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OCR A LEVEL PHYSICS A (H556): QUESTIONS BY TOPIC

Astrophysics and cosmology (5.5)

A Level Physics A (H556) · Module 5: Newtonian world and astrophysics

34 questions · 178 marks · Mark schemes included

OCR A Level Physics A (H556), June 2017 – June 2025

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HOW TO USE THIS BOOKLET

Questions run from the lowest mark tariff to the highest, so similar questions sit together.

Click any row below to jump straight to that question.

On every question page, click ANSWER in the top-right corner to jump to its mark scheme.

Diagrams, graphs, tables and data are printed exactly as they appeared in the original papers.

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QUESTIONS

34 questions · 178 marks · lowest tariff first



MULTIPLE-CHOICE QUESTIONS

17 questions in this booklet



15 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]

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Turn over

SECTION B

Answer **all** the questions.



13 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]



- 14 Some stars will evolve into white dwarfs.
The mass of the Sun is $2.0 \times 10^{30} \text{ kg}$.

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

- A $1.2 \times 10^{30} \text{ kg}$
- B $2.0 \times 10^{30} \text{ kg}$
- C $2.7 \times 10^{30} \text{ kg}$
- D $3.2 \times 10^{30} \text{ kg}$

Your answer

[1]



- 15** 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** $9.8 \times 10^6 \text{ m s}^{-1}$
B $1.0 \times 10^7 \text{ m s}^{-1}$
C $2.9 \times 10^8 \text{ m s}^{-1}$
D $3.0 \times 10^8 \text{ m s}^{-1}$

Your answer

[1]

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Question 16 begins on page 10



SECTION B

Answer **all** the questions.



- 7 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]

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- 5 A spectral line corresponds to a wavelength λ_1 in the laboratory.
The same spectral line observed in the spectrum of a receding galaxy corresponds to a wavelength λ_2 .
The distance of the galaxy from the Earth is d . The speed of light in a vacuum is c .

What is the correct expression for the Hubble constant H_0 ?

A $H_0 \approx \frac{c(\lambda_2 - \lambda_1)}{d\lambda_1}$

B $H_0 \approx \frac{c\lambda_1}{d(\lambda_2 - \lambda_1)}$

C $H_0 \approx \frac{c\lambda_2}{d\lambda_1}$

D $H_0 \approx \frac{c\lambda_1}{d\lambda_2}$

Your answer

[1]

15 The parallax angle for a star is 0.015 seconds of arc.

What is the distance in parsecs (pc) of the star from the Earth?

- A** 67 pc
- B** 133 pc
- C** 220 pc
- D** 2.1×10^{18} pc

Your answer

[1]



SECTION B

Answer **all** the questions.



- 14 A galaxy, 1.0×10^9 light-years away from the Earth, has a recession speed of $23\,000 \text{ km s}^{-1}$.

Which expression, based on the information above, is correct for the age of the universe in seconds?

A $\text{age} = \frac{1.0 \times 10^9}{23\,000 \times 10^3}$

B $\text{age} = \frac{1.0 \times 10^9 \times 1.5 \times 10^{11}}{23\,000}$

C $\text{age} = \frac{1.0 \times 10^9 \times 9.5 \times 10^{15}}{23\,000 \times 10^3}$

D $\text{age} = \frac{1.0 \times 10^9 \times 3.1 \times 10^{16}}{23\,000 \times 10^3}$

Your answer

[1]



- 15** Astronomers observe approximately the same number of distant galaxies per unit volume of space in all directions.

Which idea does this observation support?

- A** Big bang model of the universe
- B** Cosmological principle
- C** Existence of dark matter
- D** Hubble's law

Your answer

[1]

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Turn over

SECTION B

Answer **all** the questions.



13 During the evolution of the universe there was a period of inflation.

Which forms of matter, if any, existed 10^{-10} s after the big bang?

- A** Atoms
- B** Leptons
- C** None
- D** Quarks

Your answer

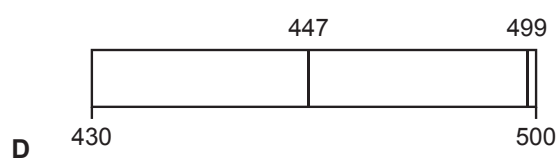
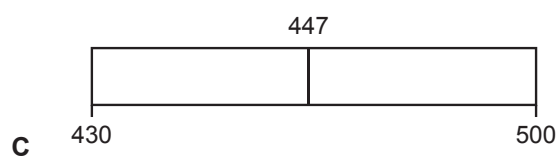
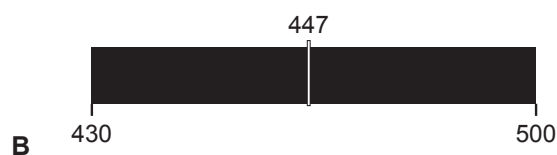
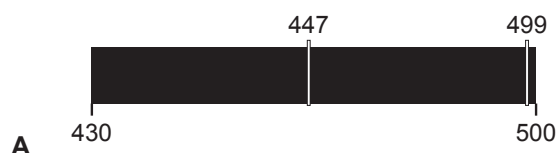
[1]



- 14 Part of the emission spectrum for hydrogen in a laboratory is shown. All wavelengths are given in nm.



Which diagram shows the corresponding part of the absorption spectrum observed from Earth emitted from a galaxy moving away with a velocity of $0.031c$?



Your answer

[1]

15 An early estimate for the Hubble constant was $500 \text{ km s}^{-1} \text{ Mpc}^{-1}$.

What is the value of this estimate in units of s^{-1} ?

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

A 2.3×10^{-18}

B 1.6×10^{-17}

C 1.6×10^{-5}

D 0.5

Your answer

[1]



15 Stars rotate around the centre of their galaxy.

Observations suggest that the stars at the edges of galaxies are moving at much higher velocities than expected.

What is the name given to the current explanation for these observations?

- A** Chandrasekhar limit
- B** Dark matter
- C** The Cosmological principle
- D** Wien's displacement law

Your answer

[1]

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- 7 The apparent position of a star changes by an angle of 1.0×10^{-4} degrees between observations made 6 months apart from the same place on Earth.

What is the distance of the star from Earth in parsecs?

- A 2.8
- B 5.6
- C 170
- D 330

Your answer

[1]



10 Which of the following determines whether a super red giant evolves to a black hole?

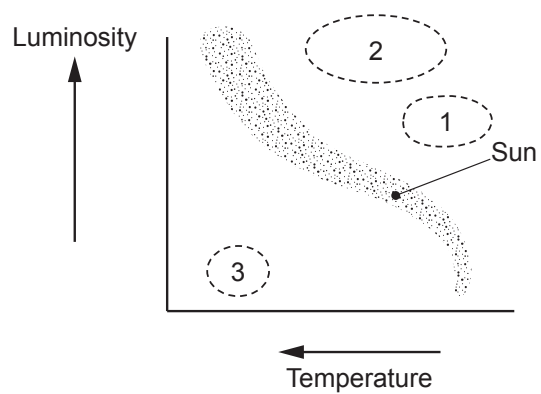
- A** Dark matter
- B** Electron degeneracy
- C** Mass of the core
- D** The Chandrasekhar limit

Your answer

[1]



12 Which option correctly gives the likely evolution of the Sun?



A 1 → 2 → 3

B 1 → 3

C 2 → 1 → 3

D 2 → 3

Your answer

[1]

15 Which of these statements about the Universe is implied by the Cosmological principle?

- A** Dark energy is found in every galaxy
- B** Kepler's laws can be applied to any solar system
- C** Matter and anti-matter were formed in the very early Universe
- D** Microwave background radiation corresponds to a temperature of 2.7 K

Your answer

[1]



4-MARK QUESTIONS

1 question in this booklet



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

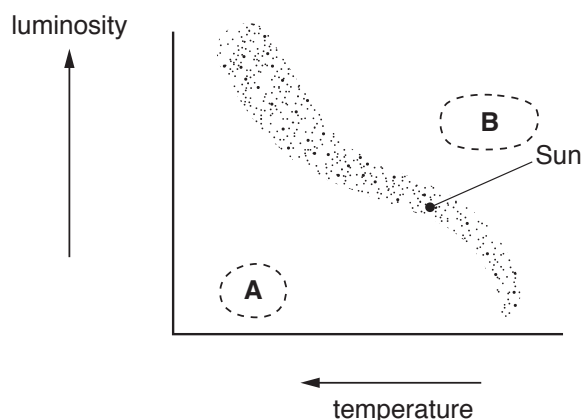


Fig. 19

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

(a) 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]

6-MARK QUESTIONS

2 questions in this booklet



22* A star has a mass similar to that of the Sun.

