3 (5–6 marks) Expect T1 and T2 for the Big Bang Theory Expect full discussion of red shift points R1, 2, 3 and 4 Expect at least B1 and B2 for the Blue Shift Expect C1 and any three from C2, C3, C4, C5 for CMBR <i>There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.</i> Level 2 (3–4 marks) Expect T1 and T2 for the Big Bang Theory Expect R1 and R2; red shift identified but no explanation why it implies an expanding Universe Expect B1 and B2; blue shift identified with no explanation of cause Expect any three from C1, 2, 3, 4 and 5; CMBR evidence recalled but linked to the Big Bang <i>There is a line of reasoning presented with some structure. The information presented is in the most-part relevant and supported by some evidence.</i> Level 1 (1–2 marks) Expect T1 or T2 for the Big Bang Theory Expect R1, R2 or B1, B2; red shift or blue shift identified but without explanation or link to Big Bang Theory Expect at least one from C1, 2, 3, 4 and 5; CMBR evidence recalled but not linked to the Big Bang <i>The information is basic and communicated in an unstructured way. The information is supported by limited evidence and the relationship to the evidence may not be clear.</i> 0 marks No response or no response worthy of credit.	B1 × 6	Big Bang Theory (T) 1 Predicts that all galaxies will be receding. 2 Galaxy velocity proportional to distance from Earth. Red Shift (R) 1 Radiation from Virgo shows increase in wavelength or red shift 2 Change in wavelength caused by motion of galaxy or reference to Doppler Effect 3 Evidence that Virgo is receding from Earth. 4 Support for Big Bang theory. Blue Shift (B) 1 Andromeda shows blue shift 2 Andromeda approaching Earth 3 Caused by gravitational attraction. CMBR (C) 1 Formed as gamma radiation at Big Bang 2 Galactic red shift to microwave wavelength 3 Intensity is uniform in all directions 4 Corresponds to a temperature of 2.7K 5 (Very small) ripples in intensity corresponding to formation of first stars or galaxies.
			Total	14	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
6			C	1	
			Total	1	
7			C	1	
			Total	1	
8			A	1	
			Total	1	
9			C	1	
			Total	1	
10			Arrow acting along line from planet towards sun	B1	Any arrow length
			Total	1	
11	a		Recessional speed / velocity of galaxy is proportional to its distance (from us)	B1	
	b	i	Velocity determined by Doppler shift of spectral lines	B1	
		ii	Suitable straight line of best fit through origin	M1	
		ii	Appropriate pair of values (d, v) taken from line, $H_0 = v/d$	M1	
		ii	$400 \text{ km s}^{-1} \text{ Mpc}^{-1} \leq H_0 \leq 600 \text{ km s}^{-1} \text{ Mpc}^{-1}$	A1	
		iii	$H_0 = 500 \times 10^3 / 10^6 \times 3.1 \times 10^{16} = 1.6 \times 10^{-17} \text{ s}^{-1}$	C1	
		iii	$t = 1 / H_0 = 1 / 1.6 \times 10^{-17} = 6.2 \times 10^{16} \text{ s}$	C1	
		iii	age = 2.0×10^9 (years)	A1	Accept answers between 1.6×10^9 (years) and 2.5×10^9 (years) CF
	c	i	(Stronger) gravitational attraction between nearby galaxies affects motion / clustering of galaxies	B1	
		ii	Expansion rate may not have been constant / non-linear expansion / effect of dark energy causing accelerating rate of expansion	B1	
			Total	10	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
12		i	$n = 3$ to $n = 2$	B1	allow between or and when there is a downward arrow on Fig. 8.1
		ii	$E_{32} + E_{21} = E_{31}$	C1	accept equation using $1/\lambda$ or $1/590 + 1/440 = 1/\lambda_{31}$ allow 2 or 3 sf allow 2/3 for using 550 for 590 nm giving 244 nm Examiner's Comments This question discriminated well between the better candidates; only the strongest scoring full marks. The two most common answers were to add or subtract the two given wavelengths despite the fact that the diagram referred to energies and candidates had written earlier that energy is inversely proportional to wavelength.
		ii	$hc/\lambda_{32} + hc/\lambda_{21} = hc/\lambda_{31}$	C1	
		ii	$1/590 + 1/440 = 1/252$ so $\lambda_{31} = 250 \times 10^{-9}$ (m)	A1	
			Total	4	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
13		i	Discrete energy (of electrons in an atom) / quantised energy (of electrons in an atom) / permitted energy (states of electrons in an atom).	B1	Examiner's Comments Most candidates, across the ability spectrum, struggled to give an acceptable definition of an energy level. Energy levels were seen as '<i>shells</i>' or '<i>orbits</i>' rather than the quantised energy of electrons within the atom.
		ii	$(E = \frac{hc}{\lambda})$ $E = \frac{6.63 \times 10^{-34} \times 3.0 \times 10^8}{7.2 \times 10^{-11}} \text{ or } E = 2.763 \times 10^{-15} \text{ (J)}$	C1	Note : The answer must be negative to score the A1 mark Note: 4.4×10^{-16} (J) scores 2 marks Examiner's Comments Most candidates correctly determined the energy of the X-ray photon. The value of the energy level labelled B had to be a negative value. The most common answer was 4.4×10^{-16} J, which scored two marks.
		ii	value of energy level = - (3.2 - 2.763) $\times 10^{-15}$ (J)	C1	
		ii	value of energy level = - 4.4×10^{-16} (J)	A1	
		iii	(λ_0 is) halved.	M1	Allow explanation in terms of $eV = hc/\lambda$. Examiner's Comments Many candidates, made good use of the clues provided in the question, to give well reasoned explanations. The equations $E = hc/\lambda$ or $eV = hc/\lambda$ were often used to support the answers. A small number of candidates gave qualitative answers such as '<i>the energy increases and therefore the wavelength is shorter</i>' and scored no marks.
		iii	Explanation: Reference to (photon / electron kinetic) energy doubled and $E = hc/\lambda$ or $E \propto 1/\lambda$.	A1	
			Total	6	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
14	a		$(p = 1/d)$ $d = \frac{8.6 \times 9.5 \times 10^{15}}{3.1 \times 10^{16}}$ (pc) or $d = 2.64$ (pc) $p = 0.38$ (arc seconds)	C1 A1	Allow full credit for alternative methods. Examiner's Comments This was a tough question, but many candidates did exceptionally well to calculate the distance of 2.64 pc for Sirius B. A pleasing number of candidates then went on to use either trigonometry or the equation $p = 1/d$ to calculate the parallax angle in arc seconds.
	b		$(\frac{\Delta\lambda}{\lambda} = \frac{v}{c})$ fractional change = $\frac{7600}{3.0 \times 10^8}$ percentage change = $2.5 \times 10^{-3} \%$	C1 A1	Allow 1 mark for 2.5×10^{-5} (factor of 100 missed out). Examiner's Comments Most candidates demonstrated good understanding of the Doppler equation and correctly calculated the percentage change in the wavelength of the spectral line. A very small number of candidates left the final answer as a ratio rather than a percentage.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
	c		The suggestion is incorrect because Hubble's law applies to (distant receding) galaxies. or The suggestion is incorrect because Hubble's law does not apply to stars in our own galaxy.	B1	Do not allow this mark if 'Sirius / star is moving towards us' is also included. Examiner's Comments The majority of the candidates stated Hubble's law but failed to answer the question. A disturbing number of candidates were convinced that this law could be applied to a star within our galaxy. Some decent answers were spoilt with comments such as '<i>the statement is incorrect because Hubble's law is for receding galaxies but Sirius is moving towards us</i>'. The omission rate for this question was high at about 10%.
			Total	5	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
15	a		The universe is homogeneous. and isotropic (on a large scale).	B1 B1	Examiner's Comments The answers were brief with a mention of <i>homogeneous and isotropic</i> , so most candidates scored two marks. Many candidates even defined these terms and showed a good understanding the cosmological principle. Some candidates were convinced that the question was asking about Olbers' paradox.
	b		The intensity of the microwaves is the same in all directions. These microwaves correspond to a temperature of 2.7 K or The temperature of the universe is 2.7 K. The expansion of the universe following the big bang led to cooling and hence we observe microwaves rather than short wavelength e.m. waves / gamma waves.	B1 B1 B1	Allow the microwave (background radiation) is isotropic. Allow 3 K Allow - The short e.m. / gamma waves during the early stages of the universe have been 'stretched out' / 'red-shifted' to microwaves by the expansion. Examiner's Comments The majority of the candidates were aware that the microwaves represented the universe to be at a temperature of 2.7 K. The descriptions were generally good with many candidates recognising the expansion of the universe led to cooling and hence we now observe microwaves rather than the short wavelength gamma radiation. The use of technical terms was generally good and it was easy to follow the text.
	c		$\left(\rho = \frac{3H_0^2}{8\pi G}\right)$ $H_0 = \sqrt{\frac{8\pi \times 6.67 \times 10^{-11} \times 9.7 \times 10^{-27}}{3}}$ $H_0 = 2.328 \times 10^{-18} \text{ (s}^{-1}\text{)}$ $(\text{age} = 1/H_0)$	C1	Allow any subject

