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EDEXCEL A LEVEL PHYSICS: QUESTIONS BY TOPIC

Space (10)

A Level Physics Topic 10

33 questions · 202 marks · Mark schemes included

A Level only content · Pearson Edexcel 8PH0 / 9PH0 papers, 2016–2025

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HOW TO USE THIS BOOKLET

Questions are grouped by specification sub-topic and run from the lowest mark tariff to the highest within each one.

Click any row below to jump straight to that sub-topic or 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

33 questions · 202 marks · 4 sub-topics



SUB-TOPIC 10.1

BLACK-BODY RADIATION AND LUMINOSITY

Sub-topic 10.1 · 11 questions · 77 marks · lowest tariff first



7 A black body radiator of temperature T and surface area A has a luminosity L .

Which of the following is the luminosity of a black body radiator with surface area $A/2$ and temperature $2T$?

☐ A $\frac{L}{2}$

☐ B L

☐ C $4L$

☐ D $8L$

(Total for Question 7 = 1 mark)



7 A star of diameter D and surface temperature T has luminosity L .

What is the luminosity of a star of diameter $\frac{D}{2}$ and surface temperature $2T$?

- ☐ A $\frac{L}{4}$
- ☐ B L
- ☐ C $4L$
- ☐ D $16L$

(Total for Question 7 = 1 mark)



4 Which of the following is a valid unit for luminosity?

☐ A W m^{-2}

☐ B N m s^{-2}

☐ C J s^{-1}

☐ D J m^{-2}

(Total for Question 4 = 1 mark)



5 Betelgeuse is a red giant star.

The surface temperature of Betelgeuse is T_{B} and the surface area of Betelgeuse is A_{B} .
The surface temperature of the Sun is T_{S} and the surface area of the Sun is A_{S} .

Which row in the table shows a correct comparison of the surface temperature and surface area of Betelgeuse with those of the Sun?

	$T_{\text{B}} > T_{\text{S}}$	$A_{\text{B}} > A_{\text{S}}$
☐ A	false	false
☐ B	false	true
☐ C	true	false
☐ D	true	true

(Total for Question 5 = 1 mark)



13 Aldebaran is a red giant star.

For a black body radiator of Aldebaran's surface temperature, the wavelength λ_{max} at which the intensity is maximum is $7.43 \times 10^{-7} \text{ m}$.

Determine the luminosity of Aldebaran.

radius of Aldebaran = $3.14 \times 10^{10} \text{ m}$

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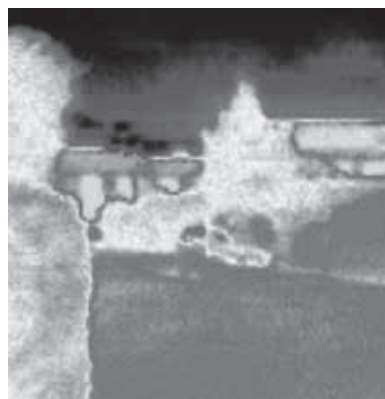
Luminosity = ...

(Total for Question 13 = 4 marks)



- 12 Infrared cameras are used to create images that show the infrared radiation emitted by objects.

The photographs show the same scene taken first with an ordinary camera and then with an infrared camera.



- (a) Deduce whether the objects shown in the photographs would be expected to have peak emissions at infrared wavelengths. Your answer should include a calculation.

(4)

longest wavelength of visible red light $\approx 700 \text{ nm}$

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- (b) The photograph shows the result when someone tries to take an infrared photograph of the same scene through a window. The image does not show the outdoor scene but does show an image of the photographer.



State what can be concluded about glass and infrared radiation.

(2)

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(Total for Question 12 = 6 marks)

- 15** One of the largest stars in our galaxy is VY Canis Majoris. This star's radius is 1420 times the radius of the Sun. The luminosity of this star is 270 000 times the luminosity of the Sun.

A student states that the surface temperature of VY Canis Majoris must be much greater than the surface temperature of the Sun.

- (a) Determine whether the student's statement is correct.

surface temperature of Sun = 5780 K

luminosity of Sun = 3.85×10^{26} W

radius of Sun = 6.96×10^8 m

(3)

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- (b) Calculate the wavelength with maximum intensity in the black body radiation spectrum of VY Canis Majoris.

(2)

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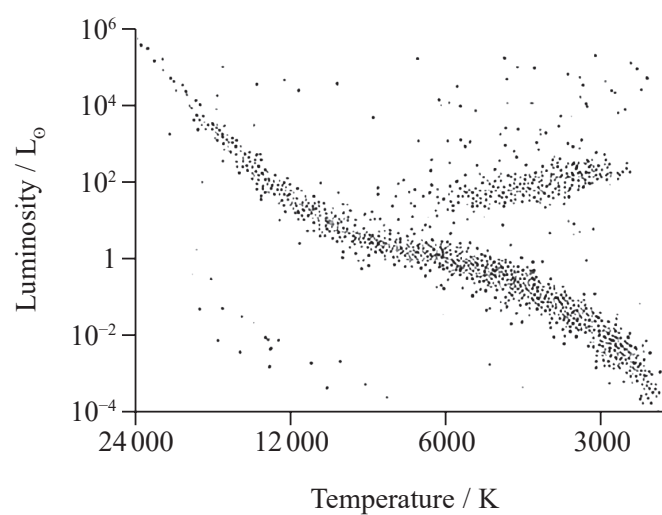
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Wavelength = ...



- (c) Add the position of VY Canis Majoris to the Hertzsprung Russell diagram to determine which type of star it is.

(2)



Type of star

(Total for Question 15 = 7 marks)

14 The photograph shows a filament bulb.



The filament is an emitter with 35% of the power output of a black body radiator of the same temperature.

- (a) When a potential difference (p.d) of 2.0 V is applied across the bulb, there is a current of 0.37 A in the filament.

Calculate the temperature of the filament.

surface area of filament = $3.9 \times 10^{-6} \text{ m}^2$

(3)

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Temperature = ...

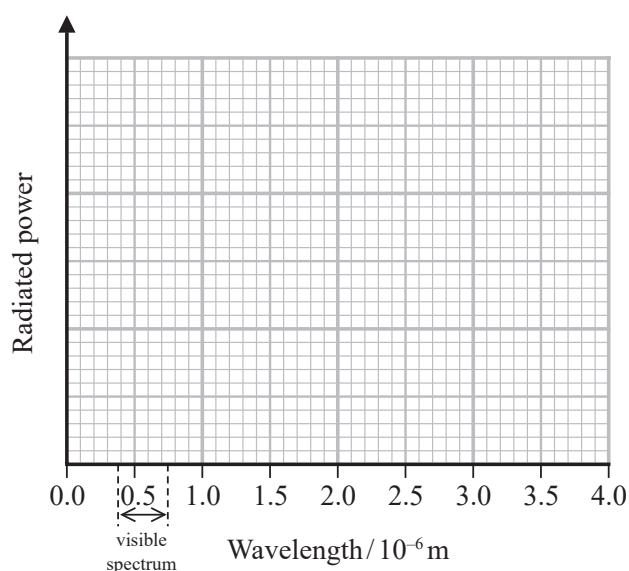
- (b) In an experiment to investigate the efficiency of a filament light bulb a p.d. was applied. The p.d. and current were measured and the light bulb was observed. The p.d. was then increased and new measurements taken.

When a small p.d. is applied to the bulb, no light is visible. If the p.d. is gradually increased, the filament starts to glow and eventually appears white.

- (i) Add to the graph to show the distribution of radiation from a black body at a temperature of 2026 K.

Your answer should include a calculation.

(5)



- (ii) Use your graph to explain why filament light bulbs are considered inefficient.

(2)

(Total for Question 14 = 10 marks)

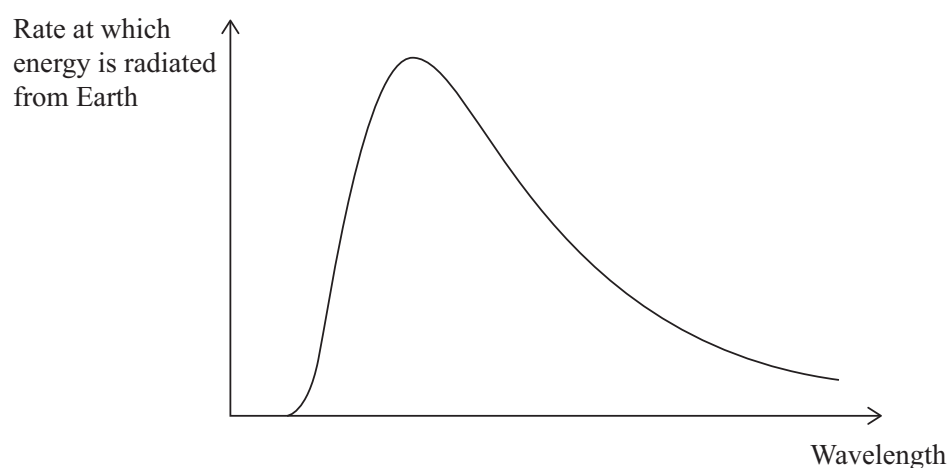


21 All objects with a temperature above absolute zero emit a spectrum of electromagnetic radiation.

(a) State what is meant by absolute zero.

(1)

(b) The graph shows how the intensity of radiation emitted by the Earth varied with wavelength in 2020.



Explain the differences between this graph and a graph representing the emission of radiation by the Earth in 2050. Assume that the average global temperature increases over time.

(4)



(c) At the end of the 19th century, Wien investigated the radiation emitted by hot objects and formulated a law.

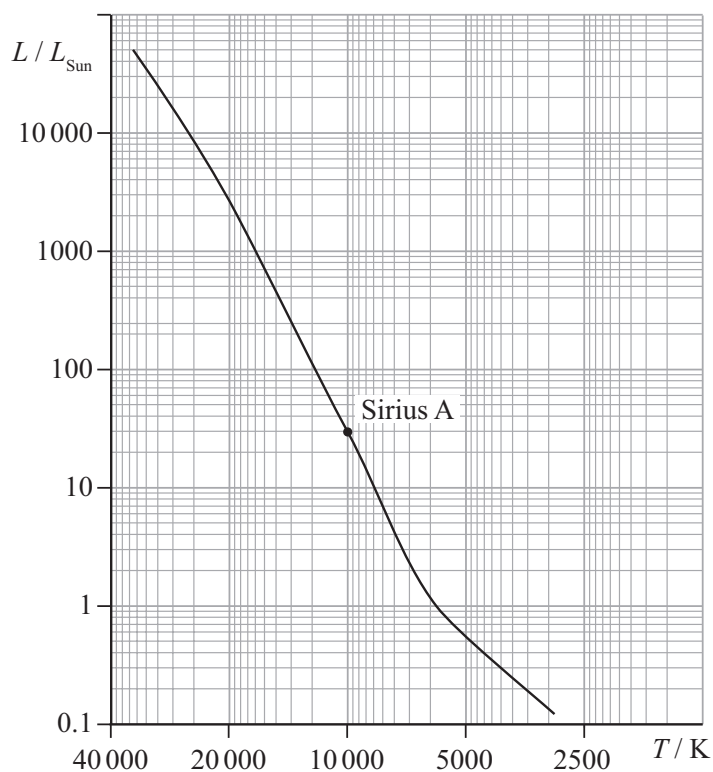
The table shows data for some stars.

Star	$\lambda_{\text{max}} / \text{nm}$	T / K
Bellatrix	132	21 500
Rigel	245	11 600
Sirius	287	9910

Deduce whether Wien’s law is confirmed by this data.

(3)

- (d) The Hertzsprung–Russell diagram below shows part of the main sequence of stars. The star Sirius A is marked on the diagram.



On a website it states that the radius of Sirius A is twice the radius of the Sun.

Deduce whether this statement is correct.

radius of the Sun = $6.96 \times 10^8 \text{ m}$

surface temperature of the Sun = 5800 K

(5)

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(Total for Question 21 = 13 marks)



18 In 1864, William Huggins and William Miller used dark lines in the spectrum of the Sun to identify elements in the Sun’s atmosphere.

*(a) Explain how gases in the Sun’s atmosphere cause dark lines in the spectrum corresponding to different elements.

(6)

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(b) The diagram shows some energy levels of a hydrogen atom.

$n = 5$ _____ -0.54 eV

$n = 4$ _____ -0.85 eV

$n = 3$ _____ -1.51 eV

Not to scale

$n = 2$ _____ -3.40 eV

$n = 1$ _____ -13.6 eV

The absorption spectrum for hydrogen includes a set of lines that all derive from transitions involving the $n = 2$ energy level. One of these lines is known as the hydrogen-alpha line.