Describe how the position of this star on a Hertzsprung-Russell (H-R) diagram changes as it evolves.

Fig. 22.1 is a blank H-R diagram.

You may add information to **Fig. 22.1** as part of your response.

Fig. 22.2 shows the relative intensities of different wavelengths of light in the spectrum of a star.

Explain how information from **Fig. 22.2** could be used to suggest the stage of evolution of the star. Describe the limitations of the analysis.

[6]

Fig. 22.1

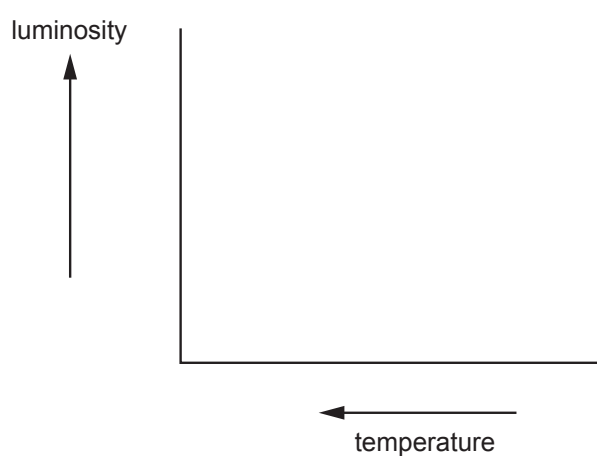
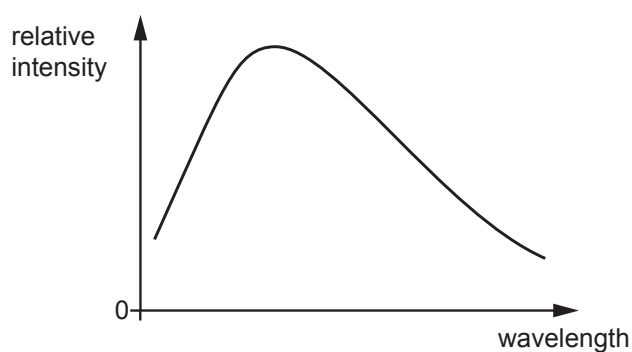


Fig. 22.2



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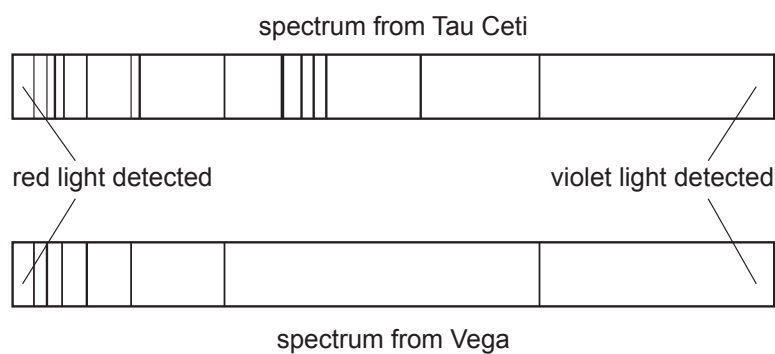
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21* Analysis of stellar light can identify the elements that are present in the outer layers of a star.

Absorption spectra of visible light collected from two main sequence stars, Vega and Tau Ceti, are shown below. The spectra were collected by a telescope orbiting the Earth. The dark lines on the diagram show wavelengths where the intensity was zero or close to zero.

- Explain the cause of the dark lines.
- Describe and explain at least one difference between the spectra.
- Analyse the spectra to determine which star is older.



[6]

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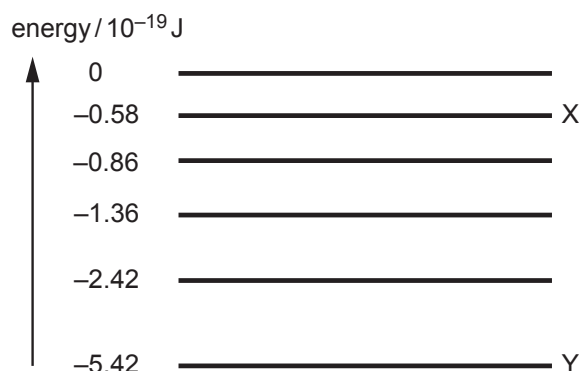


7-MARK QUESTIONS

1 question in this booklet



- 23** The diagram shows some of the energy levels of the electron in a hydrogen atom.



- (a)** An electron moves from energy level X to energy level Y.

Show that the wavelength of the photon produced is about 410 nm.

[2]

- (b)** The light from the stars in a distant galaxy is analysed on the Earth using a diffraction grating.

Dark lines are observed in the spectrum.

An astronomer concludes that the dark line at a wavelength 432 nm corresponds to the electron transition between X and Y.

- (i)** Explain the origin of the dark lines.

.....

 [2]

- (ii)** Calculate the recession velocity v of the galaxy.

$v = \dots\dots\dots \text{ms}^{-1}$ [2]

- (iii)** State the name of the theory that is supported by evidence from the measurement of the recession velocities of galaxies in the universe.

..... [1]



8-MARK QUESTIONS

2 questions in this booklet



- 24 (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.

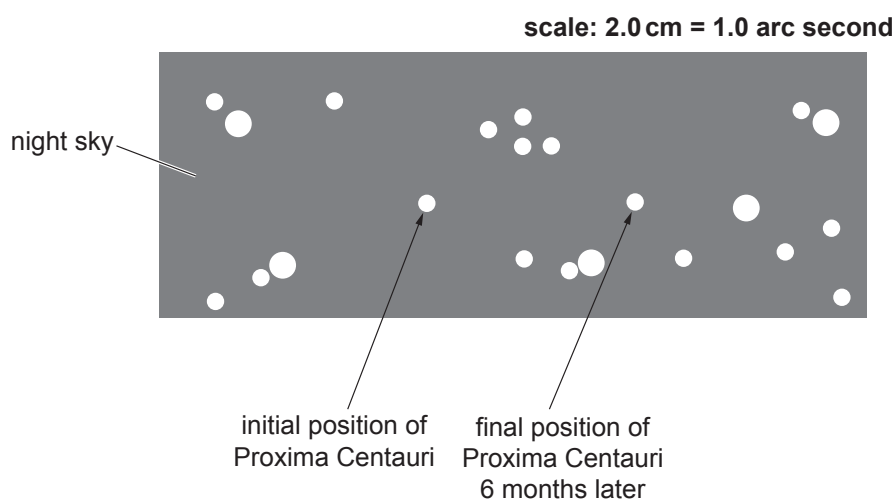


Fig. 24.1

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]

Question 24 continues on page 30

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

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

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

- (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.

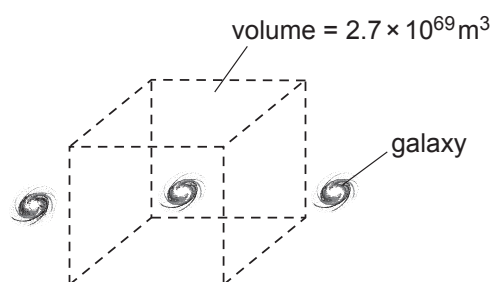


Fig. 24.2

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.

force = ... 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).

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..... [1]



- 22 (a)** A team of astronomers have measurements to determine the peak surface temperature T and luminosity L of a distant star. They plan to use Stefan's law to estimate the radius r of this star.

Explain whether the astronomers should attempt to measure T or L more precisely to reduce the uncertainty in r .

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..... [2]

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Turn over



(b)* It is suggested that the luminosity L and the mass M of a star can be compared to the Sun by the equation

$$\frac{L}{L_{\odot}} = \left(\frac{M}{M_{\odot}}\right)^b$$

where $L_{\odot}$ is the luminosity of the Sun and $M_{\odot}$ is the mass of the Sun.

The value of b is between 3 and 4.

Table 22 shows some data of five stars.