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
			$\frac{1}{\text{age} = 2.328 \times 10^{-18} \text{ or age} = 4.3 \times 10^{17}(\text{s})}$ $\text{age} = 1.4 \times 10^{10} (\text{y})$	C1 A1	Answer to 3 sf is $1.36 \times 10^{10} (\text{y})$ Examiner's Comments Candidates, across the ability range, enjoyed tackling this demanding question. Most scored full marks. The answers were logically presented and showed an excellent knowledge of critical density and age of the universe. There were fewer algebraic errors. This was a good finish for most candidates.
			Total	8	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
16	a		A core / 'star' left behind after a red giant (has shed its outer layers)	B1	Allow: It is the core of a red giant Allow: It is the remnant of a low-mass star Allow: A core / 'star' - supported by Fermi pressure / electron degeneracy (pressure) - with maximum mass of 1.4(4) solar masses / 1.4(4) $M_{\odot}$ / Chandrasekhar limit Not: It is a collapsing red giant Examiner's Comments Only about a third of the candidates gave the correct answer in terms of the evolutionary stage of a low-mass star. Many candidates lost a mark for writing correct things about a white dwarf but failing to answer the question. Many candidates did not appreciate that the white dwarf was the remnant core of a low-mass star after the red giant phase.
	b		(parallax = $1/d$) $d = 0.0059^{-1}$ (pc = 169 .49 pc) distance = $0.0059^{-1} \times 3.26$ distance = 550 ly	C1 A1	Allow other correct methods Examiner's Comments About half of the candidates scored full marks for using $d = p^{-1}$ and then converting the distance into light years. A significant number of candidates had the skill and competence to apply trigonometry to a triangle with base of length 1 AU. Some even managed to correctly recall the astronomical unit is metres. The most common error was: $d = 0.0059 \times 3.26 = 0.019 \text{ ly}$

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
	c	i	power per (unit) area or power/area	B1	Allow 'energy per (unit) area per unit time' Not: power per m² Examiner's Comments Most candidates correctly defined intensity as power divided by area. A small number of candidates defined intensity incorrectly as 'energy divided by area'.
		ii	1 (density = mass/ $\frac{4}{3}\pi r^3 \propto \text{mass}/r^3$)		
		ii	ratio = $\frac{12}{(1.1 \times 10^5)^3}$	C1	
		ii	ratio = 9.0×10^{-15}	A1	Allow: 9.0×10^{-15} : 1 Allow: 1 sf answer of 9×10^{-15}
		ii	2 (power = intensity $\times$ surface area)		
		ii	power $\propto T^4 r^2$	C1	
		ii	ratio = $\frac{4300^4 \times (1.1 \times 10^5)^2}{25000^4}$	C1	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		ii	ratio = 1.1×10^7	B1	Note: Answer to 3 sf is 1.06×10^7 Allow: $1.1 \times 10^7 : 1$ Examiner's Comments This was a good discriminating question that required careful execution. Most candidates in the upper quartile scored four or more marks. Their answers showed good development and errors were minimised. Most candidates in the lower quartile managed to get at least one mark. Candidates at this end struggled with writing the correct expressions for surface area and volume of the star. Sadly, for a significant number of candidates, the volume V of a star was given by the expression $V = 4\pi r^2/3$. A significant number of candidates confused the terms 'power' and 'intensity' and ended up calculating the ratio of intensities instead.
			Total	9	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
17	a		recessional speed / velocity of galaxy is proportional to its distance (from us)	B1	Allow: recessional speed of galaxy = Hubble constant $\times$ distance Examiner's Comments The majority of the candidates gave a correct statement of Hubble's law. It was important that galaxy was mentioned in the answer. For a disturbing number of candidates, this law applied to planets and stars in our galaxy.
	b	i	$v = 1010 \text{ (} 10^3 \text{ m s}^{-1}\text{)}$	B1	Note: Answer to 4 sf is 1014 (10^3 m s^{-1}) Examiner's Comments The correct value for the cell for v was 1010 or 1014. A range of values were allowed for the distance d. The modal mark for this question was two.
		i	d in the range 4.47 to 4.54 (10^{23} m)	B1	
		ii	(Straight line drawn through the points gradient = Hubble constant, H_0)		
		ii	gradient = $2.24 \times 10^{-18} \text{ (s}^{-1}\text{)}$	C1	Allow: gradient in the range 2.21 to 2.27×10^{-18}
		ii	age = $(2.24 \times 10^{-18})^{-1}$		
		ii	age = $4.46 \times 10^{17} \text{ (s)}$	C1	Allow ecf from incorrect value of the gradient