Deduce the transition involved in the formation of the hydrogen-alpha line.

wavelength of hydrogen-alpha line = 656.46 nm

(4)

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- (c) In 1868, William Huggins analysed light from the star Sirius A. The wavelength of the hydrogen-alpha line for light from Sirius A was slightly different from the hydrogen-alpha line observed from a source in a laboratory.

Huggins suggested that this difference could be explained using the Doppler effect and could be used to determine the speed and direction of the star's motion relative to the Earth.

- (i) Assess Huggins's suggestion.

(3)

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- (ii) Sirius A has a component of velocity away from the Earth of 5.5 km s^{-1} .

The wavelength of the hydrogen-alpha line observed from a source in the laboratory is 656.46 nm .

Calculate the wavelength of the hydrogen-alpha line as seen in the spectrum of Sirius A.

(2)

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Wavelength = ...

(Total for Question 18 = 15 marks)



11 Solar panels consisting of combinations of photovoltaic cells use energy in the radiation received from the Sun to generate electricity.

- (a) An advertisement for solar panels claims that the intensity of radiation from the Sun incident at the top of the Earth's atmosphere is more than 2 kW m^{-2} .

Assess the validity of this claim.

radius of Sun = $6.96 \times 10^8 \text{ m}$

surface temperature of Sun = 5790 K

distance from Sun to Earth = $1.50 \times 10^{11} \text{ m}$

(4)

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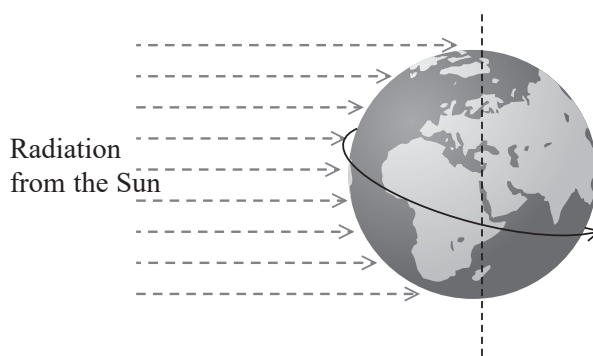
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- (b) The average intensity of radiation from the Sun incident at the Earth's surface over a 24-hour period has been determined to be 164 W m^{-2} .



- (i) The average intensity of radiation from the Sun at the Earth's surface is much less than the intensity incident at the top of the Earth's atmosphere.

Explain why.

(4)

- (ii) It is claimed that the area of solar panels needed to generate 100 GW of power is about 0.5% of the surface area of the Earth.

Assess the validity of this claim.

radius of Earth = 6.4×10^6 m

typical efficiency of solar panels = 25%

(4)



(c) Scientists are developing a space station equipped with large solar panels. The space station would be located in a geostationary orbit. The space station would transfer energy to Earth as microwaves.

- (i) A space station in a geostationary orbit is above the equator and has a period of 24 hours.

Explain one advantage of locating the space station in a geostationary orbit.

(2)

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- (ii) Calculate the height h of the space station above the equator when it is in a geostationary orbit.

mass of Earth = 6.00×10^{24} kg

24 hours = 8.64×10^4 s

(4)

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$h =$

(Total for Question 11 = 18 marks)



SUB-TOPIC 10.2

ASTRONOMICAL DISTANCES: PARALLAX AND STANDARD CANDLES

Sub-topic 10.2 · 5 questions · 23 marks · lowest tariff first



- 4 There are several different methods that can be used to determine the distance from our solar system to astronomical objects. These include the measurement of red shift, trigonometrical parallax and the use of standard candles.

Which row of the table shows a suitable method for each of the objects named?

	Nearby star	Nearby galaxy	Very distant galaxy
☐ A	parallax	red shift	standard candle
☐ B	red shift	standard candle	parallax
☐ C	parallax	standard candle	red shift
☐ D	red shift	parallax	standard candle

(Total for Question 4 = 1 mark)

- 3 Two stars, P and Q, are observed from Earth. The intensity of radiation from P is less than that from Q. The parallax angle for P is greater than that for Q.

Which row of the table is correct?

	Distance from Earth	Comparison of luminosities
☐ A	P is closer than Q	luminosity of P is greater than Q
☐ B	P is closer than Q	luminosity of P is less than Q
☐ C	P is further away than Q	luminosity of P is greater than Q
☐ D	P is further away than Q	luminosity of P is less than Q

(Total for Question 3 = 1 mark)

- 5 X and Y are identical stars. When viewed from Earth the intensity of star X is four times the intensity of star Y.

Which of the following explanations is possible?

- ☐ A X is twice as far away as Y.
- ☐ B X is four times as far away as Y.
- ☐ C Y is twice as far away as X.
- ☐ D Y is four times as far away as X.

(Total for Question 5 = 1 mark)



13 The distance to astronomical objects relatively close to the Sun is determined using trigonometric parallax. For objects beyond a certain distance standard candles are used.

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

(1)

(b) Explain why trigonometric parallax is not used beyond a certain distance.

(2)

(c) Describe how distances too large for the use of standard candles can be determined.

(3)

(Total for Question 13 = 6 marks)



19 In 2016 the Breakthrough Starshot initiative was announced. This project intends to send a fleet of small probes to Proxima Centauri, the nearest star to the Sun. This journey would take about twenty years.

(a) The radiation intensity at Earth from Proxima Centauri is $3.25 \times 10^{-11} \text{ W m}^{-2}$.
The luminosity of the Sun is $L_{\odot}$.

(i) Show that the luminosity of Proxima Centauri is about $0.002 L_{\odot}$.

(3)

distance to Proxima Centauri = $4.00 \times 10^{16} \text{ m}$

$L_{\odot} = 3.85 \times 10^{26} \text{ W}$

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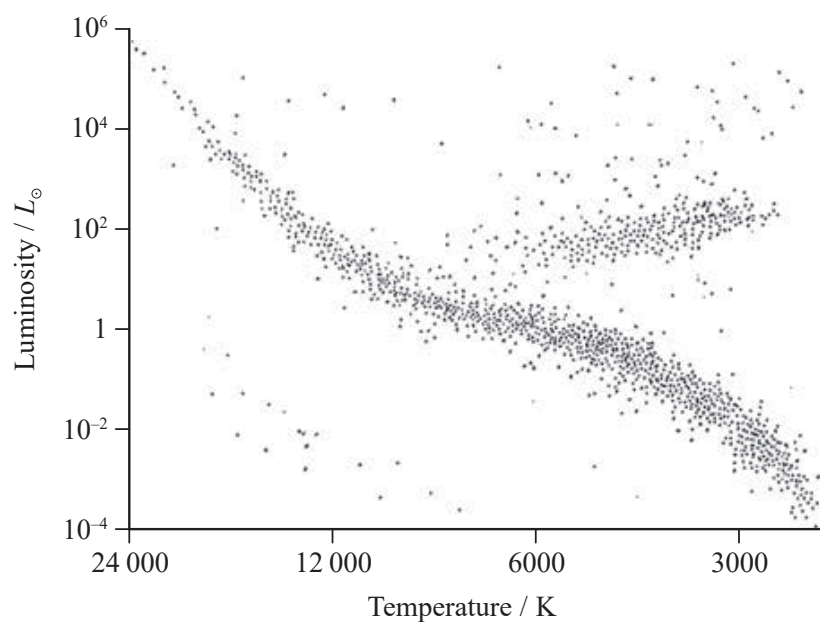


- (ii) Proxima Centauri is described on a website as a main sequence star.

Determine whether the surface temperature of Proxima Centauri is consistent with a position on the main sequence of the Hertzsprung-Russell diagram.

(3)

radius of Proxima Centauri = 9.81×10^7 m



(b) The composition of a star can be determined by analysis of its absorption spectrum.

Explain why there are certain specific frequencies missing from the spectrum.

(5)

(c) Describe how the distance to nearby stars like Proxima Centauri is determined.

(3)

(Total for Question 19 = 14 marks)



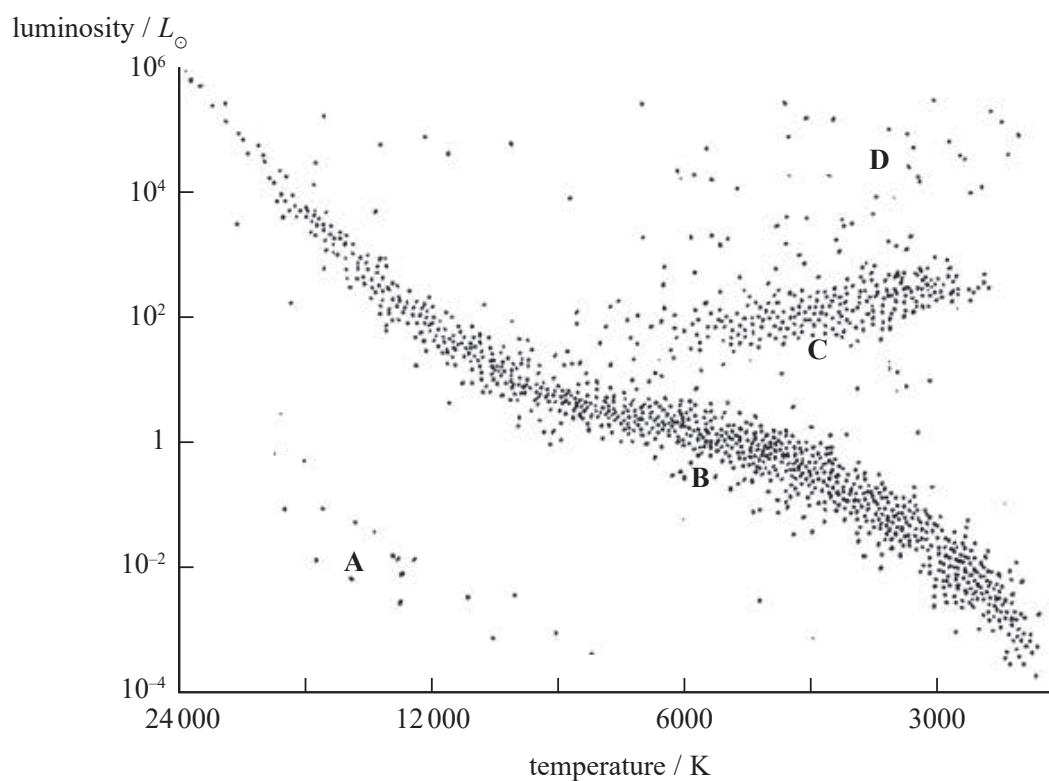
SUB-TOPIC 10.3

STELLAR EVOLUTION AND THE HERTZSPRUNG-RUSSELL DIAGRAM

Sub-topic 10.3 · 9 questions · 52 marks · lowest tariff first



6 Four regions A, B, C and D are labelled on the Hertzsprung-Russell diagram.

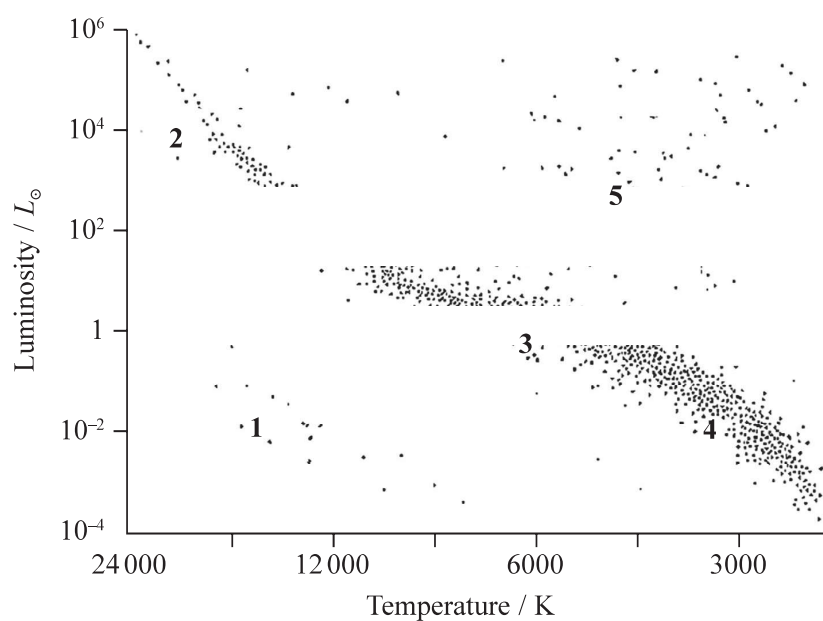


Which region includes the position of the Sun?

