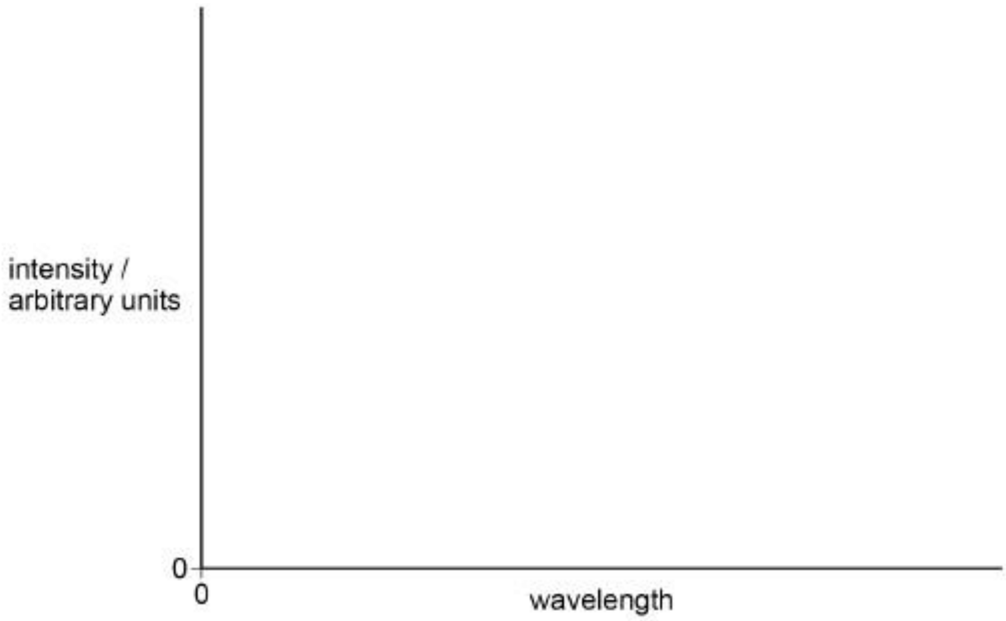
Classification of stars

Q1.

(a) Sketch, on the axes, the black-body radiation curve for a typical star.



(2)

(b) Explain, with reference to the SI units involved, how the curve you have drawn can be used to determine the black-body temperature of the star.

(3)

(c) Two stars, 61 Cygnus A and 61 Cygnus B, can be seen very close together in the constellation Cygnus. Early astronomers were unsure whether the two stars form a binary system, or simply appear in the same line of sight.

The table shows some of the properties of the two stars.

Temperature	Radius /	Apparent

	/ K	km	magnitude
61 Cygnus A	4500	4.7×10^5	5.2
61 Cygnus B	4100	4.1×10^5	6.1

Evaluate whether the data support the suggestion that the two stars form a binary system.

In your answer you should

- compare the two stars as seen by an observer on Earth
- support your evaluation with suitable calculations.

(6)

(d) What is the spectral class of 61 Cygnus A?
Tick (✓) the correct box.

A ☐

F ☐

G ☐

K ☐

(1)
(Total 12 marks)

Q2.

The table summarises some of the properties of four stars in the constellation Hercules.

Star	Distance/pc	Spectral class	Apparent magnitude
Kornephoros	43	G	2.8
Rasalgethi	110	M	3.0
Rutilicus	11	G	2.8
Sarin	23	A	3.1

(a) Define the parsec. You may use a diagram as part of your answer.

(2)

(b) Deduce which star is larger, Kornephoros or Rutilicus.

(3)

(c) One of the four stars has the peak in its black-body radiation curve at a wavelength of 1.0 μm.

Calculate the corresponding temperature for this curve.

temperature = ____________________ K

(2)

(d) Explain which star produced the black-body radiation curve described in question (c).

____

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(2)

(e) Which star has the brightest absolute magnitude?

Tick (✓) the correct box.

Kornephoros ☐

Rasalgethi ☐

Rutilicus ☐

Sarin ☐

(1)

(f) Determine the absolute magnitude of Sarin.

absolute magnitude = ____________________

(3)

(Total 13 marks)

Q3.

(a) Sketch, on the axes, the light curve for a typical type 1a supernova.
Label the axes with suitable scales.

(3)

(b) Type 1a supernovae can be used as standard candles.

Explain what is meant by a standard candle.

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(1)

(c) Measurements of type 1a supernovae in 1999 led to a controversy concerning the behaviour of the Universe.

Describe this controversy and how the measurements led to it.

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(3)

(Total 7 marks)

Q4.