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		ii	age = 1.4×10^{10} (y)	A1	Allow: A maximum of 2 marks if values from the table are used instead of the gradient of the line drawn on Fig. 11.2 Note: No marks for a bald 14 billion years Examiner's Comments This was generally a well-answered question with many knowing the value for the age of the universe. The gradient of the best-fit straight line was often calculated correctly and errors in powers of ten were rare. The conversion of the age of the universe from seconds to years was done correctly. A small number of candidates used a data point to determine the age, There was a penalty of one mark for such an approach.
	c		Big bang: Creation / birth / expansion / evolution of the universe or The universe was very hot / very dense / singularity (at the start) Evidence: Any two from: • Microwave / background radiation / 3 K (or 2.7 K) • Existence of (primordial) helium / lithium / lighter elements • Tiny variation (or ripples) in (background) temperature	B1 B1 × 2	Not: More matter than antimatter / baryonic asymmetry Examiner's Comments There were exuberant answers to this question, with many candidates scoring at least two marks. Candidates were often using the additional pages provided to provide a robust answer. It was good to see that many candidates were familiar with the existence of primordial helium (and other 'lighter' elements) in the early stages of the universe. Almost all candidates gave a decent explanation of the big bang and knew about the existence of the cosmic microwave background radiation or the temperature of about 3 K. Some candidates gave elaborate, but unnecessary description of Olbers paradox. The omission rate for this question was very low indeed.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
			Total	9	
18	a		$\lambda_1 = d \sin 12.5 = 4.33 \times 10^{-7} \text{ m}$ giving $1/d = 5 \times 10^5$ or $d = 2 \times 10^{-6}$ $\lambda_3 = \sin 19.0/5 \times 10^5 = 6.51 \times 10^{-7} \text{ (m)}$ or $\lambda_1 = d \sin 12.5 = 4.33 \times 10^{-7}$ and $\lambda_3 = d \sin 19.0$ so $\lambda_3 = 4.33 \times 10^{-7} \sin 19.0/\sin 12.5 = 6.51 \times 10^{-7} \text{ (m)}$	C1 A1	or $\lambda_2 = d \sin 14.0 = 4.84 \times 10^{-7} \text{ (m)}$ or use $\lambda_2 = d \sin 14.0 = 4.84 \times 10^{-7} \text{ m} \sin 19.0/\sin 12.5 = 0.326/0.216 = 1.50$
	b	i	the uncertainty in the measurement of angle is the same for all angles and the bigger the angle measured the smaller the % error	B1	
		ii	$n_{\max} = d \sin 90$	C1	
		ii	$= 1/(5 \times 10^5 \times 4.33 \times 10^{-7}) = 4.6$ but n is an integer so $n = 4$	A1	
	c	i	3 downward arrows correctly labelled.	B1	longest being $4.33 \times 10^{-7} \text{ (m)}$
		ii	$\Delta E = hc/\lambda$	C1	
		ii	$\lambda = 6.63 \times 10^{-34} \times 3 \times 10^8 / 4.8 \times 10^{-20} = 4.1(4) \times 10^{-6} \text{ (m)}$	A1	
		ii	region: infra red	B1	allow ecf if wavelength calculation incorrect.
			Total	9	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
19	a		$\text{angle} = \tan^{-1} (1.3 \times 10^{20} / 24 \times 10^{22})$ $\text{angle} = 0.31 (^{\circ})$	B1	Note: Using $\sin^{-1}$ is correct; it gives the same answer of 0.31° Examiner's Comments Examiners concluded that it was the lack of understanding of the term 'subtended' in the question that caused confusion. Only a third of the candidates used simple trigonometry to arrive at the correct answer of 0.31°. Some of the answers were very large, e.g. 89°. Such an angle did not register as being unrealistic.
	b		$\left(\frac{\Delta \lambda}{\lambda} = \frac{v}{c} \right)$ $\frac{\Delta \lambda}{656.3} = \frac{2.5 \times 10^5}{3.0 \times 10^8} \text{ (Any subject)}$ $\Delta \lambda = 0.55(\text{nm})$	C1 A1	Note: Answer to 3 sf is 0.547 (nm) Note: 5.5×10^{-10} on the answer line scores 1 mark Examiner's Comments This was another confidently tackled question. The Doppler equation was used well, with most answers for the change in wavelength given in nm. A very small number of candidates struggled to convert their answer of 5.5×10^{-10} m into nm.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
	c		$\frac{GMm}{r^2} = \frac{mv^2}{r} \text{ or } \frac{GM}{r} = v^2$ $\frac{GM}{0.65 \times 10^{20}} = (2.5 \times 10^5)^2 \text{ (any subject)}$ mass = 6.09×10^{40} (kg) (number of stars = $6.09 \times 10^{40} / 2.0 \times 10^{30}$)	C1 C1 C1	Allow other correct methods. Allow the following for the first two C1 marks: $F = \frac{2.0 \times 10^{30} \times (2.5 \times 10^5)^2}{0.65 \times 10^{20}}$ or 1.92×10^{21} (N) C1 $\frac{GM \times 2.0 \times 10^{30}}{(0.65 \times 10^{20})^2} = 1.92 \times 10^{21}$ (Any subject) C1 Allow: 2 out of 3 marks for use of 1.3×10^{20} (m); this gives an answer of 1.2×10^{41} (kg)

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
			number of stars = 3.0×10^{10}	A1	Possible ECF from incorrect mass of galaxy Allow 1 SF answer for the estimation Examiner's Comments The modal mark for this question was four and about a third of the candidates scored nothing for their work. A range of methods were used to arrive at the correct answer of 3.0×10^{10} stars in the Andromeda galaxy. The most popular route was starting off with the expression $\frac{GMm}{r^2} = \frac{mv^2}{r}$ A significant number of candidates also successfully used the equation for Kepler's third law. On the whole, candidates demonstrated admirable analytical and calculator skills.
			Total	7	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
20	a		Any four from: (The forces are separated) 1. Expansion / cooling 2. Creation of matter / pair production 3. More matter than antimatter 4. Quarks and leptons (soup) 5. Quarks combine to form hadrons / baryons / nucleons / protons / neutrons 6. Imbalance of neutrons and protons / (primordial) helium / lithium / beryllium (nuclei) produced 7. Hadrons / baryons / (neutrons and) protons / combine to form nuclei (Atoms formed)  QWC: Correct sequencing of two steps from 4, 5 and 7	B1 × 4 B1	Annotation by the pencil icon Examiner's Comments The enthusiasm and knowledge of the evolution of the Universe jumped out from most scripts. The majority of the candidates scored three or more marks. A significant number of candidates used additional answer space to describe the evolution of the Universe after the formation of the atoms. This was not required by the question, but candidates were keen to describe the entire evolution, culminating with the current temperature of 2.7 K.
	b		(Recession) speed / velocity of galaxy is (directly) proportional to its distance (from us)	B1	Examiner's Comments Most candidates gave a clear definition of Hubble's law. A small number of answers were spoilt by omitting '<i>galaxy</i>' or using an inappropriate object (<i>star</i> and <i>planet</i>) in the definition.
	c	i	(ρ) $8 \times 1.673 \times 10^{-27} \text{ (kg m}^{-3}\text{)}$ or $1.34 \times 10^{-26} \text{ (kg m}^{-3}\text{)}$ $(\rho = \frac{3H_0^2}{8\pi G})$	C1	Allow $1.7 \times 10^{-27} \text{ kg}$ or $1.675 \times 10^{-27} \text{ kg}$ (neutron) or $1.661 \times 10^{-27} \text{ kg (u)}$