- ☐ A
- ☐ B
- ☐ C
- ☐ D

(Total for Question 6 = 1 mark)

1 Five regions are labelled on the Hertzsprung-Russell diagram shown.

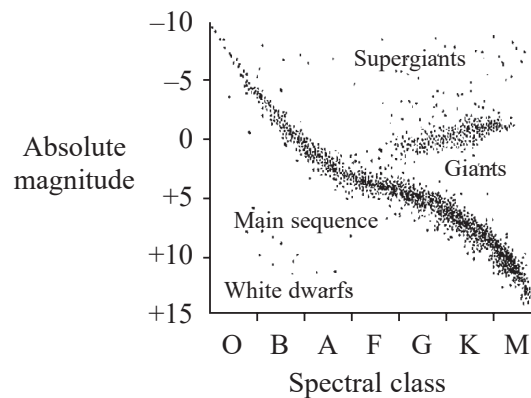


Which sequence could show part of the evolution of a star like the Sun?

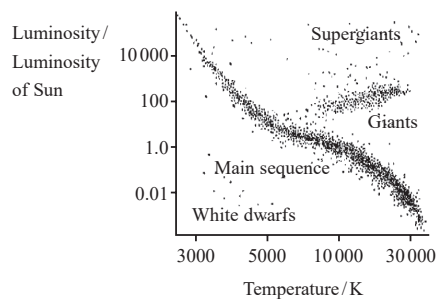
- ☐ A 1→5→3
- ☐ B 2→3→4
- ☐ C 3→5→1
- ☐ D 4→3→2

(Total for Question 1 = 1 mark)

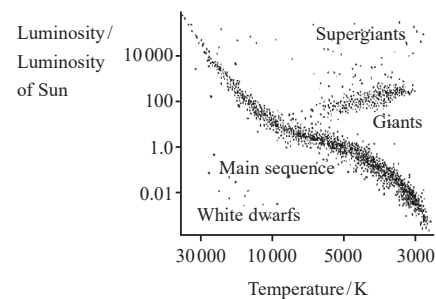
- 9 A student finds a Hertzsprung-Russell diagram in an old astronomy book and notices that the axes aren't the same as in her current textbook.



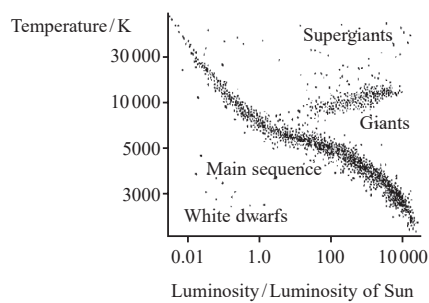
Which of the following graphs shows a correct alternative way to label the axes?



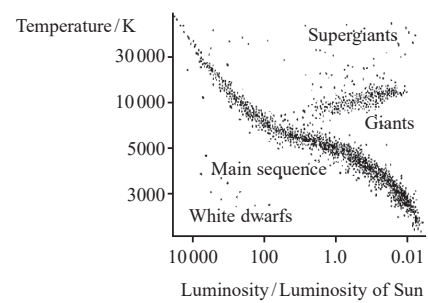
A



B



C



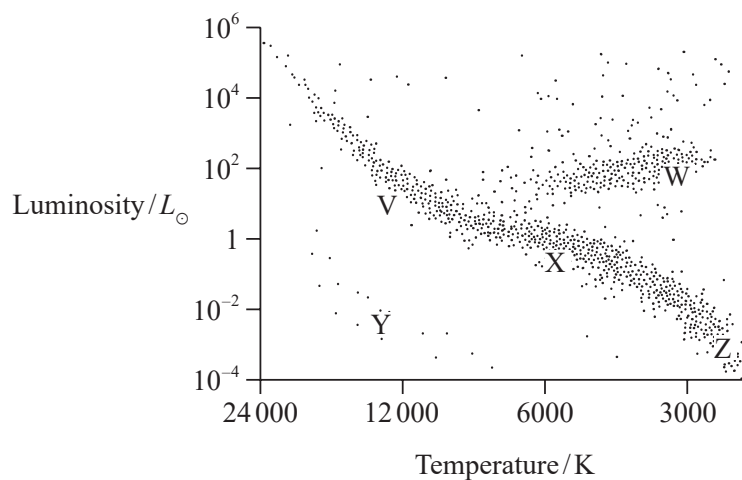
D

- ☐ **A**
- ☐ **B**
- ☐ **C**
- ☐ **D**

(Total for Question 9 = 1 mark)



- 1 A Hertzsprung–Russell diagram for stars in our galaxy is shown. V, W, X, Y and Z are positions on the diagram.



Which of the following gives a sequence of positions of the Sun during its lifetime?

- ☐ A V X Z
- ☐ B X W Y
- ☐ C X W Z
- ☐ D Z X V

(Total for Question 1 = 1 mark)

- 15** A pulsar is a rotating neutron star. The pulsar emits electromagnetic radiation as it rotates.

Scientists have recently detected the highest ever energy gamma ray photons received from a pulsar.

- (a) The energy of one of these gamma ray photons was determined to be $2.0 \times 10^{13} \text{ eV}$.

Calculate the wavelength of these gamma rays.

(4)

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Wavelength = ...

- (b) The pulsar is estimated to be travelling away from the Earth with a velocity of 750 m s^{-1} .

State why this motion away from the Earth does not significantly affect the wavelength of radiation received at the Earth.

(1)

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(Total for Question 15 = 5 marks)



***13** The energy radiated by stars is released by nuclear fusion.

Explain the conditions required to bring about and maintain nuclear fusion in stars.

(Total for Question 13 = 6 marks)



9 The majority of stars in the universe are thought to be main sequence stars. For such stars the luminosity increases with the mass of the star.

(a) It is suggested that the relationship between luminosity and mass is of the form

$$L = L_{\text{Sun}} M^p$$

where L = luminosity, M = (mass of star / mass of the Sun) and L_{Sun} and p are constants.

Explain why a graph of $\log L$ against $\log M$ would give a straight line.

(2)

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(b) The table shows data for a range of main sequence stars.

$L/10^{25}\text{W}$	M		
3.63	0.557		
469	1.88		
5920	3.52		
40 800	5.85		
294 000	9.72		

(i) Plot a graph of $\log L$ against $\log M$. You may use the columns provided to show any processed data.

(5)



- (ii) Determine values for p and L_{Sun} and hence state the mathematical relationship between L and M .

(4)

(Total for Question 9 = 11 marks)



17 Astronomers observing stars at the centre of our galaxy have suggested that many of them are orbiting a supermassive black hole. The mass of this black hole is $9.2 \times 10^{36} \text{ kg}$.

- (a) Calculate the orbital period for a star in a circular orbit at a distance of $1.9 \times 10^{14} \text{ m}$ from a black hole of this mass.

(3)

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Orbital period = ...

- (b) The star S0-2 is in a highly elliptical orbit around the position of the black hole.

At its point of closest approach, S0-2 is at a distance of $1.8 \times 10^{13} \text{ m}$ from the centre of the black hole.

At the most distant point of its orbit, S0-2 is $2.7 \times 10^{14} \text{ m}$ from the black hole.

- (i) Show that the change in gravitational potential between the closest and most distant points in this orbit is about $3 \times 10^{13} \text{ J kg}^{-1}$.

(2)

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- (ii) At its point of closest approach, the star is travelling at a speed of $8.1 \times 10^6 \text{ m s}^{-1}$.

Calculate the speed of S0-2 at the furthest point in its orbit using the change in gravitational potential.

$$\text{mass of S0-2} = 2.4 \times 10^{31} \text{ kg}$$

(3)

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Speed = ...

- (c) Trigonometric parallax and Hubble's law are two methods used to determine astronomical distances.

Explain whether either of these methods is suitable to determine the distance to S0-2.

(3)

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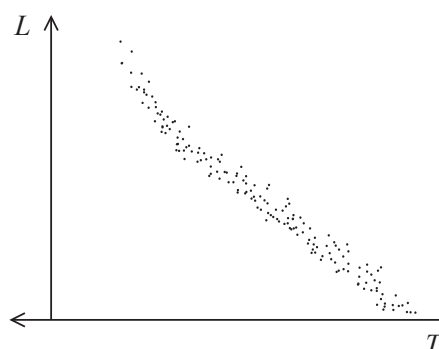
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(Total for Question 17 = 11 marks)



- 9 A Hertzsprung-Russell (HR) diagram shows how the luminosity L depends on the surface temperature T for a group of stars.

The HR diagram below is for a young star cluster.



- (a) (i) Explain how we can tell that the young star cluster is in the early stages of its evolution.

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- (ii) Explain why the most massive stars in the cluster have the greatest luminosities.

(4)

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(b) The HR diagram on the previous page shows an approximately linear relationship for stars in this cluster.

- (i) It is suggested that the relationship between luminosity L and surface temperature T is of the form

$$L = kT^n$$

where k and n are constants.

Explain why a graph of $\log L$ against $\log T$ would give a straight line.

(2)

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- (ii) The table shows data for stars in this cluster.

L/L_{Sun}	T/K		
39.5	10 600		
545	16 400		
20 600	26 800		
535 000	44 900		
1 770 000	53 300		

Plot a graph of $\log L$ against $\log T$ on the grid opposite. Use the columns provided to show any processed data.

(5)

- (iii) Determine a value for n .

(2)

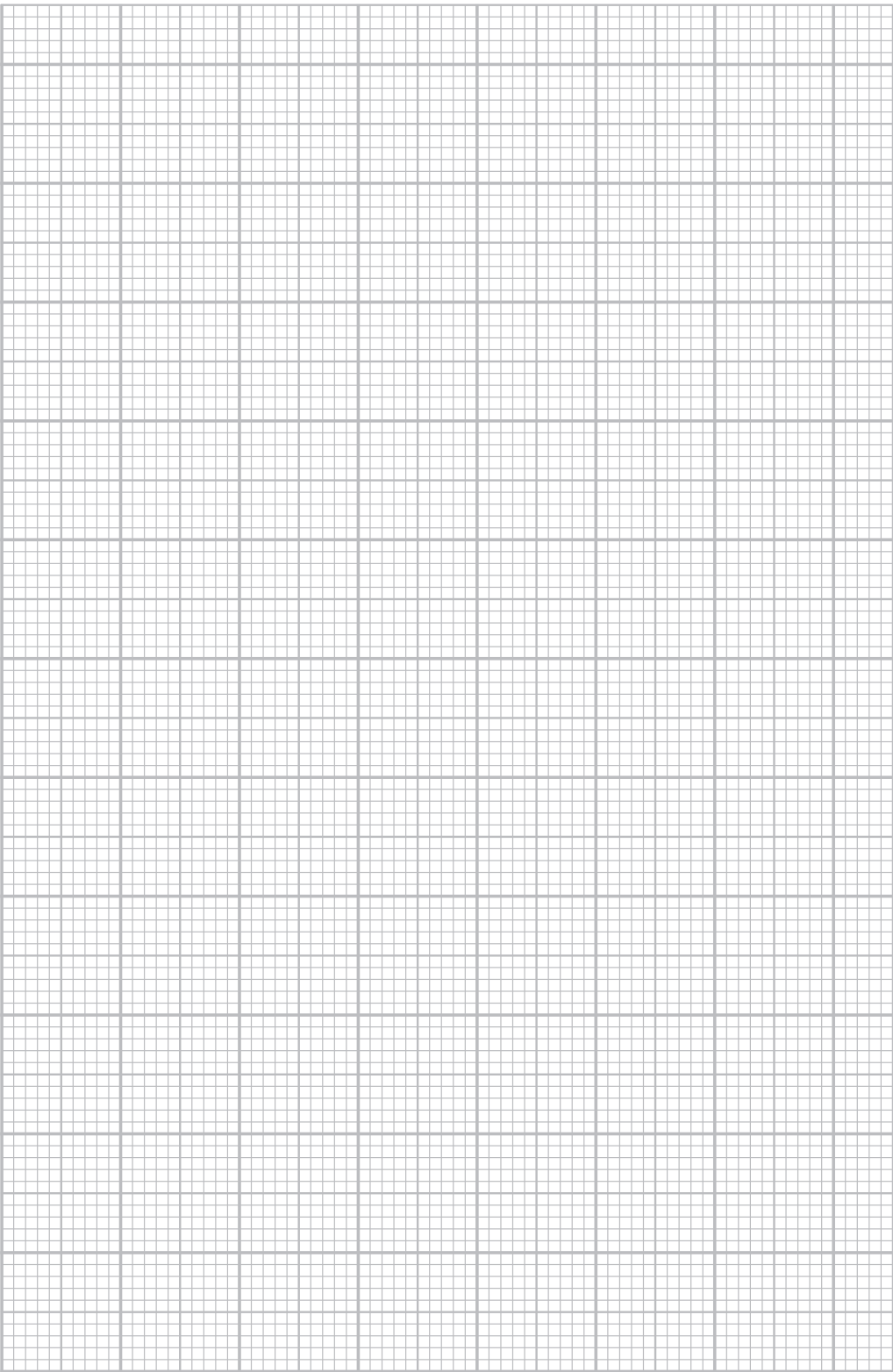
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$n =$





(Total for Question 9 = 15 marks)

SUB-TOPIC 10.4

DOPPLER SHIFT, RED-SHIFT AND COSMOLOGY

Sub-topic 10.4 · 8 questions · 50 marks · lowest tariff first



- 8 A line in the hydrogen spectrum of a star in the Milky Way galaxy is observed to have a wavelength of 656.3 nm. In a laboratory on Earth this line has a wavelength of 654.9 nm.