(a) Draw a ray diagram for an astronomical refracting telescope in normal adjustment. Your diagram should show the paths of **three** non−axial rays through both lenses.

Label the principal foci of the two lenses.

(2)

(b) Most modern optical observatories make use of reflecting telescopes rather than refracting telescopes.

Discuss the principal optical advantages of reflecting telescopes.

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(4)

(c) The Greek astronomer Hipparcos used naked-eye observations to develop a scale for comparing the apparent magnitude of stars.

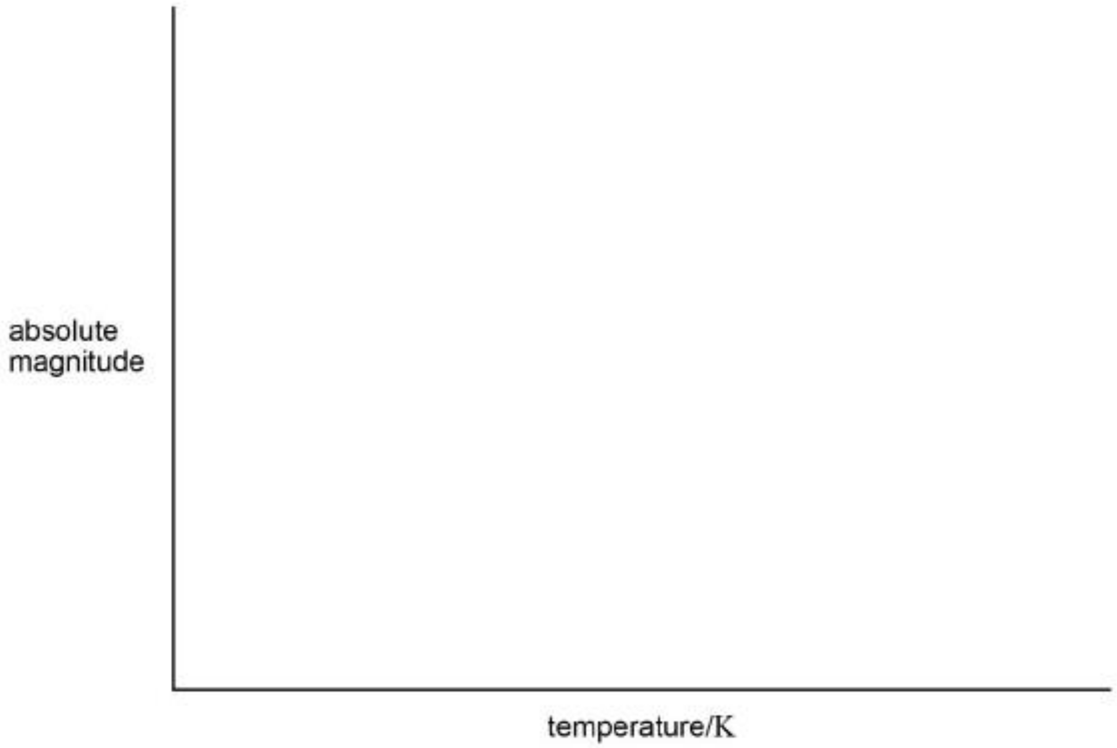
Explain what is meant by apparent magnitude and describe the main features of the

Hipparcos scale.

(6)
(Total 12 marks)

Q5.

(a) Sketch a Hertzsprung−Russell diagram on the axes on the graph below. Label the position of the main sequence, white dwarf and giant stars.



(3)

(b) Label the minimum and maximum values on the scale of each axis.

(2)

(c) Some of the properties of three stars are shown in the table below.

	Rigel	**Omicron 2 Eridani**	**Regulus A**
distance/light year	860	16.5	79
apparent magnitude	0.13	9.5	1.3
temperature/K	12 000	16 500	12 500

Identify the spectral class to which all three stars belong.

Tick (✓) the correct answer in the right hand column.

	✓ if correct
A	
B	
F	
G	
K	
M	

O	

(1)

(d) Explain your answer to part **(c)**.

____

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(2)

(e) The three stars belong to different parts of the Hertzsprung−Russell diagram.

Deduce which star is a white dwarf.

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(3)

(Total 11 marks)

Q6.

In 2013 a gamma-ray burst was detected from a region of space between the constellations of Leo and Ursa Major.

(a) State the event that was the likely cause of this gamma−ray burst.

____

____

(1)

(b) Measurements of the optical remnant of the event revealed an object with a red shift z of 0.34.