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		i	$H_0 = \sqrt{\frac{8\pi \times 6.67 \times 10^{-11} \times 1.34 \times 10^{-26}}{3}}$ (Any subject)	C1	
		i	$H_0 = 2.7 \times 10^{-18} \text{ (s}^{-1}\text{)}$	A1	Note: Answer is $2.8 \times 10^{-18} \text{ (s}^{-1}\text{)}$ when $1.7 \times 10^{-27} \text{ kg}$ is used Examiner's Comments This was an impressively answered question. The critical density equation was manipulated correctly to calculate the Hubble constant in s^{-1}. Once again, the algebraic and calculator skills were superb. A very small number of candidates used the critical density of $8 \text{ (kg m}^{-3}\text{)}$ and this gave an incorrect answer of $6.7 \times 10^{-5} \text{ s}^{-1}$.
		ii	$(\text{age} =) \frac{1}{2.7 \times 10^{-18}} \quad \text{or} \quad 3.7 \times 10^{17} \text{ (s)}$	C1	Possible ECF from (i)
		ii	$\text{age} = 1.2 \times 10^{10} \text{ (y)}$	A1	Allow use of $1 \text{ y} = 3.15 \times 10^7 \text{ (s)}$ or $3.16 \times 10^7 \text{ (s)}$ Note: Answer is $1.1 \times 10^{10} \text{ (y)}$ when $2.8 \times 10^{-18} \text{ (s}^{-1}\text{)}$ and 3.16×10^7 are used Examiner's Comments The omission rate for this question was very low indeed and it was a good to see that most candidates gained two marks for calculating the correct age of the Universe. A small number of candidates also scored full marks for $4.7 \times 10^{-4} \text{ y}$ thanks to error carried forward from the previous incorrect answer of $H_0 = 6.7 \times 10^{-5} \text{ s}^{-1}$.
			Total	11	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
21	a		*Level 3 (5-6 marks) Clear use of data and discussion of MBR. <i>There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.</i> Level 2 (3-4 marks) Some use of data and discussion of MBR. <i>There is a line of reasoning presented with some structure. The information presented is in the most-part relevant and supported by some evidence.</i> Level 1 (1-2 marks) Limited use of data or limited discussion of MBR. <i>The information is basic and communicated in an unstructured way. The information is supported by limited evidence and the relationship to the evidence may not be clear.</i> 0 marks No response or no response worthy of credit.	B1x6	Indicative scientific points may include: Use of data - The table of values for d and v support the idea of an expanding Universe. - Calculate of H_0 more than once using data. - age = $t = \frac{1}{H_0}$ used correctly to calculate t. - Age calculated correctly in s or in y. - Furthest galaxies travelling faster. - Space expanding in all directions. - Use data to plot graph of v against d to determine H_0 / graph of d against v to find t. - More data needed since anomalies in the table. Discussion of MBR (microwave background radiation) - Early Universe extremely hot / very dense. - High energy gamma photons existed in the early Universe. - As space expanded the wavelength of these photons / waves 'stretched' out. - We now observe this as microwave background radiation. - Temperature of the Universe is now 2.7 K
	b	i	$\Delta\lambda = \frac{\lambda v}{c} = \frac{486 \times 10^{-9} \times 960 \times 10^3}{3.00 \times 10^8}$	C1	
		i	$\Delta\lambda = 1.56 \text{ (nm)}$	C1	
		i	$\lambda = 486 + 1.56 = 488 \text{ (nm)}$	A1	
		ii	$d = 1.25 \times 10^{-6} \text{ m}$ $\theta = \sin^{-1}\left(\frac{2 \times 486 \times 10^{-9}}{1.25 \times 10^{-6}}\right)$	C1	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		ii	$\theta = 51^\circ$	A1	Allow 1 mark $\theta = \sin^{-1}\left(\frac{2 \times 488 \times 10^{-9}}{1.25 \times 10^{-6}}\right) = 51^\circ;$ incorrect 488 nm used instead of 486 nm.
	c		Dark matter / black holes	B1	Allow: anti-matter / dark energy
			Total	12	
22	a		$\lambda_{\max} \times T$ should be constant if Wien's law is obeyed. At least data from three stars is used to carry out the test and a clear conclusion.	M1 A1	Ignore POT Note $\lambda_{\max} \times T$ values are $2.91 (\times 10^{-3})$, $2.91 (\times 10^{-3})$, $2.88 (\times 10^{-3})$ and $2.99 (\times 10^{-3})$ – hence expect 'yes the law is obeyed'.
	b	i	distance = $550 \times 9.5 \times 10^{15}$ (m)	C1	
		i	$L = \frac{4\pi \times (550 \times 9.5 \times 10^{15})^2}{4.0 \times 10^{-4}} \times 2.6 \times 10^{-11}$	C1	
		i	$L = 2.2 \times 10^{31}$ (W)	A1	
		ii	$(r = \sqrt{\frac{L}{4\pi\sigma T^4}});$ $r = \sqrt{\frac{2.2 \times 10^{31}}{4\pi \times 5.67 \times 10^{-8} \times (3.1 \times 10^3)^4}}$	C1	Possible ECF from (i) Allow any subject
		ii	$r = 5.8 \times 10^{11}$ (m)	A1	
		iii	$\text{mass} = 4.4 \times 10^{-5} \times 4/3\pi \times (5.8 \times 10^{11})^3$ $g = \frac{6.67 \times 10^{-11} \times 4.4 \times 10^{-5} \times 4/3\pi \times (5.8 \times 10^{11})^3}{(5.8 \times 10^{11})^2}$	C1	Possible ECF from (ii)
		iii	$g = 7.1 \times 10^{-3}$ (N kg ⁻¹)	A1	
			Total	9	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
23		i	$E = hc/\lambda$; $\Delta\varepsilon = E_1 - E_2 = hc\Delta\lambda/\lambda^2$	C1	allow calculation of $E = hc/\lambda$ twice and difference taken
		i	$\Delta\varepsilon = 6.63 \times 10^{-34} \times 3 \times 10^8 \times 0.6 \times 10^{-9} / 5.9^2 \times 10^{-14}$	C1	
		i	$\Delta\varepsilon = 3.4 \times 10^{-22} \text{ (J)}$	A1	
		ii	$\sin \theta = n\lambda/d$; $1/d = 3 \times 10^5 \text{ (m}^{-1}\text{)}$	C1	or similar allow 20.72 – 20.70
		ii	$\theta_1 - \theta_2 = \sin^{-1} (2 \times 589.6 \times 3 \times 10^{-4}) - \sin^{-1} (2 \times 589 \times 3 \times 10^{-4})$	M1	
		ii	$\theta_1 - \theta_2 = 20.717 - 20.695 = 0.022^\circ$	A1	
			Total	6	
24			B	1	Examiner's Comments This question required the temperatures to be converted into kelvin before finding the peak wavelength, giving option B rather than option A. This question provided opportunities for middle-grade candidates.
			Total	1	
25			B	1	Examiner's Comments This question did not discriminate very well at all. The key point is that the emission lines all undergo the same fractional wavelength increase, so that the longer wavelengths will have larger absolute increase, as indicated by option B. Option A gives lines which are all the same absolute increase.
			Total	1	
26			C	1	Examiner's Comments This question proved particularly straightforward and accessible to nearly all candidates.
			Total	1	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
27	a	i	<u>electron</u> bound to nucleus / represents energy <u>electron</u> must gain to leave the atom / total energy of <u>electron</u> in atom is less than that of a free electron	B1	Allow ionisation level defined as zero as AW for 'represents electron must gain energy to leave atom / move up energy level' Allow potentials for attractive forces are negative. Examiner's Comments This item provided good discrimination between the candidates. Many responses referred incompletely to the negative charge of the electron being the only factor, whereas the correct explanation is much more to do with the electron requiring energy to leave the atom and the ionization level being defined as the zero point. Some candidates were on the right path when they referred to the equivalent statement for gravitational potential energies.
		ii	1 energy = 2.55 (eV) 2 energy = $2.55 \times 1.60 \times 10^{-19}$ (J) $\lambda = \frac{6.63 \times 10^{-34} \times 3.0 \times 10^8}{2.55 \times 1.60 \times 10^{-19}} \quad (\text{Allow any subject})$ wavelength = 4.9×10^{-7} (m) wavelength = 490 (nm)	B1 C1 C1 A1	Ignore sign Possible ECF from (ii)1 Note: wavelength = 488 (nm) to 3 sf Examiner's Comments Virtually all candidates correctly evaluated the energy difference to be 2.55 eV. Negative values were condoned but are unlikely to be accepted in future series. Many candidates correctly calculated the wavelength of emitted light, although a minority did not convert the energy into joules or performed the required conversion to nanometres incorrectly.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
	b	i	<u>Electron(s)</u> makes a transition to a lower (energy) level / loses energy and emitting a photon(s) / EM radiation	B1	Examiner's Comments Many candidates muddled up emission (lines emitted by a source) and omission (as in lines absorbed by a low pressure gas when a continuous spectrum passes through it, as in an absorption spectrum), so could not score the mark. Some focused on the experimental procedure of using a diffraction grating. A third of candidates correctly stated that the electron dropped down to a lower energy state, releasing a photon or the equally acceptable 'EM radiation'
		ii	Reduce grating separation / increase distance between grating and screen	B1	Allow 'use finer grating' or 'use grating with more lines mm^{-1}' Not 'smaller slit size' Examiner's Comments This item tested knowledge of specification 5.5.2 (g) and PAG 5. It would be advisable for Centres, where possible, to allow candidates to observe the effect of changing the slit separation and the grating-screen separation independently. Approximately a third of students correctly suggested making one of those adjustments, even if they expressed the former as 'increase the number of lines per mm'. Some candidates presented arguments about plotting the graph on a smaller scale or measuring the wavelength in picometres in an attempt to resolve the peaks in the plot, which was a mis-interpretation of the question.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		iii	wavelength (of peak) = 661.5 nm $v = 3.0 \times 10^8 \times (661.5 - 656.3) / 656.3$ recession velocity = 2.4×10^6 (m s ⁻¹)	C1 C1 A1	Allow: between 661 and 662 nm Note: check divided by 656.3 nm Range of acceptable answers. $2.1(5) - 2.6(1) \times 10^6$ Examiner's Comments Examiners were pleased to see this item answered well, with the majority of candidates gaining either two or three marks. Those that did not either misread the position of the red-shifted spectral peak, did not recognise that they were looking for the peak wavelength or did not use the 'at rest' wavelength for the denominator of the expression for the change in wavelength.
		iv	(Relative) abundance of hydrogen (AW)	B1	Allow 'Hydrogen commonly found in stars' (AW) Examiner's Comments Just over half of all candidates realised that the useful property of hydrogen was its relative abundance in stars and hence galaxies.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
	c		Less intense Galaxy is moving faster and therefore greater / longer wavelength (AW) Periodic shift in wavelength (if plane of orbit is in line of sight) (ORA)	B1 B1 B1	Allow 'greater red shift' / 'greater Doppler shift' / 'to the right' for longer wavelength Allow argument referring to splitting of line because of relative velocities of two component stars. Not idea of blue shift. Examiner's Comments Some 9% of all candidates declined to answer this item, the highest rate for any item on this paper. The most common correct response linked higher distance with higher recessional velocity and thus higher increase in wavelength. Higher ability candidates explained that the orbiting stars would have different velocities relative to the Earth resulting in a periodic change in wavelength from the central peak. References to blue-shifting were erroneous and contradictory.
			Total	14	
28			D	1	Examiner's Comments The key to this question is to find the energy of the photon (from $E = hf$) which gives 2.72×10^{-19} J. The energy level X is this amount of energy <i>below</i> -5.40×10^{-19} J, which can only be answer D.
			Total	1	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
29	a		A = white dwarf and B = red giant	B1	Allow: red supergiant for B Not: neutron star for A
	b	i	$(\lambda T = \text{constant})$ $550 \times 5800 = 370 \times T$ $T = 8600 \text{ (K)}$	C1 A1	Allow however expressed Answer is 8620 to 3 sf
		ii	P on the main sequence and to LEFT of Sun.	B1	Allow: ECF from (b)(i) Note: temperature of Sun is 5800 K. <u>Examiner's Comments</u> This whole question was well answered in general. Very few could not identify white dwarf and red giant stars. The calculation of the surface temperature was straightforward with a minority suggesting that $\lambda_{\text{max}} \propto T$. In either case, most candidates plotted the position of Beta Pictoris on the HR plot successfully.
			Total	4	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
30	a		Uniform distribution of matter (everywhere in the Universe)	B1	Allow: density of Universe (approximately) constant throughout Not: references/idea of isotropic/"looks the same in all directions" <u>Examiner's Comments</u> Just under half of the candidates got this term correct. The majority that did not confused this term with isotropic or used insufficiently clear language, such as 'the universe is the same everywhere'.