Which of the following expressions gives the magnitude of the velocity of the star relative to Earth?

- ☐ A $\frac{656.3}{654.9} \times 3 \times 10^8 \text{ m s}^{-1}$
- ☐ B $\frac{654.9}{(656.3 - 654.9)} \times 3 \times 10^8 \text{ m s}^{-1}$
- ☐ C $\frac{654.9}{656.3} \times 3 \times 10^8 \text{ m s}^{-1}$
- ☐ D $\frac{(656.3 - 654.9)}{654.9} \times 3 \times 10^8 \text{ m s}^{-1}$

(Total for Question 8 = 1 mark)



6 The diagram shows a source of sound waves and an observer.

source

observer



Which row of the table shows a situation which would result in a decrease in the frequency of sound observed?

	Source	Observer
☐ A	moves to the right at 20 m s^{-1}	moves to the left at 20 m s^{-1}
☐ B	moves to the right at 20 m s^{-1}	moves to the right at 20 m s^{-1}
☐ C	moves to the right at 20 m s^{-1}	stationary
☐ D	stationary	moves to the right at 20 m s^{-1}

(Total for Question 6 = 1 mark)



- 4 Scientists believe that our universe is currently expanding. One possible fate is for the universe to reach a maximum size and then start to contract.

Which of the following descriptions of a universe with this fate is correct?

- ☐ A a closed universe
- ☐ B a critical universe
- ☐ C a flat universe
- ☐ D an open universe

(Total for Question 4 = 1 mark)



- 11** A spectral line with wavelength 655.88 nm is detected on Earth from the Triangulum Galaxy. The wavelength of this spectral line measured using a laboratory source is 656.28 nm.

Calculate the velocity of the Triangulum Galaxy relative to the Earth.

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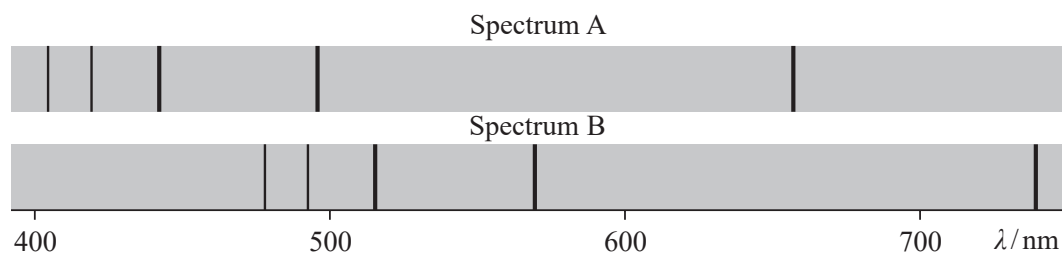
Magnitude of velocity = ...

Direction = ...

(Total for Question 11 = 3 marks)



- 14 The diagram shows the spectra produced by two stars. Spectrum A is produced from the light from the Sun and spectrum B is produced from the light from a distant star.



The dark lines are produced when light from the core of the star is absorbed by hydrogen atoms in the outer regions of the star. Light is then re-radiated, but in all directions, giving rise to the dark lines in the spectrum.

- (a) Explain why the long wavelength lines are shifted by a greater amount than the short wavelength lines.

(2)

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- (b) One of the lines in the hydrogen spectrum occurs at a wavelength of 656 nm in the laboratory.

Explain what conclusion can be made from the shift in wavelength of this line in spectrum B. Your answer should include a calculation.

(4)

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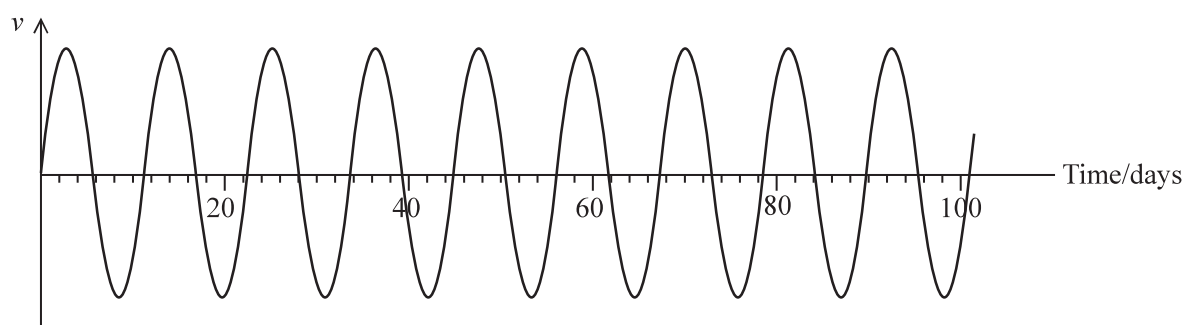
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(Total for Question 14 = 6 marks)

- 14 In 2016 astronomers announced the discovery of an Earth-like planet orbiting Proxima Centauri, the closest star to the Sun.

The planet was detected because of the small movement of the star as the planet orbited. The movement was detected using the Doppler shift in the frequency of light travelling to the Earth.

The graph shows how the component of the star's velocity v towards the Earth varied over time.



- (a) Explain how the Doppler shift was used to obtain the data shown on the graph.

(4)

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- (b) (i) Use the graph to show that the angular velocity of the planet is about $6 \times 10^{-6} \text{ radian s}^{-1}$.

(3)

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- (ii) The mass of Proxima Centauri is 0.12 times the mass of the Sun.

Determine the distance of the planet from Proxima Centauri.

mass of Sun = $1.99 \times 10^{30} \text{ kg}$

(3)

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Distance = ...

(Total for Question 14 = 10 marks)



12 Barnard's star is a red dwarf star in the vicinity of the Sun. The wavelength of a line in the spectrum of light emitted from Barnard's star is measured to be 656.0 nm. The same light produced by a source in a laboratory has a wavelength of 656.2 nm.

(a) Calculate the velocity of Barnard's star relative to the Earth.

(3)

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Velocity = ...

(b) A diffraction grating can be used to analyse the radiation emitted by a variety of sources.

(i) A diffraction grating of known grating spacing is used in a school laboratory to analyse the light emitted by a laser.

Describe how the diffraction grating is used and the measurements that should be taken.

(3)

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- (ii) A diffraction grating with grating spacing of 2.2×10^{-6} m is used to determine the difference in wavelength for the spectral line emitted by Barnard's star.

Comment on the suitability of using a diffraction grating with this spacing. You should include appropriate calculations.

(4)

- (c) Visible light from the star originates from the photosphere. In the photosphere of Barnard's star, hydrogen and helium atoms are at a temperature of 3100 K.

- (i) Calculate the mean kinetic energy of an atom in the photosphere at a temperature of 3100 K.

(2)

Mean kinetic energy = ...

- (ii) Describe how these atoms emit visible light.

(2)

(Total for Question 12 = 14 marks)



- 15** The photograph below was taken by the James Webb Space Telescope (JWST) and shows a group of galaxies that formed shortly after the big bang, about 13×10^9 years ago.



(Source: © NASA, ESA, CSA, STScI)

- (a) (i) Derive the equation $T = 1/H_0$ where T is the age of the universe.

(1)

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- (ii) State one assumption made in your derivation.

(1)

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- (iii) The parsec (pc) is a unit used for astronomical distances. 1 pc is 3.1×10^{16} m.

The accepted range for the Hubble constant H_0 is $(60\text{--}80)\text{ km s}^{-1} \text{ Mpc}^{-1}$.

Deduce whether the observation by the JWST leads to a value of H_0 within the accepted range.

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

(3)

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- (b) The light from one of the galaxies, called Maisie, has a redshift z of 14.
The wavelength of light from Maisie detected at the telescope is $4.0 \times 10^{-6} \text{ m}$ and lies within the infrared section of the electromagnetic spectrum.

(i) Calculate the wavelength of light emitted by Maisie.

(3)

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Wavelength emitted = ...

(ii) Explain why the light emitted by Maisie arrives at the telescope as infrared.

(2)

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- (c) One of the infrared detectors on the JWST is made from material with a work function of 0.30 eV .

Deduce whether this detector can detect the light from Maisie.

(4)

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(Total for Question 15 = 14 marks)



MARK SCHEMES

official mark schemes



7	D - 8L	1
	Incorrect Answers: Correct method: $\div 2$ for area change and $\times 24$ for temperature change A – only applies $\div 2$ for area change B – applies $\div 2$ for area change and $\times 2$ for temperature change C – applies $\div 1/2$ for area change and $\times 2$ for temperature change Or applies $\div 2$ for area change and $\times (2 \times 4)$ for temperature change	



7	C	The only correct answer is C: luminosity is proportional to temperature⁴ which means a 16-fold increase, and luminosity is proportional to area, which is proportional to diameter², and so means a 4-fold decrease, so there is a 4-fold increase overall A is not the correct answer because this only accounts for the decrease due to decreasing diameter B is not the correct answer because this is the answer obtained if the power applied to temperature is 2 instead of 4 D is not the correct answer because the effect of area is not included	1
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Question Number	Answers	Mark
4	The only correct answer is C <i>A is incorrect because luminosity must have the units of power</i> <i>B is incorrect because luminosity must have the units of power</i> <i>D is incorrect because luminosity must have the units of power</i>	1



Question Number	Answers	Mark
5	The only correct answer is B <i>A is incorrect because a red giant star has larger surface area but a lower surface temperature than the Sun</i> <i>C is incorrect because a red giant star has larger surface area but a lower surface temperature than the Sun</i> <i>D is incorrect because a red giant star has larger surface area but a lower surface temperature than the Sun</i>	1



Question Number	Acceptable answers	Additional guidance	Mark
13	• Use of $\lambda_{\text{max}} T = 2.898 \times 10^{-3} \text{ m K}$ (1) • Use of $A = 4\pi r^2$ (1) • Use of $L = \sigma A T^4$ (1) • $L = 1.63 \times 10^{29} \text{ W}$ (1)	<u>Example of calculation</u> $7.43 \times 10^{-7} \text{ m} \times T = 2.898 \times 10^{-3} \text{ m K}$ $T = 3900 \text{ K}$ $A = 4\pi (3.14 \times 10^{10} \text{ m})^2$ $= 1.24 \times 10^{22} \text{ m}^2$ $L = 5.67 \times 10^{-8} \text{ W m}^{-2} \text{ K}^{-4} \times 1.24 \times 10^{22} \text{ m}^2 \times (3900 \text{ K})^4$ $L = 1.63 \times 10^{29} \text{ W}$	4

(Total for Question 13 = 4 marks)



Question Number	Acceptable answers	Additional guidance	Mark
12(a)	- Use of $\lambda_{\max} T = 2.898 \times 10^{-3} \text{ m K}$ (1) ... with sensible temperature expressed in Kelvin (1) - E.g. $\lambda_{\max} = 9.89 \times 10^{-6} \text{ m}$ for 293 K (1) - Value is greater than max wavelength of red light so is in IR region (1) Or (if starting from 700 nm) - Use of $\lambda_{\max} T = 2.898 \times 10^{-3} \text{ m K}$ $T = 4100 \text{ K}$ - Comparison with stated sensible temperature ($^{\circ}\text{C}$ or K) - Temperature is too high so wavelength greater than max wavelength of red light so is in IR region	<u>Example of calculation</u> $\lambda_{\max} T = 2.898 \times 10^{-3} \text{ m K}$ $\lambda_{\max} = 2.898 \times 10^{-3} \text{ m K} / 293 \text{ K}$ $\lambda_{\max} = 9.89 \times 10^{-6} \text{ m}$ MP4 consistent with calculation	4
12 (b)	- Glass reflects (these wavelengths of) IR radiation (1) - Glass does not transmit (these wavelengths of) IR radiation (1)	Accept IR does not pass through glass	2