Main sequence star	$\frac{M}{M_{\odot}}$	$\frac{L}{L_{\odot}}$
Pi Andromedae A	6.5	800
Alpha Coronae Borealis A	3.2	80
Gamma Virginis	1.7	6.0
Eta Arietis	1.3	2.5
70 Ophiuchi A	0.78	0.4

Table 22

Fig. 22 shows the $\lg\left(\frac{L}{L_{\odot}}\right)$ against $\lg\left(\frac{M}{M_{\odot}}\right)$ plot for these stars.

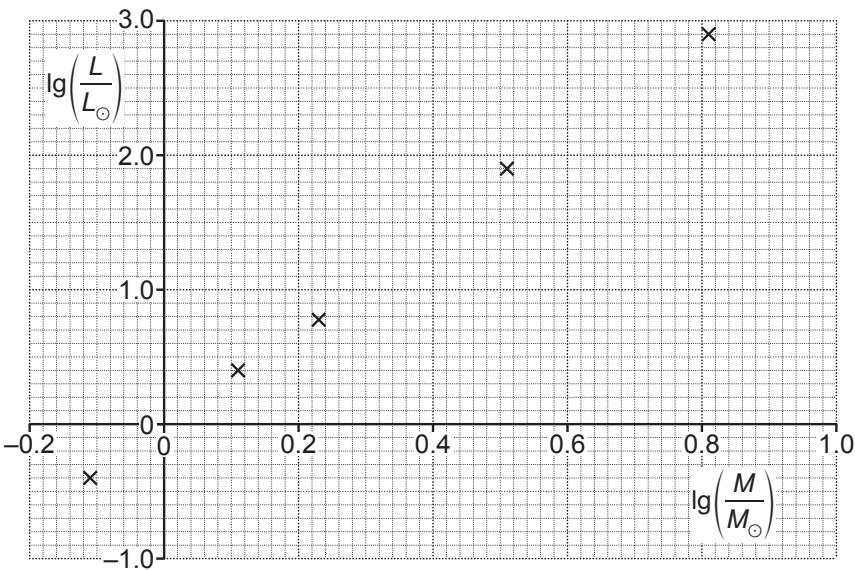


Fig. 22

The luminosity of a star is directly proportional to the rate of fusion of hydrogen nuclei.

Use **Fig. 22** to determine b and use your knowledge of Hertzsprung–Russell (HR) diagrams to deduce how the lifespan of hotter stars compares with lifespans of cooler stars. **[6]**

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9-MARK QUESTIONS

3 questions in this booklet



- 23 (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 $68 \text{ km s}^{-1} \text{ Mpc}^{-1}$.

$\lambda = \dots\dots\dots \text{ nm}$ [3]

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

.....
 [1]

(c) The Universe evolved from the Big Bang.

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

[4]



- 23 (a)* 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.

[6]

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Question 23 continues on page 28



(b) Kepler's third law can be applied to a satellite in a geostationary orbit around the Earth.

- (i) Complete the equation for Kepler's third law below.
You do not need to define any of the terms.

$$\dots\dots\dots = \frac{4\pi^2}{GM} \dots\dots\dots \quad [1]$$

- (ii) The mass of Earth is 6.0×10^{24} kg.
Calculate the radius of the circular path of a satellite in a geostationary orbit around the Earth.

radius = $\dots\dots\dots$ m [2]

24 (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]

10-MARK QUESTIONS

3 questions in this booklet



3 This question is about the Sun and its radiation.

- (a) (i) Use the data below to show that the luminosity of the Sun is about $4 \times 10^{26} \text{ W}$.
- radius of Sun = $7.0 \times 10^8 \text{ m}$
 - 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.

$T = \dots\dots\dots \text{ K}$ [3]

***(b)** A student attends a lecture about the Sun and makes the following notes.

1. The Sun loses more than 4×10^9 kg of its mass every second to maintain its luminosity.
2. Treating hydrogen nuclei (protons) as an ideal gas, a temperature of 10^{10} K provides a kinetic energy of about 1 MeV, which is necessary for fusion.
3. However, the Sun's core temperature is only 10^7 K, so the chance of protons fusing on collision is very small. This explains why the Sun has such a long lifetime.

Explain the principles of physics which are involved in each of the three points.
You should include relevant formulae, but no numbers or calculations are required.

[6]

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- 23** The Hipparcos space telescope used stellar parallax with a precision of 9.7×10^{-4} arcseconds to determine the distance to stars.

One of the stars studied was Polaris A. Data about this star is in the table below.

Parallax angle	7.5×10^{-3} arcseconds
Radius	2.1×10^{10} m
Mass	1.1×10^{31} kg
Surface temperature	6000 K
Temperature of the atmosphere of the star	4.0×10^6 K

- (a) (i)** Estimate the maximum stellar distance in parsecs that could be measured using Hipparcos.

maximum stellar distance = ...pc **[1]**

- (ii)** Calculate the percentage uncertainty in the calculated value of the distance to Polaris A.

percentage uncertainty = ... % **[2]**

- (b)** A continuous stream of particles called a solar wind flows from the surface of the star into the surrounding space.

These particles include helium nuclei of mass 6.6×10^{-27} kg.

Assume that the atmosphere is modelled as an ideal gas.

- (i)** Show that the typical kinetic energy of a helium nucleus in the atmosphere is about 10^{-16} J.

[2]

- (ii) The gravitational potential energy of a helium nucleus in the outer layer of the star is $-2.3 \times 10^{-16} \text{ J}$.

Calculate the gravitational potential energy U at the maximum distance from the star that a helium nucleus could reach.

$U = \dots\dots\dots \text{ J [1]}$

- (iii) Calculate the distance from the centre of the star reached by this helium nucleus.

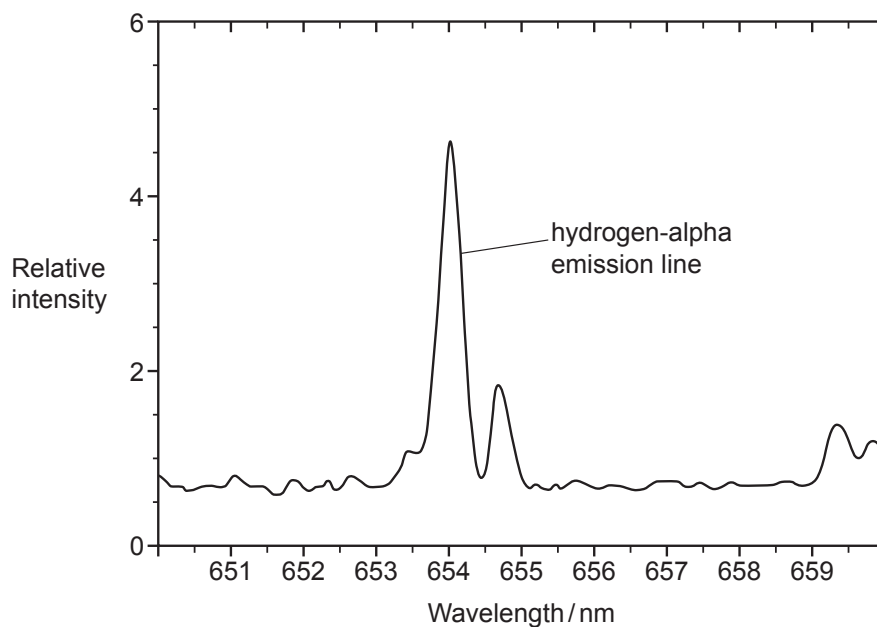
distance = $\dots\dots\dots \text{ m [3]}$

- (iv) Explain why the star has a solar wind that reaches a much greater distance from the star than found in (iii).

$\dots\dots\dots$
 $\dots\dots\dots \text{ [1]}$

- 23** The diagram below shows the part of the spectrum of light from the galaxy M87 with a strong hydrogen-alpha emission line.

The spectrum of a sample of hydrogen gas analysed in a laboratory on Earth showed this emission line to be at 656.3 nm.



- (a)** Calculate the magnitude of the recession velocity of M87.

velocity = ... km s^{-1} [3]

- (b)** Estimate the distance in light years to M87 using Hubble's law.

Hubble's constant $H_0 = 2.5 \times 10^{-19} \text{ s}^{-1}$

distance = ... ly [2]

- (c) Estimate the percentage uncertainty in the distance calculated in part (b) using the width of the emission line in the diagram.

percentage uncertainty = $\pm$ % [2]

- (d) Other methods have shown M87 is actually 50 million light years from Earth.