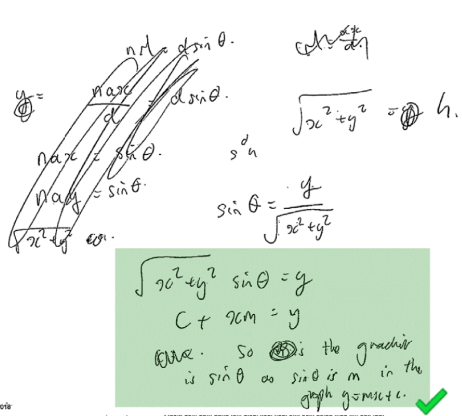
Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
b	i		$v = 68 \times 200 = 13600 \text{ (km s}^{-1}\text{) or } 13.6 \times 10^6 \text{ m s}^{-1}$ $(\Delta\lambda = \frac{v}{c} \times \lambda)$ (change in λ) $13600 \times 10^3 \times 280 / 3.00 \times 10^8$ or 13 (nm) or $13 \times 10^{-9} \text{ (m)}$ $(\lambda = 280 + 13)$ $\lambda = 290 \text{ (nm)}$	C1 C1 A1	Allow: Any correct velocity if unit matches. Allow: ECF for incorrect v Answer to 3 sf is 293 (nm) Allow: ECF for incorrect Δλ <u>Examiner's Comments</u> This is a more challenging question with several steps. In multiplying the distance in Mpc by the H0 as quoted, the velocity of the galaxy was 13600 km s^{-1}. Some candidates handled the units well in this question, reaching a change in wavelength of 13 nm. If the candidate got as far as that, then approximately half then went on to add the change in wavelength correctly. The change is added as the galaxy is going away from us. Exemplar 7 $v = H_0 d$ $v = 68 \times 200$ $= 13600 \text{ km s}^{-1}$ $= 13600000 \text{ m s}^{-1}$ $1.269 \times 10^{-8} + 280 \times 10^{-9}$ $= 2.93 \times 10^{-7}$ $\frac{\Delta\lambda}{\lambda} \approx \frac{v}{c}$ $\frac{\Delta\lambda}{280 \times 10^{-9}} \approx \frac{13600000}{3 \times 10^8}$ $\Delta\lambda = 1.269 \times 10^{-8}$ $\lambda = 293 \text{ nm}$ This candidate has laid out the calculation very carefully. It is obvious that they have handled the idea that the speed of light is given in m s^{-1} and that the galaxy's velocity is in km s^{-1}. This gives the correct change in wavelength and eventually the correct wavelength.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		ii	Any suitable <u>one</u> from: • Very/infinately dense • Idea that escape velocity $\geq$ or 'light cannot escape it'	B1	Allow: singularity Allow: physical radius $\leq$ event horizon radius Allow: Distorts space(time) significantly / bends light significantly Allow: Emits Hawking radiation Examiner's Comments Lots of candidates had some good ideas here, and had clearly read widely about black holes. The better answers were those that were specific to black holes rather than merely 'high mass', for example. Good ideas included: • 'has an escape velocity greater (or equal to) the speed of light' • 'infinately dense' • 'emits Hawking radiation' • 'event horizon greater than physical radius'
	c		Any three from: 1 At the Big Bang the Universe is a singularity / very dense / very hot 2 Expansion / inflation / high energy (gamma) photons but no matter 3 Quarks and leptons form / Quark–Gluon Plasma phase 4 Quarks combine to form neutrons / protons / hadrons 5 Hadrons / neutrons <u>and</u> protons / nucleons combine to make nuclei All candidate's points in the correct sequence	M1x3	Allow for point 1: fundamental forces unified Ignore: Any phase after nuclei phase e.g. recombination era /formation of atoms/formation of CMBR Examiner's Comments Many candidates did well on this question as they had learnt the stages and the order of those stages well. The most common reason for loss of marks was not including details about leptons or getting the stages in the wrong order.
			Total	9	