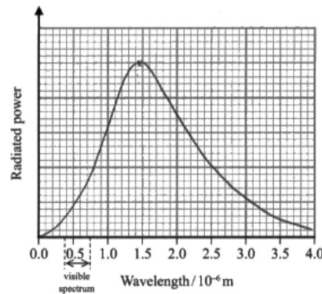
(Total for Question 12 = 6 marks)



Question Number	Acceptable answers	Additional guidance	Mark
15 (a)	- Use of $L = 4\pi r^2 \sigma T^4$ (1) - With 270 000 or 1420 (1) $T = 3494$ K which is smaller than the temperature of the Sun, so it is not correct Or $T = 0.605 T_{\text{Sun}}$ which is smaller than the temperature of the Sun, so it is not correct (1)	<u>Example of calculation</u> $3.85 \times 10^{26} \text{ W} \times 270\,000 = 4 \times \pi \times 5.67 \times 10^{-8} \times (1420 \times 6.96 \times 10^8 \text{ m})^2 \times T^4$ $T = 3494 \text{ K}$	3
15 (b)	- Use of $\lambda_{\text{max}} T = 2.898 \times 10^{-3} \text{ m K}$ (1) $\lambda_{\text{max}} = 8.29 \times 10^{-7} \text{ m}$ (ecf for T from (a)) (1)	<u>Example of calculation</u> $\lambda_{\text{max}} \times 3494 \text{ K} = 2.898 \times 10^{-3} \text{ m K}$ $\lambda_{\text{max}} = 8.29 \times 10^{-7} \text{ m}$	2
15 (c)	- Add to top right (1) - Red giant/supergiant (1)	Consistent with the answer from (a) for both marking points Accept hypergiant	2

(Total for Question 15 = 7 marks)



Question Number	Acceptable answers	Additional guidance	Mark
14 (a)	- Use of $P = IV$ (1) - Use of $L = A\sigma T^4$ (1) $T = 1800 \text{ K}$ (1)	<u>Example of calculation</u> $P = 2.0 \text{ V} \times 0.37 \text{ A} = 0.74 \text{ W}$ $0.74 \text{ W} = 0.35 \times 3.9 \times 10^{-6} \text{ m}^2 \times 5.67 \times 10^{-8} \text{ W m}^{-2} \text{K}^{-4} \times T^4$ $T^4 = 9.56 \times 10^{12} \text{ K}^4$ $T = 1758 \text{ K}$	3
14 (b)(i)	- Use of $\lambda_{\text{max}} T = 2.898 \times 10^{-3} \text{ m K}$ (1) $\lambda_{\text{max}} = 1.4 \times 10^{-6} \text{ (m)}$ (1) - correct black body radiation shape (1) - peak at correct wavelength (1) - line not zero at long wavelength and not positive at 0.0 on wavelength axis (1)	<u>Example of calculation and graph</u> $\lambda_{\text{max}} \times 2026 \text{ K} = 2.898 \times 10^{-3} \text{ m K}$ $\lambda_{\text{max}} = 1.43 \times 10^{-6} \text{ m}$ 	5
14 (b) (ii)	- Most radiation at infrared or λ_{max} isn't in the visible spectrum or only a small proportion of radiation/power in visible spectrum (1) - Ratio of useful output/input is therefore very small Or so proportion of energy transfer that is useful is small (1)		2
(Total for Question 14 = 10 marks)			



Question Number	Acceptable Answer	Additional Guidance	Mark
21(a)	The temperature at which the (mean) molecular kinetic energy is zero (1)	Accept The lowest temperature possible	1
21(b)	An explanation that makes reference to the following points: - The peak of the curve is higher (1) - The rate at which energy is radiated is proportional to temperature to the power of 4. (1) - The peak of the curve is displaced to the left (1) - The wavelength at which maximum rate of energy radiated occurs is inversely proportional to the temperature (1)	MP1 and MP3 allow correct sketch on graph MP2 allow reference to Stefan's law MP4 allow reference to Wien's law	4
21(c)	- Use of $\lambda_{\max}T$ with data for one star (1) - Use of $\lambda_{\max}T$ with data for all three stars (1) - Statement that values are similar/constant for each star AND comparison with Wein's Law constant (1)	<u>Example of calculation</u> $\lambda_{\max}T = 132 \text{ nm} \times 21500 \text{ K} = 2.838 \times 10^6 \text{ nm K}$ $\lambda_{\max}T = 245 \text{ nm} \times 11600 \text{ K} = 2.842 \times 10^6 \text{ nm K}$ $\lambda_{\max}T = 287 \text{ nm} \times 9940 \text{ K} = 2.844 \times 10^6 \text{ nm K}$	3



21(d)	• Use of $L = 4\pi r^2 \sigma T^4$ • Luminosity and temperature of Sirius A read from graph • Use of Luminosity of Sirius A with luminosity of the Sun. • $\frac{r_{\text{Sirius A}}}{r_{\text{Sun}}} = 1.84$ Or $r = 1.28 \times 10^9 \text{ m}$ • Comparison between candidate's ratio and given ratio with valid conclusion Or Comparison between $2 \times r_{\text{Sirius}}$ and r_{Sun} with a valid conclusion	Example of calculation $L = 4\pi(6.96 \times 10^8 \text{ m})^2 \times 5.67 \times 10^{-8} \text{ W m}^{-2} \text{ K}^{-4} \times (5800)^4$ $\therefore L = 3.91 \times 10^{26} \text{ W}$ Luminosity of Sirius = $30 L_{\text{Sun}}$ and $T = 10\,000 \text{ K}$ $r = \sqrt{\frac{30 \times 3.91 \times 10^{26} \text{ W}}{4\pi \times 5.67 \times 10^{-8} \text{ W m}^{-2} \text{ K}^{-4} \times (10\,000 \text{ K})^4}}$ $\therefore r = 1.28 \times 10^9 \text{ m}$ $\frac{r_{\text{Sirius A}}}{r_{\text{Sun}}} = \frac{1.28 \times 10^9 \text{ m}}{6.96 \times 10^8 \text{ m}} = 1.84$ $1.84 \approx 2$, therefore claim is correct	5
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(Total for Question 21 = 13 marks)



Question Number	Acceptable answers	Additional guidance	Mark																																								
*18(a)	This question assesses a student’s ability to show a coherent and logically structured answer with linkages and fully-sustained reasoning. Marks are awarded for indicative content and for how the answer is structured and shows lines of reasoning. The following table shows how the marks should be awarded for indicative content. <table><tr><th>Number of indicative marking points seen in answer</th><th>Number of marks awarded for indicative marking points</th><th>Max linkage mark available</th><th>Max final mark</th></tr><tr><td>6</td><td>4</td><td>2</td><td>6</td></tr><tr><td>5</td><td>3</td><td>2</td><td>5</td></tr><tr><td>4</td><td>3</td><td>1</td><td>4</td></tr><tr><td>3</td><td>2</td><td>1</td><td>3</td></tr><tr><td>2</td><td>2</td><td>0</td><td>2</td></tr><tr><td>1</td><td>1</td><td>0</td><td>1</td></tr><tr><td>0</td><td>0</td><td>0</td><td>0</td></tr></table>	Number of indicative marking points seen in answer	Number of marks awarded for indicative marking points	Max linkage mark available	Max final mark	6	4	2	6	5	3	2	5	4	3	1	4	3	2	1	3	2	2	0	2	1	1	0	1	0	0	0	0	The following table shows how the marks should be awarded <table><tr><td></td><td>Number of marks awarded for structure of answer and sustained line of reasoning</td></tr><tr><td>Answer shows a coherent and logical structure with linkages and fully sustained lines of reasoning demonstrated throughout</td><td>2</td></tr><tr><td>Answer is partially structured with some linkages and lines of reasoning</td><td>1</td></tr><tr><td>Answer has no linkages between points and is unstructured</td><td>0</td></tr></table> for structure and lines of reasoning. Guidance on how the mark scheme should be applied: The mark for indicative content should be added to the mark for lines of reasoning. For example, an answer with five indicative marking points which is partially structured with some linkages and lines of reasoning scores 4 marks (3 marks for indicative content and 1 mark for partial structure and some linkages and lines of reasoning). If there are no linkages between points, the same five indicative marking points would yield an overall score of 3 marks (3 marks for indicative content and no marks for linkages).		Number of marks awarded for structure of answer and sustained line of reasoning	Answer shows a coherent and logical structure with linkages and fully sustained lines of reasoning demonstrated throughout	2	Answer is partially structured with some linkages and lines of reasoning	1	Answer has no linkages between points and is unstructured	0	
Number of indicative marking points seen in answer	Number of marks awarded for indicative marking points	Max linkage mark available	Max final mark																																								
6	4	2	6																																								
5	3	2	5																																								
4	3	1	4																																								
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	Number of marks awarded for structure of answer and sustained line of reasoning																																										
Answer shows a coherent and logical structure with linkages and fully sustained lines of reasoning demonstrated throughout	2																																										
Answer is partially structured with some linkages and lines of reasoning	1																																										
Answer has no linkages between points and is unstructured	0																																										



	Indicative content: IC1 Electrons are in (discrete) energy levels IC2 Absorption of (a single) photon causes an electron to move to a higher energy level IC3 Photon energy = hf Or photon energy is proportional to frequency IC4 Energy of (absorbed) photon must equal difference in energy levels IC5 The (changes in) energy levels are specific to each element IC6 Different wavelengths/frequencies of light are absorbed		6
18(b)	• Use of $c = f\lambda$ (1) • Use of $\Delta E = hf$ (1) • Use of $1 \text{ eV} = 1.6 \times 10^{-19} \text{ J}$ (1) • Change in energy equal to 1.89 eV and transition from energy level 2 to energy level 3 (1)	<u>Example of calculation</u> $f = 3.00 \times 10^8 \text{ m s}^{-1} / 656.46 \times 10^{-9} \text{ m}$ $= 4.57 \times 10^{14} \text{ Hz}$ $E = 6.63 \times 10^{-34} \text{ J s} \times 4.57 \times 10^{14} \text{ Hz}$ $= 3.03 \times 10^{-19} \text{ J}$ $= 3.03 \times 10^{-19} \text{ J} / 1.60 \times 10^{-19} = 1.89 \text{ eV}$ $1.89 \text{ eV} - 3.40 \text{ eV} = -1.51 \text{ eV} = \text{level 3}$	4



18(c)(i)	(According to the Doppler effect) if the source is moving away from the observer the wavelength will increase (1) (According to the Doppler effect) there is a change in wavelength proportional to velocity (1) - He is correct (as speed and direction can be determined). (1) MP3 dependent on MP1 and MP2	Allow converse statement i.e. If the source is moving towards the observer the wavelength will decrease	3
18(c)(ii)	- Use of $\Delta\lambda/\lambda_0 = v/c$ (1) $\lambda = 656 \times 10^{-9} \text{ m}$ (1)	Must see $656.46 \times 10^{-9} \text{ m}$ in denominator <u>Example of calculation</u> $\Delta\lambda = 656.46 \times 10^{-9} \text{ m} \times 5.5 \times 10^3 \text{ m s}^{-1} / 3.00 \times 10^8 \text{ m s}^{-1}$ $= 0.012 \times 10^{-9} \text{ m}$ Moving away, so add $\Delta\lambda$ $\lambda = 656.46 \times 10^{-9} \text{ m} + 0.012 \times 10^{-9} \text{ m}$ $\lambda = 656.47 \times 10^{-9} \text{ m}$	2

(Total for Question 18 = 15 marks)