Suggest why M87 might contradict Hubble's law.

.....
.....
..... [2]

- (e) Suggest **one** reason why the Big Bang theory is still the accepted model of the origin of the Universe.

.....
..... [1]

11-MARK QUESTIONS

2 questions in this booklet



- 6 (a) Describe the **Doppler effect**.

.....
 [1]

- (b) Explain how ultrasound is used to measure the speed of blood flow in an artery.

.....

 [2]

- (c) 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.

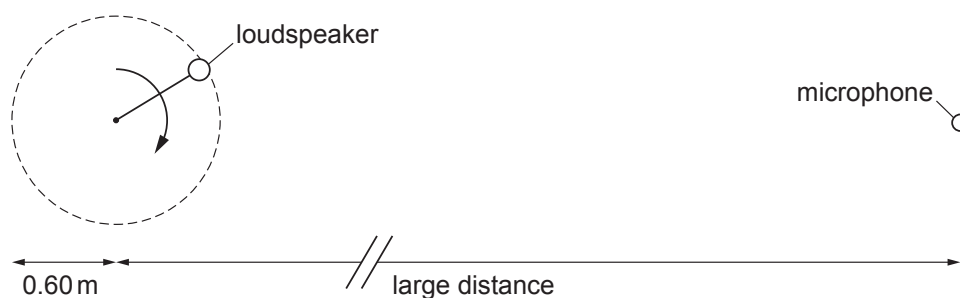


Fig. 6.1

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

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

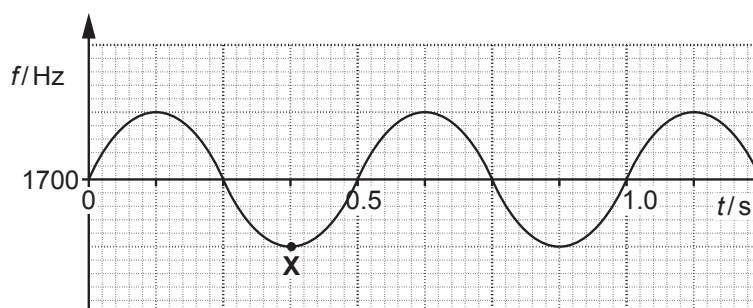


Fig. 6.2

- (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]

- (d) In their laboratory notes, one student writes about the **accuracy** of the measurements whereas the other writes about their **precision**.

Define these terms.

accuracy:

.....

precision:

..... [2]



3 A pulsar is a rapidly rotating neutron star that emits radio waves.

(a) (i) Describe the formation of a neutron star.

.....

.....

.....

..... [2]

(ii) State **one** characteristic of a neutron star.

.....

.....

.....

..... [1]

(b) A typical neutron star can be modelled as a sphere with mass $\approx 2 \times 10^{30}$ kg and radius ≈ 10 km.

Show that the average density of a neutron star is similar to the average density of an atomic nucleus.

- radius of a nucleon ≈ 1 fm

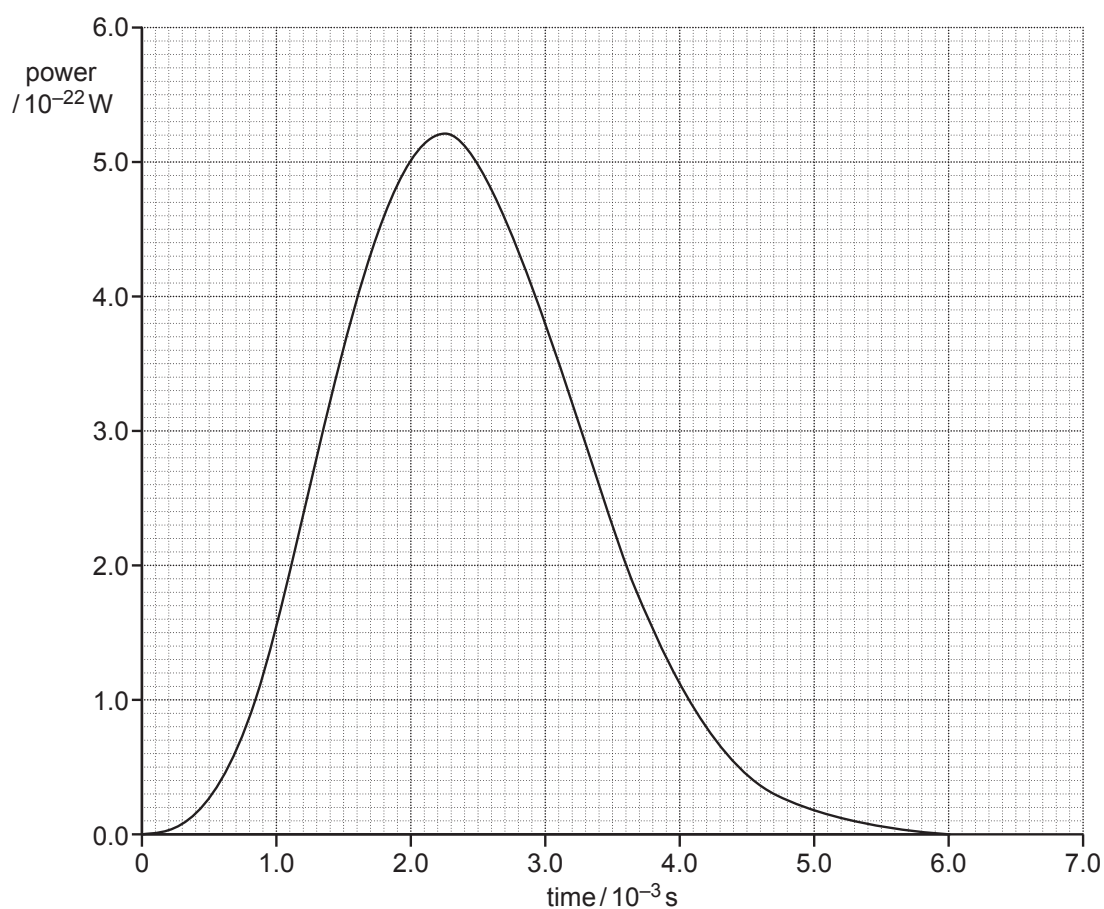
[3]

Question 3 continues on page 10



- (c) An astronomer uses a radio telescope to observe a pulsar.

The graph below shows the power that the telescope receives due to the radio waves from one full rotation of a pulsar.



- (i) By calculating the area between the curve and the horizontal axis, estimate the total energy received by the telescope in one full rotation of the pulsar.

total energy received = ... J [2]

- (ii) The surface area of the telescope is about 3000 m^2 .

The distance to the pulsar is about 300 pc.

By assuming that the radiation from the pulsar is emitted equally in all directions, estimate the total energy emitted in one full rotation.

energy emitted = ... J [3]

14-MARK QUESTIONS

2 questions in this booklet



- 21 (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**.

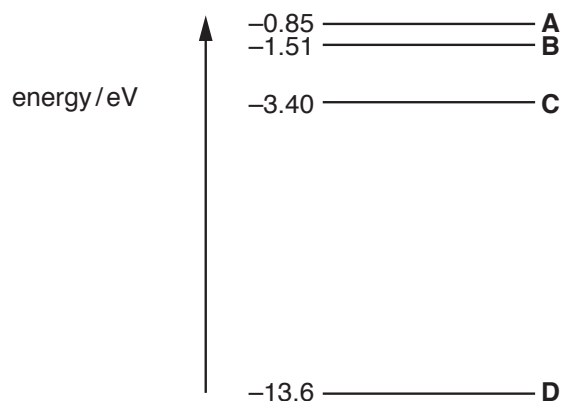


Fig. 21.1 (not to scale)

- (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]

- 2 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.