Mark Scheme

Question	Answer/Indicative content	Marks	Guidance
31 a	$y = \sin(\theta) \sqrt{x^2 + y^2}$ compared with "y=mx+c"	B1	Allow: gradient = $\frac{\Delta y}{\Delta(\sqrt{x^2 + y^2})}$ with $\sin(\theta) = \text{O/H}$ Not: gradient = $\frac{y}{(\sqrt{x^2 + y^2})}$ unless "c=0" seen. Examiner's Comments Candidates found this item tricky even if they realised that $\sin(\theta) = y/\sqrt{x^2 + y^2}$ and then re-arranged the equation into a form comparable with the general equation of a straight line, "y=mx +c". Unless that comparison was clear, then the mark could not be credited. Exemplar 8  The exemplar shows a clear way of demonstrating how to show that the gradient of the line of the graph should be $\sin(\theta)$.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
	b	i	(Straight line of best fit showing) <u>gradient</u> = 0.73 $(d \sin \theta = n\lambda)$ $\frac{1.0 \times 10^{-3}}{600} \times 0.73 = 2 \times \lambda$ $\lambda = 6.1 \times 10^{-7} \text{ (m)}$	C1 C1 A1	Allow: gradient in range 0.70–0.76. Allow: evaluation of $\theta = 44\text{--}50$ (degrees) in place of gradient Allow: any subject Note: Gradient in range 0.70–0.76 gives λ in range $(5.8 - 6.4) \times 10^{-7} \text{ m}$ <u>Examiner's Comments</u> Many candidates could plot the best fit straight line and attempted to calculate the gradient. Not many candidates after that point realised that the gradient had given them $\sin(\theta)$ and could make no further meaningful progress. Common errors included not calculating d correctly from the quoted number of lines mm^{-1} or, less frequently, was using a value different from 2 for n.
		ii	(Scales/distances are large compared with the absolute uncertainty so) <u>absolute uncertainty is too small</u> to be shown (reasonably on this graph's scale) (AW)	B1	Ignore: error too small <u>Examiner's Comments</u> 20 per cent of candidates did not attempt this item. Some candidates were on the right lines but very few mentioned about absolute uncertainty and that for these instruments and this graph, the absolute uncertainty was too small to view on this scale.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		iii	(The values for λ or θ will be) less precise (as independent measurements less likely to agree) (AW)	B1	Examiner's Comments About two fifths of candidates appreciated that the precision would not be as good with a protractor, as repeated measurements would be less likely to cluster in close proximity. <i>Precision</i> The term 'precision' is defined on page 40 of the Practical Skills Handbook, along with other useful terms that attempt to describe the quality of data
			Total	6	

Mark Scheme

Question		Answer/Indicative content	Marks	Guidance
32	a	Level 3 (5 - 6 marks) Clear procedure or correct determination of wavelength, plus reasonable estimation of uncertainty in λ or $(\sin) \theta$ <i>There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.</i> Level 2 (3 – 4 marks) Description of procedure or correct determination of λ, but no estimation of uncertainty or Clear estimation of uncertainty in wavelength but limited description of procedure and/or determination of λ or $(\sin) \theta$ or Some description of procedure, an attempt to determine the wavelength, and an attempt to estimate uncertainty in some of the measurements (e.g. in x) <i>There is a line of reasoning presented with some structure. The information presented is in the most part relevant and supported by some evidence.</i> Level 1 (1 – 2 marks) A limited selection from the scientific points worthy of credit. <i>There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.</i> 0 marks <i>No response or no response worthy of credit. <u>Frontal</u></i>	1 (AO3)	Use level of response annotations in RM Assessor, e.g. L2 for 4 marks, L2⁺ for 3 marks, etc. <u>L1 maximum for any answers which use formula $\lambda = ax/D$</u> Indicative scientific points may include: Procedure • use formula $n\lambda = d\sin\theta$ • $n = 1$ since first order spectrum • find d using number of lines/mm = 300 mm⁻¹ • find θ using distance of grating from plastic ruler = 0.50 m and $x = 0.10$ m (not protractor) Determination of wavelength • calculate d ($= 10^{-3}/300$) = 3.3×10^{-6} m • use $x = 0.10$ m and distance to grating = 0.50 m to calculate $\tan \theta$ ($= 0.2$) • $\theta = 11.3^\circ$ • $\sin \theta = 0.196$ • alternatively, calculate hypotenuse of triangle (using Pythagoras's theorem) = 0.51 m, giving $\sin \theta$ ($= 0.10/2600^{1/2}$) = 0.196 • allow use of small angle rule ($\sin \theta \approx \tan \theta \approx \theta = 0.2$) • calculate λ ($= 0.196 \times 10^{-3}/300$) = 650 nm Estimation of uncertainty • negligible uncertainty in d (and n) • uncertainty in $\sin \theta$ is found using uncertainty in distance measurements • uncertainty in each distance measurement is ± 1.0 mm or ± 0.5 mm or ± 2.0 mm • maximum % uncertainty in $\tan \theta / \theta / \sin \theta = 3\%$ • so % uncertainty in $\lambda = \% \text{ uncertainty in } \sin \theta = 3\%$

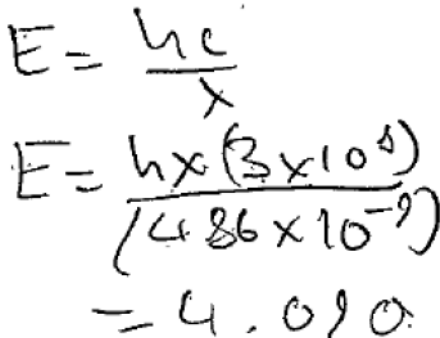
Mark Scheme

Question	Answer/Indicative content	Marks	Guidance
			<u>Examiner's Comments</u> Unfortunately, a significant number of candidates did not recognise the diffraction grating experiment here, confusing it with the double slit experiment and so using the formula $\lambda = ax/D$. This may be because the formula $n\lambda = d\sin\theta$ is in the astrophysics section of the formula sheet. Candidates who chose to use the correct formula $n\lambda = d\sin\theta$ were given for choosing the correct values for n, d and θ, for a correct calculation of λ, and for an accurate error analysis. Candidates who did not calculate λ could still gain full marks, as long as they gave accurate instructions as to how this could be done. Strong candidates successfully calculated a reasonable estimate of uncertainty in λ by combining the uncertainties in the distance measurements which had been used to find $\sin\theta$. AfL The experiment to measure the wavelength of light using a diffraction grating is PAG 5.1 and so is often carried out in Year 12. It may be beneficial to carry out this practical activity in Year 13 instead during the study of spectral lines, to reinforce use of the formula $n\lambda = d\sin\theta$. OCR support Being aware of the contents of the data, formulae and relationship booklet and its layout will support candidates, alleviating the need to recall numerical values of constants and allowing retrieval of correct formulae, or giving assurance that the student has recalled correctly.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
					Exemplar 7 Red photons occur only at the 4th order (a). There are 300 lines per millimeter, which is 300,000 per meter. ~~Very small separation is~~ Need to measure the angle θ between the 3rd and 4th order to use equation $d \sin \theta = n \lambda$ to solve for λ. A more fully decked room would be better as it's easier to determine what the colours are and see the light. Exemplar 7 illustrates many aspects of a Level 1 response. Although the correct formula has been identified, it will not give a correct value for λ because incorrect values for n, d and θ have been chosen. The response has been put at the bottom of Level 1 because, although there is an attempt at a logical structure, almost all of the information it contains is inaccurate and therefore not relevant.