Question Number	Acceptable Answer	Additional Guidance	Mark
11(a)	- Use of $L = 4\pi r^2 \sigma T^4$ (1) - Use of $I = \frac{L}{4\pi d^2}$ (1) $I = 1.37 \text{ (kW m}^{-2}\text{)}$ (1) - This is less than 2 (kW m⁻²) and so the claim is false. (1)	Example of calculation: $L = 4\pi(6.96 \times 10^8 \text{ m})^2 \times 5.67 \times 10^{-8} \text{ W m}^{-2} \text{ K}^{-4} (5790 \text{ K})^4$ $L = 3.88 \times 10^{26} \text{ W}$ $I = \frac{3.88 \times 10^{26} \text{ W}}{4\pi(1.50 \times 10^{11} \text{ m})^2} = 1372 \text{ W m}^{-2}$	4
11(b)(i)	An explanation that makes reference to the following points: - Radiation is absorbed/scattered passing through the atmosphere. (1) - Radiation is reflected from the top of the atmosphere (1) - Only half of the Earth's surface has radiation from the Sun incident on it at any one instant. (1) - The intensity of radiation (normal to the surface) is greater at the equator than at the poles. (1)		4
11(b)(ii)	- Use of $A = 4\pi r^2$ (1) - Use of efficiency = $\frac{\text{useful power output}}{\text{total power input}}$ (1) - Use of $I = \frac{P}{A}$ (1) % of surface needed is 0.0005%, so claim is not valid (1) [Accept reverse calculation to show power generated by cells over 0.5% of the Earth would generate $1.06 \times 10^5 \text{ GW}$]	Example of calculation: $A = \frac{P}{I} = \frac{100 \times 10^9 \text{ W}}{0.25 \times 164 \text{ W m}^{-2}} = 2.44 \times 10^9 \text{ m}^2$ $A = 4\pi \times (6.4 \times 10^6 \text{ m})^2 = 5.15 \times 10^{14} \text{ m}^2$ $\% \text{ needed} = \frac{2.44 \times 10^9 \text{ m}^2}{5.15 \times 10^{14} \text{ m}^2} \times 100\% = 0.00047\%$	4

11(c)(i)	- Satellite would always be above the same point on the Earth's surface (1) - So that contact/communication with the space station would be maintained at all times (1)		2
11(c)(ii)	Use of $F = \frac{GMm}{r^2}$ with $F = m\omega^2 r$ (1) Use of $\omega = 2\pi/T$ (1) $r = 4.23 \times 10^7 \text{ m}$ (1) $h = 3.6 \times 10^7 \text{ m}$ (1) OR Use of $F = \frac{GMm}{r^2}$ with $F = \frac{mv^2}{r}$ (1) Use of $v = 2\pi r/T$ (1) $r = 4.23 \times 10^7 \text{ m}$ (1) $h = 3.6 \times 10^7 \text{ m}$ (1)	<u>Example of calculation:</u> $m\omega^2 r = \frac{GMm}{r^2}$ $\therefore \left(\frac{2\pi}{T}\right)^2 = \frac{GM}{r^3}$ $\therefore r = \sqrt[3]{\frac{GMT^2}{4\pi^2}}$ $r = \sqrt[3]{\frac{6.67 \times 10^{11} \text{ N m}^2 \text{ kg}^{-2} \times 6.00 \times 10^{24} \text{ kg} \times (8.64 \times 10^4 \text{ s})^2}{4\pi^2}}$ $r = 4.23 \times 10^7 \text{ m}$ $h = r - R_E = 4.23 \times 10^7 \text{ m} - 6.4 \times 10^6 \text{ m} = 3.59 \times 10^7 \text{ m}$	4

(Total for Question 11 = 18 marks)



Question Number	Acceptable answer	Additional guidance	Mark
4	C	The only correct answer is C because the correct method for a nearby star is parallax, for a nearby galaxy is standard candle and for a very distant galaxy is red shift A is not correct because only the nearby star method is correct B is not correct because only the nearby galaxy method is correct D is not correct because none of the methods are correct	1



Question Number	Acceptable answers	Additional guidance	Mark
3	The only correct answer is B A is not correct as the luminosity of P must be less than Q C is not correct as P is closer than Q D is not correct as P is closer than Q		1



Question Number	Answer	Mark
5	The only correct answer is C, Y is twice as far away as X. A is not correct because $I = \frac{L}{4\pi x^2}$ and L is the same for each star B is not correct because $I = \frac{L}{4\pi x^2}$ and L is the same for each star D is not correct because $I = \frac{L}{4\pi x^2}$ and L is the same for each star	1



Question Number	Acceptable answers	Additional guidance	
13(a)	Object of known luminosity (1)		<u>1</u>
13(b)	- The (parallax) angle becomes very small Or the diameter of the Earth's orbit is very small (1) - Giving a (very) large percentage uncertainty (1)		<u>2</u>
13(c)	- Measure change in wavelength / frequency (1) - Determine relative velocity using redshift formula (1) - Then apply $v = H_0 d$ (1)		<u>3</u>

(Total for Question 13 = 6 marks)

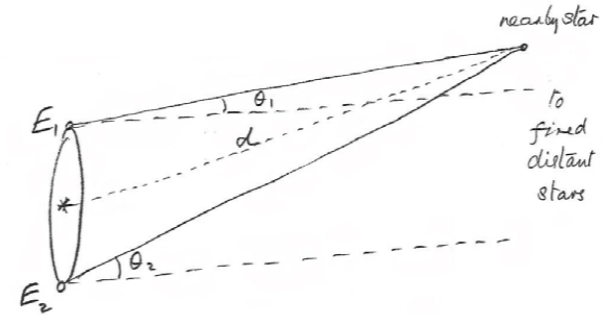


Question Number	Acceptable Answers	Additional Guidance	Mark
19(a)(i)	• use of $I = L / 4\pi d^2$ (1) • $L = 6.53 \times 10^{23} \text{ W}$ (1) • = 0.17% of Sun (1)	<u>Example of calculation</u> $3.25 \times 10^{-11} \text{ W m}^{-2} = L / 4\pi(4.00 \times 10^{16} \text{ m})^2$ $L = 6.53 \times 10^{23} \text{ W}$ $6.53 \times 10^{23} \text{ W} / 3.85 \times 10^{26} \text{ W} = 0.17\%$	3
19(a)(ii)	• use of $L = \sigma AT^4$ (1) • $T = 3124 \text{ (K)}$ (1) • Statement relating calculated values of T and L to main sequence on H-R diagram (1)	<u>Example of calculation</u> $6.53 \times 10^{23} \text{ W} = 5.67 \times 10^{-8} \text{ W m}^{-2} \text{ K}^{-4} \times 4\pi (9.81 \times 10^7 \text{ m})^2 \times T^4$ $T = 3124 \text{ K}$	3
19(b)	• atoms/electrons have fixed/discrete/specific energy levels (1) • electrons get excited by absorbing <u>photons</u> (1) • energy of <u>photon</u> absorbed = difference in energy levels (1) • only certain transitions possible, so only certain <u>photon</u> energies absorbed so only certain frequencies missing (1) • the set of frequencies absorbed depends on the element (1)	Answers in terms of emission spectrum can be awarded MP1, 4 and 5	5
19(c)	• The star is viewed from two positions at 6 month intervals (1) • Or The star is viewed from opposite ends of its orbit diameter about the Sun (1) • The change in angle/position of the star against backdrop of fixed stars is measured (1)	Marks may be obtained from suitably annotated diagrams e.g MP1 and MP2:	3



- Trigonometry is used to calculate the distance to the star [Do not accept Pythagoras]
- Or**
The diameter/radius of the Earth's orbit about the Sun must be known

(1)



(Total for Question 19 = 14 marks)

6	B – (point on graph with luminosity $\neq L_{\odot}$)	1
	Incorrect Answers: A – luminosity $\neq L_{\odot}$ C – luminosity $\neq L_{\odot}$ D – luminosity $\neq L_{\odot}$	



Question Number	Acceptable answer	Additional guidance	Mark
1	C	The only correct answer is C : main sequence – red giant – white dwarf A is not correct because it is white dwarf – red giant – main sequence B is not correct because it moves along the main sequence from large to small D is not correct because it moves along the main sequence from small to large	1



9	B	The only correct answer is B because the y axis is luminosity and the x axis shows temperature decreasing A is not the correct answer because the y axis is luminosity but the x axis shows temperature increasing C is not the correct answer because the x axis is luminosity and the y axis is luminosity D is not the correct answer because the x axis is luminosity and the y axis is luminosity	1
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Question Number	Answer	Mark
1	The only correct answer is B <i>A is not correct because V, X and Z are all on the main sequence</i> <i>C is not correct because Z is on the main sequence and the sun will become a white dwarf, which is position Y</i> <i>D is not correct because Z, X and V are all on the main sequence</i>	1



Question Number	Acceptable Answer	Additional Guidance	Mark
15(a)	• Conversion from eV to J • Use of $E = hf$ • Use of $c = f\lambda$ • $\lambda = 6.2 \times 10^{-20} \text{ m}$	(1) <u>Example of calculation</u> $E = 2.0 \times 10^{13} \text{ eV} \times 1.60 \times 10^{-19} \text{ J eV}^{-1} = 3.2 \times 10^{-6} \text{ J}$ (1) $3.2 \times 10^{-6} \text{ J} = 6.63 \times 10^{-34} \text{ J s} \times f$ (1) $f = \frac{3.2 \times 10^{-6} \text{ J}}{6.63 \times 10^{-34} \text{ J s}} = 4.83 \times 10^{27} \text{ Hz}$ (1) $\lambda = \frac{3.0 \times 10^8 \text{ m s}^{-1}}{4.83 \times 10^{27} \text{ Hz}} = 6.22 \times 10^{-20} \text{ m}$	4
15(b)	• The speed of the pulsar is negligible compared with the speed of light	(1) Attempt at calculation may result in this conclusion and so should gain mark Accept idea of speed being much smaller Accept comment that red shift is negligible/very small, if based on a calculation	1

(Total for Question 15 = 5 marks)



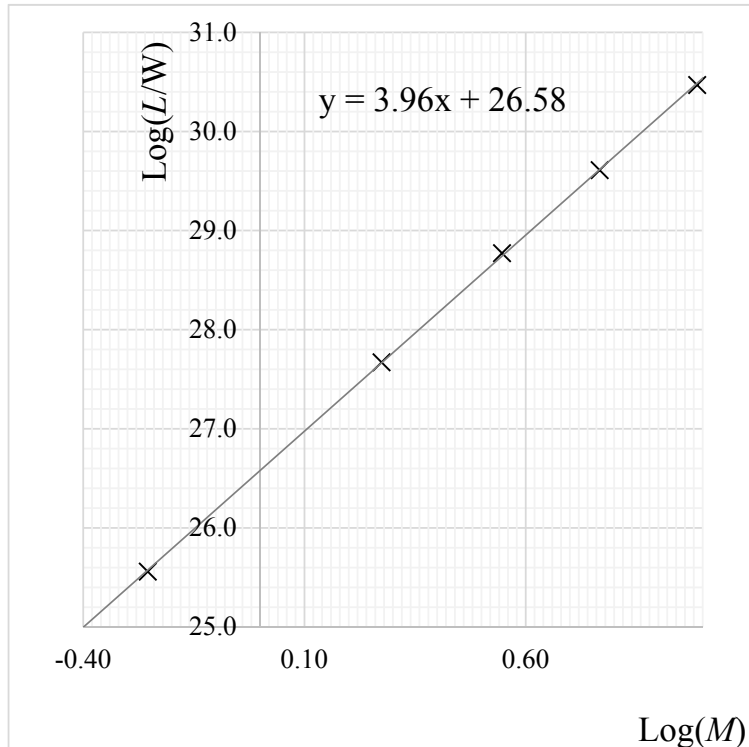
Question Number	Acceptable answers	Additional guidance	Mark																																								
*13	This question assesses a student’s ability to show a coherent and logically structured answer with linkages and fully-sustained reasoning. Marks are awarded for indicative content and for how the answer is structured and shows lines of reasoning. The following table shows how the marks should be awarded for indicative content. <table><tr><th>Number of indicative marking points seen in answer</th><th>Number of marks awarded for indicative marking points</th><th>Max linkage mark available</th><th>Max final mark</th></tr><tr><td>6</td><td>4</td><td>2</td><td>6</td></tr><tr><td>5</td><td>3</td><td>2</td><td>5</td></tr><tr><td>4</td><td>3</td><td>1</td><td>4</td></tr><tr><td>3</td><td>2</td><td>1</td><td>3</td></tr><tr><td>2</td><td>2</td><td>0</td><td>2</td></tr><tr><td>1</td><td>1</td><td>0</td><td>1</td></tr><tr><td>0</td><td>0</td><td>0</td><td>0</td></tr></table>	Number of indicative marking points seen in answer	Number of marks awarded for indicative marking points	Max linkage mark available	Max final mark	6	4	2	6	5	3	2	5	4	3	1	4	3	2	1	3	2	2	0	2	1	1	0	1	0	0	0	0	The following table shows how the marks should be <table><tr><td></td><td>Number of marks awarded for structure of answer and sustained line of reasoning</td></tr><tr><td>Answer shows a coherent and logical structure with linkages and fully sustained lines of reasoning demonstrated throughout</td><td>2</td></tr><tr><td>Answer is partially structured with some linkages and lines of reasoning</td><td>1</td></tr><tr><td>Answer has no linkages between points and is unstructured</td><td>0</td></tr></table> awarded for structure and lines of reasoning. Guidance on how the mark scheme should be applied: The mark for indicative content should be added to the mark for lines of reasoning. For example, an answer with five indicative marking points which is partially structured with some linkages and lines of reasoning scores 4 marks (3 marks for indicative content and 1 mark for partial structure and some linkages and lines of reasoning). If there are no linkages between points, the same five indicative marking points would yield an overall score of 3 marks (3 marks for indicative content and no marks for linkages).		Number of marks awarded for structure of answer and sustained line of reasoning	Answer shows a coherent and logical structure with linkages and fully sustained lines of reasoning demonstrated throughout	2	Answer is partially structured with some linkages and lines of reasoning	1	Answer has no linkages between points and is unstructured	0	6
		Number of indicative marking points seen in answer	Number of marks awarded for indicative marking points	Max linkage mark available	Max final mark																																						
		6	4	2	6																																						
		5	3	2	5																																						
		4	3	1	4																																						
		3	2	1	3																																						
		2	2	0	2																																						
		1	1	0	1																																						
		0	0	0	0																																						
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Answer is partially structured with some linkages and lines of reasoning	1																																										
Answer has no linkages between points and is unstructured	0																																										