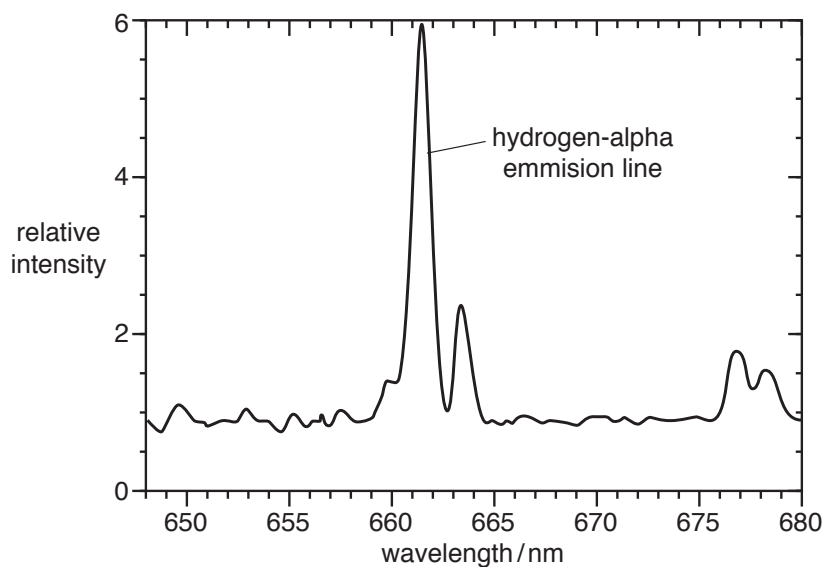


Fig. 21.2

- (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 = ... ms^{-1} [3]

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

.....
..... [1]

- (c) Light from a similar star is viewed in a galaxy **further** away. The star is part of a pair of stars which orbit a common centre of mass.

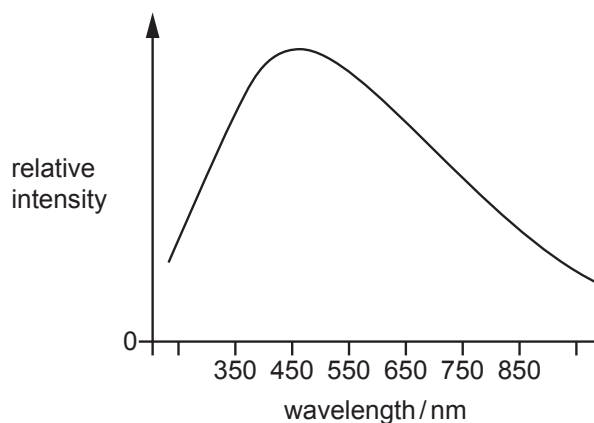
Describe and explain how the equivalent spectrum might appear.

.....
.....
.....
.....
.....
.....
..... [3]

- 21** This question is about analysing the electromagnetic radiation from the star Nu Persei in the Milky Way galaxy.

Fig. 21.1 shows the relative intensities of different wavelengths of electromagnetic radiation from Nu Persei.

Fig. 21.1



The surface temperature of the Sun is 5800 K and its wavelength at which maximum intensity is emitted is 500 nm.

The luminosity of Nu Persei is 2.3×10^{29} W.

(a)

- (i)** Use **Fig. 21.1** to show that the surface temperature of Nu Persei is about 6300 K.

[2]

- (ii)** Estimate the radius of Nu Persei.

radius = ... m **[3]**

- (b) Electromagnetic radiation is collected from Nu Persei by a sensor with an efficiency of 11% and cross-sectional area $1.0 \times 10^{-4} \text{ m}^2$.

The radiant power collected by the sensor is $7.0 \times 10^{-15} \text{ W}$.

- (i) Show that the radiant power per unit area arriving at the sensor is about $6 \times 10^{-10} \text{ W m}^{-2}$.

[2]

- (ii) By the time the electromagnetic radiation from Nu Persei reaches Earth, the radiation from Nu Persei is evenly distributed over a spherical area with radius equal to the distance between Nu Persei and Earth.

Calculate the distance of Nu Persei from Earth in light years.

distance = ... light years [4]

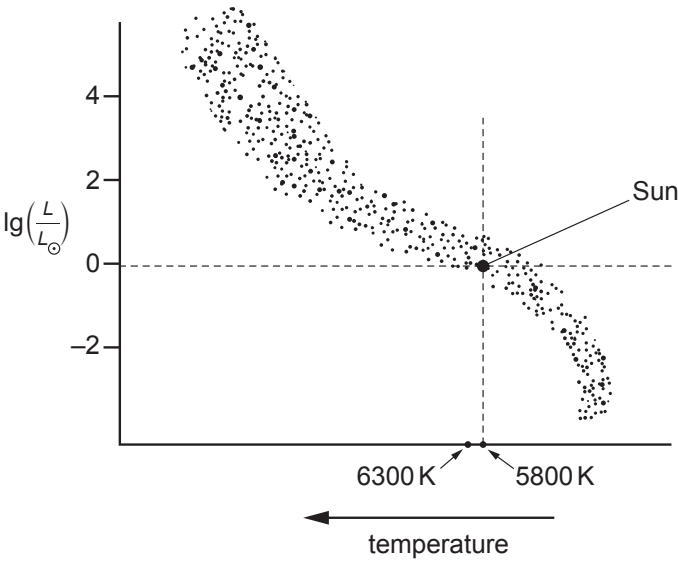
- (c) The luminosity of Nu Persei was estimated using the temperature of Nu Persei and the Hertzsprung-Russell (HR) diagram in **Fig. 21.2**. L is the luminosity of a star and $L_{\odot}$ is the luminosity of the Sun.

The temperature data from earlier in this question is repeated in the table below.

Star	Surface temperature / K
Sun	5800
Nu Persei	6300

Comment on the uncertainty in your value, calculated in **b(ii)**, of the distance of Nu Persei from Earth. You may write on the diagram as part of your answer.

Fig. 21.2



.....
.....
.....
..... [3]

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15-MARK QUESTIONS

1 question in this booklet



23 Algol is a triple-star system, with stars Aa1, Aa2 and Aa3 orbiting each other. This triple-star is 90 light-years from the Earth.

(a) Here is some data on the star Aa1.

- radius = $(1.90 \pm 0.14) \times 10^9 \text{ m}$
- mass = $(6.31 \pm 0.42) \times 10^{30} \text{ kg}$.

Calculate the gravitational field strength g at the surface of Aa1 to **3** significant figures. Include the absolute uncertainty in your answer. Assume that the other stars of the system exert negligible gravitational force on Aa1.

$$g = \dots\dots\dots \pm \dots\dots\dots \text{ N kg}^{-1} \text{ [4]}$$

(b) The table shows some data about the three stars of Algol.

Star	Luminosity of star / $L_{\odot}$	Surface temperature of star / K
Aa1	182	13 000
Aa2	6.92	4500
Aa3	10.0	7500

The luminosity of each star is in terms of the solar luminosity $L_{\odot}$.

(i) Define the **luminosity** of a star.

.....
 [1]

(ii) Use Stefan's law to determine the ratio $\frac{\text{radius of star Aa2}}{\text{radius of star Aa3}}$.

$$\text{ratio} = \dots\dots\dots \text{ [2]}$$

- (iii) Use Wien's displacement law to explain which star would have the **longest** wavelength at the peak intensity of the emitted electromagnetic radiation.

.....

 [2]

- (iv) Suggest how an astronomer using just an optical telescope can deduce that the three stars of Algol have different surface temperatures.

.....
 [1]

- (v) The light from each star passing through a diffraction grating shows an absorption line spectrum.

Explain how a specific absorption line is produced in this type of spectrum in terms of **photons** and **electrons**.

.....

 [3]

- (c) The Aa1 star could evolve into a black hole.

State **two** ways in which the black hole would differ from the Aa1 star.

1.