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Question			Answer/Indicative content	Marks	Guidance
	b	i	$E = (hc/\lambda) = 6.63 \times 10^{-34} \times 3(00) \times 10^8 / 486 \times 10^{-9}$ $E = 4.09 \times 10^{-19} \text{ (J)}$	B1 B1	This is a 'show that' question so the mark is for giving the full substitution of values leading to an answer correct to 3 SF <u>Examiner's Comments</u> This question was successfully attempted by the majority of candidates. Exemplar 8  Exemplar 8 shows the most common incorrect response. The candidate has not realised that, in a 'show that' question, an equation, full substitution and calculated response are all required. This includes inserting numerical values for the constants h and c.
		ii	(vertical) arrow pointing downwards from -1.36 to -5.45	B1 B1	<u>Examiner's Comments</u> The majority of candidates scored at least 1 mark, although some would have been helped by better presentation.
			Total	9	

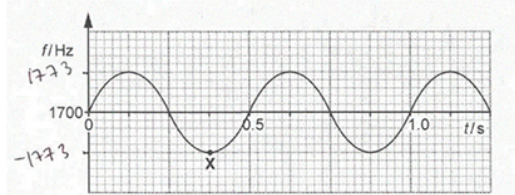
Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
33	a		Observed frequency is different to source frequency when source moves relative to observer.	B1	Allow synonyms for 'observed' e.g. perceived / detected / measured Allow any correct description of relative motion e.g. when source moves towards an observer (but not when source / observer moves) Allow the change in <u>observed</u> frequency / the <u>apparent</u> change or shift in frequency when source moves relative to observer Allow wavelength in place of frequency Answers must convey the difference between observed frequency and source frequency rather than a change in source frequency <u>Examiner's Comments</u> Very few candidates were able to score this mark. Misconception When a wave source moves towards or away from an observer, the frequency of the wave does not change; it only appears to have changed when viewed by the observer. Exemplar 9 Exemplar 9 illustrates a typical incorrect response.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
	b	i	$T = 0.50 \text{ (s) or } f = 2.0 \text{ (Hz)}$ $v = (2\pi r/T) = 2\pi \times 0.60/0.5$ $v = 7.5 \text{ (m s}^{-1}\text{)}$	C1 M1 A0	Allow $1.2\pi/0.5$ or 2.4π $= 7.54 \text{ (m s}^{-1}\text{)}$ <u>Alternative method:</u> $\omega = 4\pi$ or $12.6 \text{ (rad s}^{-1}\text{)}$ (C1) $v (= r \omega) = 0.60 \times 12.6$ or 2.4π (M1) $= 7.54 \text{ (m s}^{-1}\text{)}$ (A0) <u>Examiner's Comments</u> Most candidates scored this mark. Some tried to use the Doppler equation to find the speed of the sound (rather than the speed of the loudspeaker).
		ii	$\Delta f (\approx vf/c) = (7.5 \times 1700) / 330$ $\Delta f = 40 \text{ (Hz) (or 39Hz)}$	C1 A1	Note that c represents the velocity of sound <u>Examiner's Comments</u> The question had stated clearly that the students were investigating the Doppler effect, and candidates were expected to use the Doppler equation $\Delta f/f \approx v/c$.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		iii	y-axis labelled with correct scale	B1	Allow as a minimum one labelled point i.e. 1740 or 1660 ECF(c)(ii) for incorrect Δf Examiner's Comments Many candidates left 6(c)(iii) blank, although full marks could have been given from ECF from (c)(ii). The most common error here was using + and – the value obtained in (c)(ii), rather than subtracting or adding it to 1700, as demonstrated in Exemplar 10 below. Exemplar 10  (ii) The speed of sound in this experiment is 330 ms^{-1}. Calculate the maximum change in frequency Δf of the sound detected by the microphone. $\Delta f = \frac{v \cdot f}{c} = \frac{330 \cdot 1700}{1700} = 330$ $= \Delta f = 77.3$ $\Delta f = 77.3 \text{ Hz [2]}$
		iv	X labelled at lowest point of circle on Fig. 6.1	B1	Examiner's Comments The purpose of this question was to test whether candidates could associate a maximum decrease in observed frequency (a 'red shift') with motion directly away from the observer / microphone. Unfortunately, not many were able to place the cross correctly, with many leaving this response blank.
			Total	7	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
34			A	1	
			Total	1	
35			D	1	<u>Examiner's Comments</u> The Chandrasekhar limit for the mass of a white dwarf is 1.4 solar masses. The mass of the Sun is 2.0×10^{30} kg, so the mass limit for a white dwarf is 2.8×10^{30} kg. Only star D exceeds this limit, so it cannot be a white dwarf.
			Total	1	
36			B	1	<u>Examiner's Comments</u> Option D is the speed of light, so the galaxy cannot be travelling this fast. The change in wavelength for the galaxy is 20 nm. The laboratory wavelength for this light is 590 nm. The relationship we need is that the fractional change in wavelength for light from a galaxy approximately equals the fraction of the speed of light for that galaxy. The fractional change in wavelength is $20/590 = 3.39\%$ 3.39% of the speed of light = $1.02 \times 10^7 \text{ m s}^{-1}$, i.e. option B. Option A was the most common incorrect response, which is the speed when the change in wavelength is divided by the wavelength of light from the galaxy.
			Total	1	

Mark Scheme

Question	Answer/Indicative content	Marks	Guidance
37	Level 3 (5–6 marks) Correct calculations for radius and temperature range or distance or intensity for Earth-like temperature within given distance range, with clear explanation. <i>There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.</i> Level 2 (3–4 marks) Radius calculated or at least one temperature of planet calculated and some explanation. <i>There is a line of reasoning presented with some structure. The information presented is in the most-part relevant and supported by some evidence.</i> Level 1 (1–2 marks) Some explanation and an attempt at least one calculation. <i>There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.</i> 0 marks No response or no response worthy of credit.	B1x6	Use level of response annotation in RM Assessor, e.g. L2 for 4 marks, L2^ for 3 marks etc. Indicative scientific points may include: Explanation • TRAPPIST-1 is cooler than the Sun • The planets are closer to TRAPPIST-1 • Possible for temperature on planets to be like Earth • For life to exist, temperature is not the only factor • $L = 4\pi r^2 \sigma T^4$ (Any subject) Calculations • Calculation of 'constant' for Earth: $4(.19) \times 10^5$ • For inner-most planet, $T = 430 \text{ K}$ • For outer-most planet, $T = 180 \text{ K}$ • Calculation of distance for $T = 290 \text{ K}$, i.e. $3.4 \times 10^9 \text{ (m)}$ • There must therefore be a planet with temperature similar to that of the Earth • $L = 4\pi r^2 \sigma T^4$ used to calculate radius of TRAPPIST-1 • Radius of TRAPPIST-1 is $8.5 \times 10^7 \text{ (m)}$ or L/T^4 is smaller for TRAPPIST-1 • Comparison of calculated intensities at extreme distances around TRAPPIST-1 to intensity at Earth <u>Examiner's Comments</u> This level of response question was very well answered, largely due to the highly mathematical content. Higher level responses showed clarity of method as well as one of a range of ways of supporting the idea that life may be possible on the planets of TRAPPIST-1. Many candidates opted to show that the temperature of the nearest planet was approximately 430 K while that at the

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
					furthest planet was approximately 180 K. The argument went that there must be a distance at which the temperature was approximately 290 K. Other methods found the distance from TRAPPIST-1 that would give a surface temperature of 290 K and showed that lay within the range of distances given in the table.
			Total	6	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
38	a	i	distance between positions = 3.1 cm $2p = 3.1/2$ (any subject) $p = 0.78$ arc seconds	M1 M1 A0	Allow distance in the range 2.9 to 3.2 cm <u>Examiner's Comments</u> Almost all candidates scored a mark for measuring the distance between promixa centauri's positions 6 months apart. The scale was well understood, giving an angle of approximately 1.5 arc seconds. The parallax angle is defined to be half of this value, giving a parallax angle in this case of 0.75 arc seconds. This final step was what prevented candidates receiving the second mark.
		ii	$(d = 1 / p)$; $d = 1 / 0.8$ or 1.25 (pc) $d = 1.25 \times 3.26$ $d = 4.1$ (ly)	C1 A1	Allow: their value for p Possible ECF from (a)(i) Answer is 4.2 using 0.78 arc seconds <u>Examiner's Comments</u> Most candidates used the data in the previous part of the question ie that the parallax angle was 0.8 arc seconds or trusted their own value which was close to 0.8 arc seconds. Nearly everyone that presented a distance in parsecs could then calculate the distance in light years.