	Indicative content: • Requires a (very) high temperature • Nuclei all have positive charge leading to a large repulsive force between nuclei • At high temperature nuclei have high <u>kinetic</u> energy, sufficient to overcome repulsion • Nuclei must get close enough to fuse (accept reference to close enough for strong force) • Requires (very) high density • Collision rate must be high enough to sustain fusion		
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(Total for Question 13 = 6 marks)



9(a)	An explanation that makes reference to the following points: Shows expansion $\log L = p \log(M) + \log(L_{\text{Sun}})$ Compares with $y = mx + c$ 2																																				
9(b)(i)	Log values correct and consistent to 3/4 SF Labels and unit Scales Plots Line of best fit  (1) (1) (1) (1) (1) <table><tr><th>Log (L /W)</th><th>Log (L /10²⁵ W)</th><th>Log (M /M_{Sun})</th></tr><tr><td>25.56</td><td>0.560</td><td>−0.254</td></tr><tr><td>27.67</td><td>2.67</td><td>0.274</td></tr><tr><td>28.77</td><td>3.77</td><td>0.547</td></tr><tr><td>29.61</td><td>4.61</td><td>0.767</td></tr><tr><td>30.47</td><td>5.47</td><td>0.988</td></tr></table> <table><tr><th>Ln (L /W)</th><th>Ln (L /10²⁵ W)</th><th>Ln (M /M_{Sun})</th></tr><tr><td>58.85</td><td>1.29</td><td>−0.585</td></tr><tr><td>63.72</td><td>6.15</td><td>0.631</td></tr><tr><td>66.25</td><td>8.69</td><td>1.26</td></tr><tr><td>68.18</td><td>10.6</td><td>1.77</td></tr><tr><td>70.16</td><td>12.6</td><td>2.27</td></tr></table> 5	Log (L /W)	Log (L /10 ²⁵ W)	Log (M /M _{Sun})	25.56	0.560	−0.254	27.67	2.67	0.274	28.77	3.77	0.547	29.61	4.61	0.767	30.47	5.47	0.988	Ln (L /W)	Ln (L /10 ²⁵ W)	Ln (M /M _{Sun})	58.85	1.29	−0.585	63.72	6.15	0.631	66.25	8.69	1.26	68.18	10.6	1.77	70.16	12.6	2.27
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68.18	10.6	1.77																																			
70.16	12.6	2.27																																			

9(b)(ii)	- Determines gradient using large triangle $-\Delta x \geq 0.6$ (1) - gradient = $(3.9 \rightarrow 4.0)$ to 2/3 SF and no units (1) - reads intercept on y-axis and takes antilog to give a value for L_{Sun} (1) - States $L = 4 \times 10^{26} M^4$ (1)	$L_{\text{Sun}} = 4 \times 10^{26} \text{ W}$ (accept any value that rounds to 4)	4

(Total for Question 9 = 11 marks)



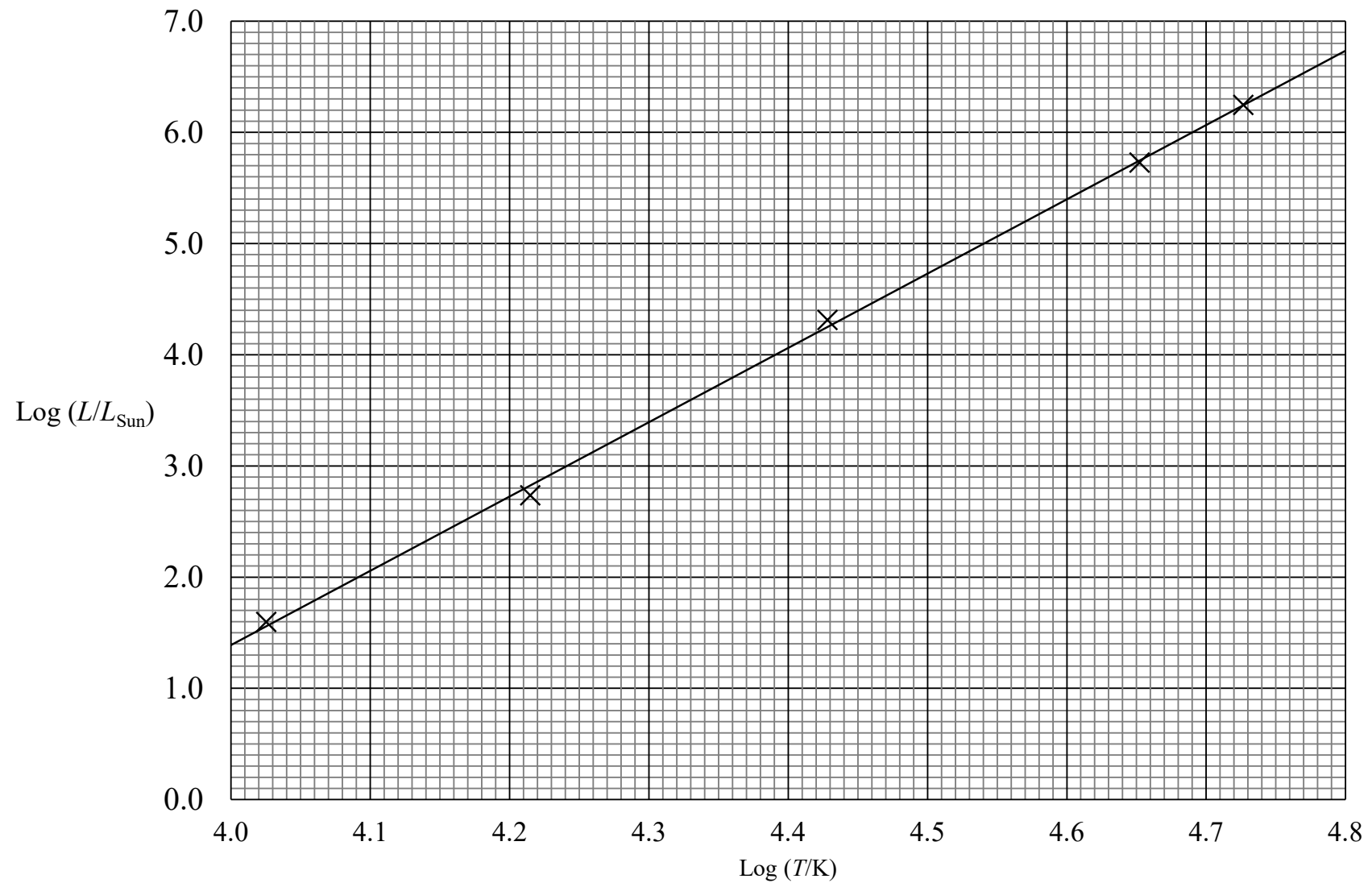
Question Number	Acceptable answers	Additional guidance	Mark
17 (a)	Use of $F = mv^2 / r$ with $F = Gm_1 m_2 / r^2$ (1) Use of $v = 2\pi r / T$ (1) $T = 6.64 \times 10^8$ s (= 21 years) (1) Or Use of $F = m\omega^2 r$ with $F = Gm_1 m_2 / r^2$ Use of $\omega = 2\pi / T$ $T = 6.64 \times 10^8$ s (= 21 years)	<u>Example of calculation</u> $F = Gm_1 m_2 / r^2 = m_2 v^2 / r = (2\pi r)^2 m_2 / r T^2$ $T^2 = 4\pi^2 r^3 / G m_1$ $= 4\pi^2 \times (1.9 \times 10^{14} \text{ m})^3 /$ $(6.67 \times 10^{-11} \text{ N m}^2 \text{ kg}^{-2} \times 9.2 \times 10^{36} \text{ kg})$ $T = 6.64 \times 10^8$ s (= 21 years)	3
17 (b)(i)	- Use of $V = -Gm / r$ (1) - Change in $V = 3.18 \times 10^{13} \text{ (J kg}^{-1}\text{)}$ (1)	<u>Example of calculation</u> $\Delta V = -Gm (1/r_2 - 1/r_1)$ $= -6.67 \times 10^{-11} \text{ N m}^2 \text{ kg}^{-2} \times 9.2 \times 10^{36} \text{ kg} \times$ $((1/2.7 \times 10^{14} \text{ m} - 1/1.8 \times 10^{13} \text{ m}))$ $= 3.18 \times 10^{13} \text{ J kg}^{-1}$	2
17 (b)(ii)	- Equate change in gravitational potential energy to change in kinetic energy Or use of $E_p = mV$ (1) - Use of $E_k = \frac{1}{2} mv^2$ (1) $v = 1.4 \times 10^6 \text{ m s}^{-1}$ (1)	<u>Example of calculation</u> $m \times 3.18 \times 10^{13} \text{ J kg}^{-1}$ $= (0.5 \times m \times (8.10 \times 10^6 \text{ m s}^{-1})^2) - (0.5 \times m v_2^2)$ $v_2 = 1.4 \times 10^6 \text{ m s}^{-1}$	3
17(c)	An explanation that makes reference to the following points: - Hubble is for cosmological distances (1) - is not suitable since S2 is in our galaxy (1) - trigonometrical parallax is suitable for local stars because the parallax angles produced are large enough to measure accurately (1)	e.g. to distant galaxies	3
(Total for Question 17 = 11 marks)			



Question Number	Acceptable Answer	Additional Guidance		Mark												
9(a)(i)	- All the stars are in the main sequence (1) - In an older cluster there would be red giant stars (1)			2												
9(a)(ii)	MAX 4 - The most massive stars experience much greater gravitational forces (1) - So core temperature and density is greatest (1) - The rate of fusion in the core is greatest (1) Or the power generated in the core is greatest (1) - The (surface) temperature is greatest (1) - The surface area of these stars is greatest (1) - So according to Stefan’s Law the power radiated from these massive stars is greatest (1)			4												
9(b)(i)	An explanation that makes reference to the following points: - Shows expansion $\log L = n \log T + \log k$ (1) - Compares with $y = mx + c$ and states that gradient is n (1)			2												
9(b)(ii)	- Log values correct and to 2 or 3 d.p. (1) - Graph axes labelled with quantities and units (1) - Scales (1) - Plots (1) - Line of best fit (1)	<table><tr><td>Log (L/L_{Sun})</td><td>Log (T/K)</td></tr><tr><td>1.597</td><td>4.025</td></tr><tr><td>2.736</td><td>4.215</td></tr><tr><td>4.314</td><td>4.428</td></tr><tr><td>5.728</td><td>4.652</td></tr><tr><td>6.248</td><td>4.727</td></tr></table>	Log (L/L_{Sun})	Log (T/K)	1.597	4.025	2.736	4.215	4.314	4.428	5.728	4.652	6.248	4.727		5
Log (L/L_{Sun})	Log (T/K)															
1.597	4.025															
2.736	4.215															
4.314	4.428															
5.728	4.652															
6.248	4.727															
9(b)(iii)	- Determines gradient using large triangle (1) $n = 6.68$ to 2 or 3 SF (1) (accept answers in range 6.6 → 6.9)			2												

(Total for Question 9 = 15 marks)