 2.
 [2]

MARK SCHEMES

official OCR mark schemes



15	C	1	
	Total	15	

6

SECTION B

Question	Answer	Marks	Guidance
-----------------	---------------	--------------	-----------------



13	A	1	
----	---	---	--



14	D	1	
----	---	---	--



15	B	1	
	Total	15	

4



7	B	1	
---	---	---	--



5	A	1	
---	---	---	--



15	A	1	
	Total	15	

4

SECTION B

General rule: For substitution into an equation, allow any subject – unless stated otherwise in the guidance

Question	Answer	Marks	Guidance
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14	C		1	
----	---	--	---	--



15	B	1	
	Total	15	

9

SECTION B

General rule: For substitution into an equation, allow any subject - unless stated otherwise in the guidance

Question	Answer	Marks	Guidance
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13	C	1	
----	---	---	--



14	C	1	
----	---	---	--



15	B	1	
	Total	15	

9

SECTION B

General rule: For substitution into an equation, allow any subject - unless stated otherwise in the guidance

Question	Answer	Mark	Guidance
-----------------	---------------	-------------	-----------------



15	B	1	
	Total	15	

9

SECTION B

General rule: For substitution into an equation, allow any subject - unless stated otherwise in the guidance

General rule: Only penalise 1sf if answer to more sf not seen

Question	Answer	Mark	Guidance
----------	--------	------	----------



7	B	1	
-	-	-	



10	C	1	
..	-	.	



12	B	1	
-----------	----------	----------	--



15	B	1	
	Total	15	

9

SECTION B

General rule: For substitution into an equation, allow any subject - unless stated otherwise in the guidance

Question	Answer	Mark	Guidance
-----------------	---------------	-------------	-----------------



19	(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.
			Total	4	

Question	Answer	Marks	Guidance
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22		Level 3 (5–6 marks) Clear description, explanation and limitations with correct annotations on diagram <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 description of evolution and some explanation of analysis or Some description of evolution and some limitations <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 description or Limited explanation or limitations <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.</i>	B1 x 6	Use level of response annotations in RM Assessor Indicative scientific points may include: Description of evolution • Main sequence labelled • Red giants/supergiants labelled • White dwarves labelled • Correct order of evolution • Dependence on mass/Chandrasekhar's limit • Evolutionary track shown on diagram Explanation of analysis • Identification of peak wavelength from graph • Use of Wien's law • Determination of temperature • Gives the horizontal co-ordinate Limitations • Does not give luminosity data • Cannot distinguish between similar temperature stars (e.g. white dwarf, main sequence or a hot super giant) • Need luminosity data to classify the star • Difficult to isolate light from stars in other galaxies to analyse • If looking at stars in other galaxies, have to account for red shift requiring emission data.
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21		Level 3 (5–6 marks) Detailed explanation of dark lines. Differences between lines discussed with explanation. Correct conclusion with reasoning <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 explanation of dark lines with some differences between lines Or Detailed description of dark lines Or Detailed description of the differences in line <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) Either Limited explanation of dark lines or a difference in lines given with an unsupported conclusion or no conclusion at all	B1 x 6	Indicative scientific points may include: Dark lines • Dark lines show wavelengths absorbed • Star produces a continuous spectrum • Atmosphere of star absorbs light • Photons are absorbed by electrons increasing/moving ‘up’ energy levels • Energy of photons match differences in energy levels of atoms • Light is re-emitted by atoms in star atmosphere • Light is re-emitted in random directions Differences (number of lines and intensities) • Tau Ceti has extra lines/Vega has fewer lines • Lines in common are different intensities (stronger/weaker) • Tau Ceti has more elements • Different proportions of hydrogen Analysis/conclusion • Vega is younger/Tau Ceti is older • Tau Ceti has had more time to fuse heavier elements
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Question			Answer	Mark	Guidance
			<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.</i>		• Tau Ceti has a lower proportion of hydrogen because it has been fusing/using it for longer • Accept that idea Vega may be older than Tau Ceti if Tau Ceti has more mass
			TOTAL	6	

23	a		Difference in energy level = 4.84×10^{-19} (J) $\lambda = hc/4.84 \times 10^{-19}$ and 4.11×10^{-7} (m) seen	M1 A1	Accept (-.58 - (-5.42)) for 4.84 Accept $E = hf$ to find f , followed by $\lambda = c/f = 4.11 \times 10^{-7}$ (m) seen Allow 4.104×10^{-7} (m) seen
	b	i	Dark lines are absorption lines / idea of photon absorption / idea of electrons absorbing energy / idea of electrons making transition to higher energy level (i.e. excitation) Caused by light passing through (cooler) stellar atmosphere or Earth's atmosphere	B1 B1	 Allow (cooler) gases/hydrogen (gas)
		ii	$\Delta \lambda / \lambda = 22/410$ or $21/411$ $v = 0.054c = 1.6(1) \times 10^7$ (m s ⁻¹)	C1 A1	NB 21/411 gives 1.5×10^7 (m s ⁻¹) Any evidence of use of 432 as denominator of $\Delta \lambda / \lambda$ is XP zero marks
		iii	Big Bang / Expanding universe i.e. Hubble's Law / dark matter or dark energy / AW	B1	ignore redshift ignore Doppler
			TOTAL	7	



24	(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
		(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
	(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.
		(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
			Total	8	



22	(a)	(%) uncertainty of T will be 4 times as significant as the uncertainty of L Should improve measurements leading to T	M1 A1	Allow reference to 4th power of T Allow comparison of $L^{(-)1/2}$ and T^2
	(b)*	Level 3 (5–6 marks) Clear description of method and analysis of data and correct 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) Some description of method and analysis of data or 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) Limited description or Limited analysis or Limited explanation <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.</i>	B1× 6	Indicative scientific points may include: Description of method - Equation using $\lg$ of both sides - Use of the $\lg X^b = b \lg X$ - Comparison with $y = mx (+ c)$ (y-intercept = 0) Analysis of data - Straight line through the origin - Gradient of the graph is b - Gradient calculated to be between 3 and 4 Explanation - Labelled sketch of HR diagram - Reference to Stefan's Law - Hotter stars (than the Sun) have greater luminosity (ratio) / luminosity ratio >1 - Hotter stars have much smaller mass ratio than luminosity ratio - Use of data (e.g luminosity of $\times 10,000$ means mass of about $\times 14$) therefore hotter stars lose mass at a much higher rate (compared to their mass) therefore hotter star lifespans are very much shorter than cooler stars
		Total	8	

23	(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"
	(b)	(i)	$v = 68 \times 200 = 13600 \text{ (km s}^{-1}\text{)} \text{ or } 13.6 \times 10^6 \text{ m s}^{-1}$ $(\Delta\lambda = \frac{v}{c} \times \lambda)$ (change in λ) $13600 \times 10^3 \times 280 / 3.00 \times 10^8 \text{ or } 13 \text{ (nm) or } 13 \times 10^{-9} \text{ (m)}$ $(\lambda = 280 + 13)$ $\lambda = 290 \text{ (nm)}$	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 $\Delta\lambda$
		(ii)	Any suitable <u>one</u> from: • Very/infinately dense • Idea that escape velocity $\geq c$ 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
	(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 A1	Allow for point 1: fundamental forces unified Ignore: Any phase after nuclei phase e.g. recombination era /formation of atoms/formation of CMBR
			Total	9	

23	(a)*	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.	B1× 6	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, $T = 430$ K • For outer-most planet, $T = 180$ K • Calculation of distance for $T = 290$ K, i.e. 3.4×10^9 (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 8.5×10^7 (m) or L/T^4 is smaller for TRAPPIST-1 • Comparison of calculated intensities at extreme distances around TRAPPIST-1 to intensity at Earth
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Question			Answer	Marks	Guidance
	(b)	(i)	$T^2 = \frac{4\pi^2}{GM} r^3$	B1	
		(ii)	$86400^2 = (4\pi^2/6.0 \times 10^{24} \times 6.67 \times 10^{-11}) r^3$ (Any subject) radius = 4.23×10^7 (m)	C1 A1	
			Total	9	



Question	Answer	Marks	Guidance
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24	(a)	(i)	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 x 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	



3	(a)	(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}
		(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 $T^4 = \frac{25L}{4\pi\sigma(1.7r)^2}$ $= \frac{25 \times 3.95 \times 10^{26}}{4\pi \times 5.67 \times 10^{-8} \times (1.7 \times 7 \times 10^8)^2}$ 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
	(b)		see next page	B1 x 6	
			Total	10	