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Question			Answer/Indicative content	Marks	Guidance
	b	i	$F = GMm/r^2$ $F = G \times (2.0 \times 10^{41})^2 / (1.4 \times 10^{23})^2$ force = 1.4×10^{26} (N)	C1 A1	Note the mark is for substitution, value of G is not required Ignore: minus sign Allow 1 mark for 1.4×10^4 N ;use of mass of star instead of mass of galaxy. <u>Examiner's Comments</u> While some lower level responses included an attempt to find the gravitational field strength rather than the force most selected the correct formula. After selecting the correct relationship, most candidates could then correctly find the force, provided that they remembered to multiply the masses and square the distance of separation.
		ii	density = $10^{11} \times 2.0 \times 10^{30} / 2.7 \times 10^{69}$ density = 7.4×10^{-29} (kg m ⁻³)	M1 A0	
		iii	Any reasonable answers questioning model such as observed average distance may be different, average mass may be wrong etc.	B1	e.g. black holes, dark energy/matter, expanding universe <u>Examiner's Comments</u> This was a question about challenging the model of the universe. The model takes into account an average mass and average distance of separation, so answers that referred to a variation in masses or distances between galaxies did not score. Higher level responses included that the universe was expanding, so that the distances involved were always changing, or that dark matter was not included in the calculations. There was no indication that candidates were constrained by time in this paper.
			Total	8	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
39			C	1	
			Total	1	
40			B	1	
			Total	1	
41			D	1	
			Total	1	
42			B	1	
			Total	1	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
43	a	i	X at closest point on orbit to the Sun	B1	Allow X on the orbit to the <u>left</u> of the Sun
		ii	(When the asteroid orbits the sun a) line segment joining the asteroid to the Sun sweeps out equal areas in equal time (intervals) Longer distance (in orbit for the same time)	B1 B1	Allow this mark on diagram (no labelling required) Allow 'equal area swept in same time'
	b	i	Work done per unit mass to move an object from infinity (to that point)	B1	Not 'work done on 1 kg'
		ii	Manipulation of $V_{(g)} = (-) GM/r$	B1	
		iii	gradient = $(-)30.4$ or equivalent working candidate's gradient or expression = $6.67 \times 10^{-11} \times M$ and M calculated correctly from that gradient $M = 4.6 \times 10^{11}$ (kg)	C1 C1 A0	Allow ± 2 Possible ECF from incorrect gradient Allow any subject
	c		Method 1: Evidence of 2.3×10^{-3} <u>and</u> 600^{-1} or $(2.3 \times 10^{-3})^{-1}$ and 600 $\frac{1}{2} v^2 = 6.67 \times 10^{-11} \times 4.6 \times 10^{11} \times (2.3 \times 10^{-3} - 600^{-1})$ $v = 0.20$ (m s ⁻¹) Method 2: Evidence of 7.0×10^{-2} <u>and</u> 5.1×10^{-2} from graph $\frac{1}{2} v^2 (= \Delta V_{(g)}) = 7.0 \times 10^{-2} - 5.1 \times 10^{-2}$ $v = 0.19$ (m s ⁻¹)	C1 C1 A1 (C1) (C1) (A1)	Possible ECF from (b)(iii) for either value of GM or M Allow $\frac{1}{2} v^2 = 30 \times (2.3 \times 10^{-3} - 600^{-1})$ Note answer can be 0.19 or 0.20 or 0.2 m s ⁻¹ Note answer can be 0.19 or 0.20 or 0.2 m s ⁻¹ Allow correct use of one piece of data arriving at a value for v for 1 mark max
			Total	10	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
44	a		Any four from • reduction in energy released by fusion • gravitational force is greater than that from radiation and gas pressure • core collapses • fusion no longer takes place in the core • fusion continues in the shell around the core • outer layers of star expand and cool • outer layers are released • reference to planetary nebula • reference to <u>white</u> dwarf (left as remnant hot core)	B1 × 4	Ignore current or previous stages of the Sun's evolution
	b	i	$\lambda T = \text{constant}$ however expressed $500 \times 5.8 \times 10^3 = 240 \times T$ <u>and</u> T correctly evaluated $T = 12000 \text{ (K)}$	C1 C1 A0	Note answer is 12080 (K) to 4 SF Allow any subject
		ii	$(L = 4\pi r^2 \sigma T^4)$ $4.62 \times 10^{31} = 4\pi \times 5.67 \times 10^{-8} \times r^2 \times 12000^4$ radius = $5.6 \times 10^{10} \text{ (m)}$	C1 A1	Note 12080 K gives $5.5 \times 10^{10} \text{ (m)}$
	c		(A white dwarf has mass equal to or) less than 1.4(4) solar masses / Chandrasekhar limit (ORA)	B1	Allow $M_{\odot}$ for solar mass Allow reference to neutron star (over Chandrasekhar limit) Allow correct reference to electron degeneracy pressure / Pauli Exclusion Principle
			Total	9	

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Question			Answer/Indicative content	Marks	Guidance
45		i	$L (= 4\pi r^2 \sigma T^4) = 4 \times \pi \times (7.0 \times 10^8)^2 \times 5.67 \times 10^{-8} \times 5800^4$ $L = 3.95 \times 10^{26} \text{ (W)}$	M1 A0	Mark is for substitution of values Allow σ for 5.67×10^{-8} <u>Examiner's Comments</u> Most candidates successfully used the formula for Stefan's Law.
		ii	By ratios: $25 = 1.7^2 \times (T/5800)^4$ $T^4 = 9.8 \times 10^{15}$ $T = 9950 \text{ (K)}$	C1 C1 A1	or $T^4 = 25L/4\pi\sigma(1.7r)^2$ $= \frac{25 \times 3.95 \times 10^{26}}{4\pi \times 5.67 \times 10^{-8} \times (1.7 \times 7 \times 10^8)^2}$ ECF for L in a(i) but only if $L = 4 \times 10^{26}$ to 1s.f. ECF for incorrect σ in a(i) Allow 9.9×10^{15} (using $L = 4 \times 10^{26}$) Allow 10,000 K <u>Examiner's Comments</u> Higher ability candidates successfully used the more elegant ratios method to reach the correct response. Lower ability candidates had more success if they broke their calculation down into smaller steps, such as calculating and writing down T^4 rather than going straight to T . Candidates should be encouraged to consider whether their responses to calculations are reasonable as this will alert them to a possible error. For example, some candidates calculated the temperature of Sirius (which they were told is the brightest star in the night sky) to be less than 1K.
			Total	4	