8	D – $\frac{(656.3 - 654.9)}{654.9} \times 3 \times 10^8 \text{ m s}^{-1}$	1
	Incorrect Answers: correct method: $\frac{\text{change in wavelength}}{\text{wavelength in laboratory}} \times \text{speed of light}$ A – uses $\frac{\text{wavelength from star}}{\text{wavelength in laboratory}} \times \text{speed of light}$ B – uses $\frac{\text{wavelength in laboratory}}{\text{change in wavelength}} \times \text{speed of light}$ C – uses $\frac{\text{wavelength in laboratory}}{\text{wavelength from star}} \times \text{speed of light}$	



Question Number	Answer	Mark
6	The only correct answer is D because there is relative motion of the objects away from each other so the wavelength is increased by the Doppler effect so the observed frequency is decreased A there is relative motion of the objects towards each other so the wavelength is decreased by the Doppler effect so the observed frequency is increased B there is no relative motion for the objects so there is no observed change in wavelength or frequency C there is relative motion of the objects towards each other so the wavelength is decreased by the Doppler effect so the observed frequency is increased	1



Question Number	Answer	Mark
4	The only correct answer is A, a closed universe because a closed universe reaches a maximum size and then contracts B is not correct because scientists do not define a ‘critical universe’ C is not correct because a flat universe reaches a maximum size D is not correct because an open universe keeps expanding forever	1



Question Number	Acceptable Answer	Additional Guidance	Mark
11	- Use of $\frac{\Delta\lambda}{\lambda} \approx \frac{v}{c}$ (1) $v = (-) 1.8 \times 10^5 \text{ m s}^{-1}$ (1) - Towards the Earth (dependent upon correct numerator in Doppler equation) (1)	<u>Example of calculation</u> $\frac{(655.88 - 656.28) \text{ nm}}{656.28 \text{ nm}} \approx \frac{v}{3.0 \times 10^8 \text{ m s}^{-1}}$ $v = \frac{(-)0.4 \text{ nm}}{656.28 \text{ nm}} \times 3.0 \times 10^8 \text{ m s}^{-1} = -1.83 \times 10^5 \text{ m s}^{-1}$	3

(Total for Question 11 = 3 marks)



Question Number	Acceptable answers	Additional guidance	Mark
14 (a)	An explanation that makes reference to the following points: - The fractional change in wavelength is proportional to the relative velocity of the source (1) - Hence the change in wavelength is proportional to the wavelength (1) OR $\frac{\Delta\lambda}{\lambda} = \frac{v}{c}$ and v and c are the same for all wavelengths Or $\frac{\Delta\lambda}{\lambda} = z$ and z is constant (1) - change in wavelength is proportional to the wavelength Or rearranges, e.g. $\Delta\lambda = x\lambda$ to demonstrate $\Delta\lambda$ is proportional to λ (1)		2
14 (b)	An explanation that makes reference to the following points: - Estimate λ_{star} (above $7 \times 10^{-7} \text{ m}$) (1) - Use of $\frac{\Delta\lambda}{\lambda} = \frac{v}{c}$ with 656 nm as denominator (1) $v = 3.8 \times 10^7 \text{ m s}^{-1}$ (range $3.4 \times 10^7 \text{ m s}^{-1}$ to $4.2 \times 10^7 \text{ m s}^{-1}$) (1) (Star is) moving away from the Earth Or (star is) receding (1)	<u>Example of calculation</u> $\frac{(7.40 \times 10^{-7} - 6.56 \times 10^{-7})}{6.56 \times 10^{-7} \text{ m}} = \frac{v}{3.00 \times 10^8 \text{ m s}^{-1}}$ $\therefore v = \frac{0.84 \times 10^{-7} \text{ m}}{6.56 \times 10^{-7} \text{ m}} \times 3.00 \times 10^8 \text{ m s}^{-1}$ $\therefore v = 3.84 \times 10^7 \text{ m s}^{-1}$	4

(Total for Question 14 = 6 marks)



Question Number	Acceptable answers	Additional guidance	Mark
14a	- The frequency/wavelength (of a line in the spectrum) emitted by the star must be measured (1) - Determine the difference between this frequency/wavelength and that emitted in the lab (1) (The Doppler equation is used to) determine the speed of the star (relative to the Earth) $v/c = \Delta f/f_0$ or $v/c = \Delta \lambda/\lambda_0$ (1) - Clear indication (stated in words or via a formula) that v is positive/approaching when the frequency has increased and negative/receding when it has decreased (1) Or corresponding statement about wavelength (1)	MP2 – accept in terms of difference between measured frequency/wavelength with average frequency/wavelength	4
bi	- Use of $\omega = 2\pi/T$ (1) - For at least 2 full cycles (1) $\omega = 6.5 \times 10^{-6}$ (radian s^{-1}) (1)	For MP3, accept correctly rounded answers in range 6.5×10^{-6} radian s^{-1} to 6.6×10^{-6} radian s^{-1} <u>Example of calculation</u> $\omega = 5 \times 2\pi / (56 \times 24 \times 60 \times 60) \text{ s}$ $= 6.49 \times 10^{-6} \text{ radian } s^{-1}$	3
bii	- Equates $F = Gm_1m_2/r^2$ and $F = m\omega^2r$ (1) Or $F = Gm_1m_2/r^2$ and $F = mv^2/r$ with $v = 2\pi r/T$ (1) - Correct rearrangement and substitution (e.g. in $r^3 = Gm_1/\omega^2$) (1) $r = 7.2 \times 10^9 \text{ m}$ (ecf from (b)(i))	<u>Example of calculation</u> $r^3 = 6.67 \times 10^{-11} \text{ N m}^2 \text{ kg}^{-2} \times 0.12 \times 1.99 \times 10^{30} \text{ kg} / (6.5 \times 10^{-6} \text{ radian } s^{-1})^2$ $r = 7.2 \times 10^9 \text{ m}$ ($r = 7.6 \times 10^9 \text{ m}$ for ‘show that’ value)	3

(Total for Question 14 = 10 marks)



12(a)	- use of $\frac{\Delta\lambda}{\lambda} = \frac{v}{c}$ with $\lambda = 656.2 \text{ nm}$ $v = 9 \times 10^4 \text{ m s}^{-1}$ - the star is moving towards the Earth	(1) (1) (1)	<u>Example of calculation:</u> $v = \left(\frac{(656.2 - 656.0) \times 10^{-9} \text{ m}}{656.2 \times 10^{-9} \text{ m}} \right) \times 3.00 \times 10^8 \text{ m s}^{-1}$ $= 9.14 \times 10^4 \text{ m s}^{-1}$	3
12(b)(i)	- set up diffraction grating at right angles to light from laser Or set up grating parallel to screen - measure the distance between the diffraction grating and the screen - measure the distance between 1st order images on the screen	(1) (1) (1)	An annotated diagram could score these marks MP3 accept between other correct specified orders.	3
12(b)(ii)	- use of $d \sin \theta = n\lambda$ - Calculation of one of the diffraction angles (for any n) - Attempt to calculate a difference in the angles Or statement that the two angles are very similar - So (accurate) measurement would be very difficult Or the difference in wavelength could not be determined with this grating	(1) (1) (1) (1)	MP4 dependent on MP3 <u>Example of calculation:</u> $\sin \theta_1 = \frac{656.2 \times 10^{-9} \text{ m}}{2.2 \times 10^{-6} \text{ m}} \quad \sin \theta_2 = \frac{656.0 \times 10^{-9} \text{ m}}{2.2 \times 10^{-6} \text{ m}}$ $\therefore \theta_1 = 17.354^\circ \quad \therefore \theta_2 = 17.348^\circ$ $\therefore \Delta\theta = 17.354^\circ - 17.348^\circ = 0.006^\circ$	4
12(c)(i)	- Use of $\frac{1}{2} m \langle c^2 \rangle = \frac{3}{2} kT$ - mean kinetic energy = $6.4 \times 10^{-20} \text{ J}$	(1) (1)	<u>Example of calculation:</u> $\frac{1}{2} m \langle c^2 \rangle = \frac{3}{2} kT$ $= \frac{3}{2} \times 1.38 \times 10^{-23} \text{ J K}^{-1} \times 3100 \text{ K} = 6.42 \times 10^{-20} \text{ J}$	2
12(c)(ii)	- There are electron transitions between energy levels in the atoms, - When electrons return to a lower level they emit energy in the form of <u>photons</u>	(1) (1)		2

(Total for Question 12 = 14 marks)



Question Number	Acceptable answers	Additional guidance	Mark
15(a)(i)	Use of $v = H_0 d$ and $v = d/t$ to derive equation (1)	<u>Example of derivation:</u> $v = H_0 d$ $v = d/t$ $d/t = H_0 d$ $1/t = H_0$ Need to see $v = d/t$	1
15(a)(ii)	- Expansion (of Universe) has been uniform Or Expansion (of Universe) at a constant rate Or Galaxy moves at constant velocity (1)	Accept H_0 is constant	1
15(a)(iii)	- Converts to s (1) - Use of $H = 1/T$ (1) 75 ($\text{km s}^{-1} \text{Mpc}^{-1}$) and conclusion that it lies within range (1) Or Upper and lower limits of values of the Hubble constant are $2.58 \times 10^{-18} \text{ s}^{-1}$ to $1.94 \times 10^{-18} \text{ s}^{-1}$, so it is in range	<u>Example of calculation:</u> Age of universe = $13 \times 10^9 \times 3.16 \times 10^7 = 4.11 \times 10^{17} \text{ s}$ $H = 1 / 4.11 \times 10^{17} \text{ s} = 2.43 \times 10^{-18} \text{ s}^{-1}$ $(2.43 \times 10^{-18} \text{ s}^{-1} \div 10^3 (\text{k}) \times 10^6 (\text{M}) \times 3.1 \times 10^{16} (\text{Pc}))$ $= 75.5 \text{ km s}^{-1} \text{Mpc}^{-1}$	3
15(b)(i)	- Use of $z = \frac{\Delta\lambda}{\lambda}$ (1) - Uses $\Delta\lambda = 4.0 \times 10^{-6} \text{ m} - \lambda$ and λ as the denominator (1) - Wavelength emitted = $2.7 \times 10^{-7} \text{ m}$ (1)	<u>Example of calculation:</u> $z = 14 = \frac{4.0 \times 10^{-6} \text{ m} - \lambda}{\lambda}$ Wavelength emitted = $2.67 \times 10^{-7} \text{ m}$	3
15(b)(ii)	An explanation that makes reference to the following points: - Wavelength of light has increased (1) One from: - Visible / UV light which was initially emitted might arrive as IR / radio (1) - Due to expanding universe/space (1)		2



15(c)	• Use of $c = f\lambda$ • Maise is moving away from us	(1)	Example of calculation:	
	• Use of $E = hf$ • Use eV to joule conversion factor • Compares correct values with conclusion such as the photon energy is larger than the work function so should be detected Or Compares correct values with conclusion such as the photon frequency is larger than the threshold frequency so should be detected Or Compares correct values with conclusion such as the photon wavelength is smaller than the wavelength for the threshold frequency so should be detected	(1) (1) (1)	Frequency of light = $3.0 \times 10^8 \text{ m s}^{-1} / 4.0 \times 10^{-6} \text{ m}$ $= 7.5 \times 10^{13} \text{ Hz}$ $E = 6.63 \times 10^{-34} \text{ J s} \times 7.5 \times 10^{13} \text{ s}^{-1}$ $= 4.97 \times 10^{-20} \text{ J}$ Or 0.31 eV $W = 0.30 \text{ V} \times 1.6 \times 10^{-19} \text{ J V}^{-1}$ $= 4.8 \times 10^{-20} \text{ J}$ Or $W = 0.30 \text{ V} \times 1.6 \times 10^{-19} \text{ J V}^{-1}$ $= 4.8 \times 10^{-20} \text{ J}$ Threshold frequency = $4.8 \times 10^{-20} \text{ J} \div 6.63 \times 10^{-34} \text{ J s} = 7.2 \times 10^{13} \text{ Hz}$ Frequency of light = $3.0 \times 10^8 \text{ m s}^{-1} / 4.0 \times 10^{-6} \text{ m}$ $= 7.5 \times 10^{13} \text{ Hz}$ Or $W = 0.30 \text{ V} \times 1.6 \times 10^{-19} \text{ J V}^{-1}$ $= 4.8 \times 10^{-20} \text{ J}$ Threshold frequency = $4.8 \times 10^{-20} \text{ J} \div 6.63 \times 10^{-34} \text{ J s} = 7.2 \times 10^{13} \text{ Hz}$ Wavelength for threshold frequency = $3.0 \times 10^8 \text{ m s}^{-1} / 7.2 \times 10^{13} \text{ Hz}$ $= 4.2 \times 10^{-6} \text{ m}$	4

(Total for Question 15 = 14 marks)