H556/03

Mark Scheme

November 2020

Question			Answer	Marks	Guidance
3	(b)	*	Level 3 (5 - 6 marks) Clear expansion of three statements <i>There is a well-developed line of reasoning which is clear and logically structured. The information presented is clear, relevant and substantiated.</i> Level 2 (3 – 4 marks) Clear expansion of two statements or Limited attempt at all three <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 attempt at one or two statements <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.</i>	B1 x 6	Use level of response annotations in RM Assessor, e.g. L2 for 4 marks, L2^ for 3 marks, etc. Indicative scientific points may include: statement 1 - fusion reactions are occurring - which change H into He - and mass is lost which releases energy - energy released = $c^2\Delta m$ Δm per second = luminosity / c^2 statement 2 - average k.e. of each proton is $\frac{3}{2}kT$ - high T means protons are travelling at high speed - so fast enough to overcome repulsive forces - and get close enough to fuse - p.e. = $e^2/4\pi\epsilon_0 r$ so T must be high enough for $\frac{3}{2}kT > e^2/4\pi\epsilon_0 r$ r is approximately 3fm statement 3 - k.e. $\propto T$ so average energy at 10^7 K is only one thousandth of the average energy at 10^{10} K when protons might fuse - but M-B distribution applies so at the high energy end there will be a few p with enough energy - quantum tunnelling across potential barrier is possible - small probability of many favourable collisions to boost energy of p 4 p must fuse to produce He; it is complicated process making probability of fusion much less - number of p in Sun is so huge that, even with such a small probability, 4×10^9 kg of p still interact s^{-1} - a larger probability means lifetime of the Sun would be shorter



H556/03**Mark Scheme****November 2020**

Question	Answer	Marks	Guidance
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23	(a)	(i)	$= 1 \div 0.00097$ $= 1000$ parsecs	A1	1030 to 3sf
		(ii)	$= 0.00097 \div 7.5 \times 10^{-3} (\times 100\%)$ $= 13\%$	C1 A1	NOT half of the precision here (reference specification) Accept 1 sig fig value 10% Unrounded answer is 12.93... %
	(b)	(i)	Use of $KE_{\text{mean}} = 3/2 kT = 3/2 \times k \times 4.0 \times 10^6$ $= \frac{3}{2} \times 1.38 \times 10^{-23} \times 4 \times 10^6$ $= 8.3 \times 10^{-17} \text{ J.}$	C1 A1	Allow k Unrounded answer is $8.28... \times 10^{-17}$
		(ii)	$= -2.3 \times 10^{-16} + 8.3 \times 10^{-17}$ $= -1.5 \times 10^{-16} \text{ J.}$	B1	Allow use of 10^{-16} J from stem to give $-1.3 \times 10^{-16} \text{ J}$ Reject response without negative sign

Question			Answer	Mark	Guidance
		(iii)	selection of GMm/r Substitution of values for M, m and energy and rearrangement $3.2 \times 10^{10} \text{ m}$ e.g. $(-) \frac{GMm}{r} = (-) 1.5 \times 10^{-16}$ $r = \frac{6.67 \times 10^{-11} \times 1.1 \times 10^{31} \times 6.6 \times 10^{-27}}{1.5 \times 10^{-16}}$ $= 3.2 \times 10^{10} \text{ m}$	C1 C1 A1	Allow ECF from (b)(ii) NB Use of values in stem gives 3.7×10^{10}
		(iv)	Reference to Boltzmann distribution / AW OR Some particles will have greater kinetic energies / lower masses	B1	
			TOTAL	10	



23	(a)	$\Delta\lambda = 656.3 - 654 \text{ (nm) or } 2.3 \text{ (nm)}$ $v = c \times \Delta\lambda / \lambda = 3 \times 10^8 \times 2.3 / 656.3$ $= 1050 \text{ km s}^{-1}$	C1 C1 A1	Allow between 2.25 and 2.35 Check denominator is 656.3 and not 654 (XP) Ignore minus sign Accept 1100 (km s ⁻¹)
	(b)	$d = v/H_0 = 1050000 \div 2.5 \times 10^{-18} = (4.2 \times 10^{23} \text{ m})$ $4.2 \times 10^{23} \text{ m} \div 9.5 \times 10^{15} = 4.4 \times 10^7 \text{ light years}$	C1 A1	ECF from (a) Using 1100 km s ⁻¹ gives $4.6 \times 10^7 \text{ ly}$
	(c)	Absolute uncertainty in $\Delta\lambda$ in range of 0.4-1.2 nm % Uncertainty = (candidate's abs uncertainty $\div$ 2.3) $\times$ 100 = 21%	C1 A1	Allow value that if rounded to 1sf would be in the range Accept 1sf answer Allow in range 17 – 52 %

Question		Answer	Mark	Guidance
(d)		Any two from: Hubble's law assumes/predicts all galaxies moving away / AW	B1	i.e. correct statement of Hubble's law
		(from evidence in question) M87 is blue shifted/moving towards the Milky Way / AW	B1	Accept has a negative recession velocity
		Idea that M87 may 'gravitationally associated' with Milky Way/Local cluster/Virgo supercluster	B1	Allow any reasonable alternative
		Suitable comment comparing absolute uncertainty with difference in velocities or percentage uncertainty with percentage difference	B1	E.g. percentage uncertainty from change in wavelength s larger than the percentage difference in the quoted distance and the calculated distance
e		One from • Cosmic microwave background evidence • Very few galaxies are blue shifted	B1	Allow decipherable truncations or acronyms e.g. CMBR, MBR Allow other reasonable ideas that supports model (e.g. nucleosynthesis ratios, He:H ratio enhancement (extra helium), universe may not be uniform and/or isotropic, no other model is consistent with the evidence, universe is still expanding)
		TOTAL	10	



6	(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
	(b)	• <u>Pulses</u> (of ultrasound waves) are aimed at / reflected from the (moving) blood (cells in the artery). • The probe / transducer is placed at an angle (usually 60°) (to the artery) • The (detected) frequency of <u>returning/reflected</u> waves is different to that of the emitted waves. • (Knowing the speed of ultrasound in blood and) the <u>ratio</u> of the frequencies enables the speed (of blood flow) to be calculated/AW	B1 x 2	Max 2 marks from 4 marking points Allow ultrasound is emitted at an angle Allow there is a change in frequency when the wave is reflected Allow v found using formula $\Delta f = 2fv\cos\theta/c$ with c defined as velocity of (ultra)sound (in the medium) not light

H556/03			Mark Scheme		June 2019
Question			Answer	Marks	Guidance
	(c)	(i)	$T = 0.50$ (s) or $f = 2.0$ (Hz)	C1	
			$v = (2\pi r/T) = 2\pi \times 0.60/0.5$	M1	Allow $1.2\pi/0.5$ or 2.4π
			$v = 7.5$ (m s ⁻¹)	A0	$= 7.54$ (m s ⁻¹)
					Alternative method: $\omega = 4\pi$ or 12.6 (rad s ⁻¹) (C1) $v (= r \omega) = 0.60 \times 12.6$ or 2.4π (M1) $= 7.54$ (m s ⁻¹) (A0)
		(ii)	$\Delta f (\approx v f/c) = (7.5 \times 1700) / 330$	C1	Note that c represents the velocity of sound
			$\Delta f = 40$ (Hz) (or 39Hz)	A1	
		(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
		(iv)	X labelled at lowest point of circle on Fig. 6.1	B1	
	(d)		Accuracy is (a quality denoting) the closeness of the measured value to the true value	B1	Allow readings/results/data/values/measurements for <i>measured value</i> ; actual/real/allowed/correct for <i>true</i>
			Precision is (a quality denoting) the closeness of agreement between measured values (obtained by repeated measurements)	B1	Allow measurements are close together/are similar/have small range/have low spread/have low scatter/have good agreement/are all close to the average
			Total	11	



3	(a)	(i)	- remnant of a (red) super giant star - star can no longer generate (enough) energy by fusion / gravitational force exceeds radiation pressure - formed by (gravitational) collapse / implosion of core (of massive star) or gravitational force in core exceeds electron degeneracy pressure - star undergoes a (Type II) supernova (explosion) - core has mass above Chandrasekhar limit / $1.4 \times$ solar mass (and below limit for black hole / 3 solar masses) (in the core) protons combine with / capture electrons to produce neutrons	B1 x 2	Credit any correct statement, ignoring incorrect statements unless they contradict a previous credited bullet point Allow any star with mass greater than 10 solar masses Allow star cannot fuse iron without losing energy Ignore star runs out of fuel / fusion stops
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Question			Answer	Mark	Guidance
3	(a)	(ii)	<i>either:</i> extremely / very dense <i>or:</i> has a very strong gravitational field <i>or:</i> supported by neutron degeneracy pressure <i>or:</i> fusion is no longer taking place <i>or:</i> core has mass above Chandrasekhar limit / 1.4 x solar mass (and below limit for black hole / 3 solar masses)	B1	Credit any correct statement, ignoring incorrect statements unless they contradict a previous credited bullet point Ignore references to size / temperature / luminosity / spin / radio waves / composed (mainly/only) of neutrons Not high density (must be extremely / very high density) Do not credit this point here if already credited in 3(a)(i)

Question			Answer	Mark	Guidance
3	(b)		$\rho = \frac{m}{V}$ and $V = \frac{4}{3}\pi r^3$ ($\approx 4 r^3$)	C1	Formulae may be inferred from either calculation Allow $m/r^3 = \text{constant}$
			density of neutron star $\approx 5 \times 10^{17} \text{ kg m}^{-3}$	A1	Ignore number of s.f. in answer Volume of neutron star $\approx 4 \times 10^{12} \text{ m}^3$
			density of nucleus $\approx 4 \times 10^{17} \text{ kg m}^{-3}$	A1	Ignore number of s.f. in answer Volume of nucleon $\approx 4 \times 10^{-45} \text{ m}^3$ $m_{\text{nucleon}} \approx u = 1.66 \times 10^{-27} \text{ kg}$ to 3 sf (allow $1.67 \times 10^{-27} \text{ kg}$) If the calculation of separate densities is not shown explicitly then the two A1 marks may be scored for either: - ratio of densities ≈ 0.8 or 1.2 $m/r^3 = 2.0 \times 10^{18} \text{ (kg/m}^3\text{)}$ for star and $1.7 \times 10^{18} \text{ (kg/m}^3\text{)}$ for nucleon $r^3/m = 5.0 \times 10^{-19} \text{ (kg/m}^3\text{)}$ for star and $6.0 \times 10^{-19} \text{ (kg/m}^3\text{)}$ for nucleon
	(c)	(i)	number of large squares = 11 ± 1	C1	May be inferred from calculation Any valid method allowed (counting squares, trapezium rule, splitting area into regular shapes) Allow number of medium squares = 44 ± 4 Allow number of small squares = 1100 ± 100
			no of squares $\times$ area of each = $11 \times 1 \times 10^{-25} = 1.1 \times 10^{-24} \text{ (J)}$	A1	Allow answers in the range 1.00×10^{-24} to 1.20×10^{-24} Allow answer to 1s.f.

Question			Answer	Mark	Guidance
3	(c)	(ii)	$300 \text{ pc} \approx 300 \times 3.1 \times 10^{16} \text{ m}$ $(= 9.3 \times 10^{18} \text{ m})$	C1	Mark is for working leading to the correct distance. Distance does not need to be seen explicitly but $9.3 \times 10^{18} \text{ m}$ implies C1
			$\text{ratio of areas} = \frac{4\pi(300 \times 3.1 \times 10^{16})^2}{3000} = \frac{1.09 \times 10^{39}}{3000}$ $(= 3.6 \times 10^{35})$	C1	Mark is for working leading to the correct ratio. Ratio does not need to be calculated but 3.6×10^{35} implies C1 Allow calculation of inverse ratio ($= 2.8 \times 10^{-36}$) Ignore unit if one is given
			$\text{energy} = \text{ratio of areas} \times \text{area under curve} =$ $4.0 \times 10^{11} \text{ (J)}$	A1	Mark is for correct answer; allow answer to 1s.f. Answer = $3.6 \times 10^{35} \times$ candidate's answer to 3c(i) Allow ECF for incorrect calculation of area / energy in 3c(i) Expect an answer in the range 3.6×10^{11} to 4.4×10^{11} Note: candidates could also calculate the answer by using ratio of energies = ratio of powers or intensity of pulsar = intensity at telescope
			Total	11	



21	(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.
		(ii)1	energy = 2.55 (eV)	B1	Ignore sign
		(ii)2	energy = $2.55 \times 1.60 \times 10^{-19}$ (J) $\lambda = \frac{6.63 \times 10^{-34} \times 3.0 \times 10^8}{2.55 \times 1.60 \times 10^{-19}}$ (Allow any subject) wavelength = 4.9×10^{-7} (m) wavelength = 490 (nm)	C1 C1 A1	Possible ECF from (ii)1 Note: wavelength = 488 (nm) to 3 sf
	(b)	(i)	<u>Electron(s)</u> makes a transition to a lower (energy) level / loses energy and emitting a photon(s) / EM radiation	B1	
		(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'
		(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) x 10 ⁶
		(iv)	(Relative) abundance of hydrogen (AW)	B1	Allow 'Hydrogen commonly found in stars' (AW)
	(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.
			Total	14	

21	a	i	Estimate of $\lambda_{\max}$ between 440 and 470 nm (T =) $5800 \times 500/460 = 6300$ K i.e. candidate's value	M1 A1	Allow 2.9 million for 5800×500 Allow assumption of 6300 K, calculation of lambda (M1) and then confirmation on graph (A1) for 2 marks
		ii	$L = 4\pi r^2 \sigma T^4$ Correct substitution of values i.e. $2.3 \times 10^{29} = 4 \pi r^2 \sigma 6300^4$ radius = $1.4(3) \times 10^{10}$ (m)	C1 C1 A1	
	b	i	$P = 7.0 \times 10^{-15} \div 0.11$ $I = 6.36 \times 10^{-14} / 1.0 \times 10^{-4} = 6.4 \times 10^{-10} \text{ (Wm}^{-2}\text{)}$	M1 A1	
		ii	$L/4\pi r^2 = 6.4 \times 10^{-10}$ $r = (L \div (6.4 \times 10^{-10} \times 4\pi))^{0.5}$ $= 5.4 \times 10^{18}$ (m) ($\div 9.5 \times 10^{15}$ =) 560 light years	C1 C1 C1 A1	Allow use of 6×10^{-10} Allow alternative method: Finding intensity at star surface C1 Using ratio of intensities = square of ratio of (star radius / distance to earth) C1 Use of 6×10^{-10} for I gives 580 ly

Question		Answer	Mark	Guidance
	c	Any three from: There is a range/ 'band' in the luminosity values at 6300 K range of luminosity is between $L_{\odot}$ and about $10 L_{\odot}$ The uncertainty in the distance calculated = $\frac{1}{2}$ the uncertainty in the luminosity AW Reference to Nu Persei not necessarily being on the main sequence	B1 B1 B1 B1	Check diagram for rewardable content
		TOTAL	14	

23	(a)	$g = \frac{G \times 6.31 \times 10^{30}}{(1.90 \times 10^9)^2}$ $g = 117 \text{ (N kg}^{-1}\text{)}$ $2 \times \frac{0.14}{1.90} + \frac{0.42}{6.31} \quad \text{or} \quad 0.21 \quad \text{or} \quad 21\%$ (absolute uncertainty =) 25 (N kg⁻¹)	C1 C1 C1 A1	Reject 0.42/(0.14 ²) = 21.4 Note: final answer of $g = 117 \pm 25 \text{ (N kg}^{-1}\text{)}$ with no working scores all 4 marks. Allow correct identification of %(r) and %(m) for 1 mark max if no other marks scored. Allow alternate method using max/min values of m and r that give the correct absolute uncertainty (28)	
	(b)	(i)	The (total radiant) power (of a star) /AW	B1	
		(ii)	$(L = 4\pi r^2 \sigma T^4)$ ratio = $\sqrt{\left(\frac{6.92 \times 7500^4}{10.0 \times 4500^4}\right)}$ ratio = 2.3(1)	C1 A1	Allow 1 mark for 5.3; square root omitted Allow 1 mark for 1:2.3 or 0.43
		(iii)	$\lambda_{(\text{max})} \propto \frac{1}{T}$ Lower temperature star will have the longest wavelength, so it is Aa2	B1 B1	Allow word equation Note Must mention wavelength <u>and</u> temperature
		(iv)	From their (different) colours	B1	

		(v)	Any <u>three</u> from: • Continuous spectrum • Light / radiation / photons passes through cooler gas/star's atmosphere • Photon(s) absorbed by electron(s) • Electron(s) excited / jump / make transition to higher energy level(s) • Electron only promoted if energy of photon matches energy gap between two given levels • Photons remitted in different directions • (so) idea of contrast with non-absorbed wavelengths	B1 × 3	
		(c)	Any <u>two</u> from: • Black hole has smaller mass / radius / size • Black hole has higher density/gravitational field strength/stronger gravitational field • black hole absorbs light / does not emit visible light • Has an escape velocity $\Rightarrow c$ • No fusion in a black hole (ORA)	B1 B1	Allow black hole emits Hawking radiation
			Total	15	