Calculate, ignoring relativistic effects, the distance to this object in light year. Give your answer to an appropriate number of significant figures.

distance = ________________ light year

(4)

(c) The total energy of the gamma−ray burst was estimated to be 10^{47} J. Many scientists are concerned that a gamma-ray burst in the direction of the Earth could cause major problems.

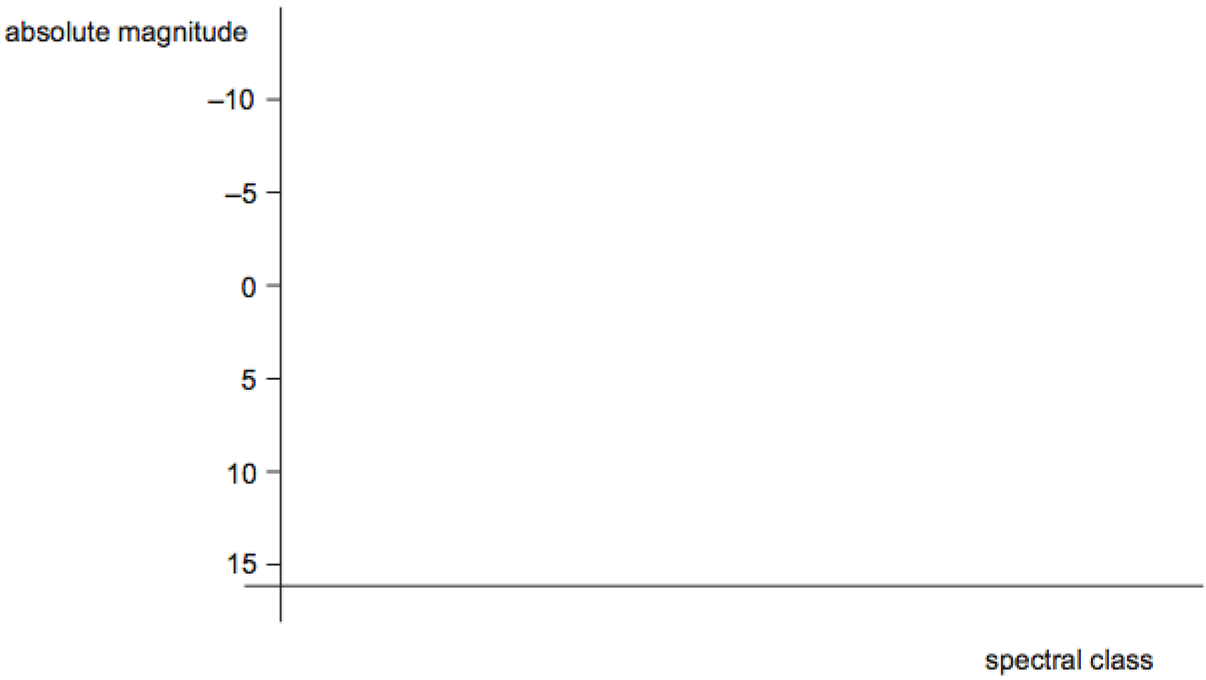
Show that this is similar to the energy that would be released if the mass of the Sun were all converted to energy.

(2)

(Total 7 marks)

Q8.

(a) The graph shows the axes of a Hertzsprung–Russell (H–R) diagram.



(i) Label the spectral class axis with a suitable scale.

(1)

(ii) Complete the H–R diagram by marking the positions of the main sequence, dwarf star and giant star regions.

(2)

(b) The table summarises some of the properties of three stars in the constellation Aries.

Star	Apparent magnitude	Temperature / K	Radius / m

Hamal	2.0	4500	1.0×10^{10}
Sharatan	2.7	9000	1.8×10^{9}
41 Arietis	3.6	12000	9.6×10^{10}

(i) With reference to the data in the table, compare the three stars.
Your answer should include a discussion of:

- the appearance to the naked eye of the three stars as seen from Earth
- the spectrum of the three stars
- the region of the Hertzsprung–Russell diagram to which each star belongs.

The quality of your written communication will be assessed in your answer.

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(6)

(ii) Hamal is 66 light years from the Earth.
Calculate the absolute magnitude of Hamal.

absolute magnitude = ____________________

(3)

(iii) Identify which star is the greatest distance from Earth.
Explain your answer.

____

____

____

(3)

(Total 15 marks)

Q9.

The table has information on two stars.

Star	**Apparent magnitude**	**Absolute magnitude**	**Spectral class**
Sirius	–1.4	–1.4	A
Rigel	0.12	–7.1	B

(a) State the difference between apparent magnitude and absolute magnitude.

(2)

(b) Sirius has an intensity of 1.18×10^{-7} Wm^{-2} at the Earth. The distance between Sirius and the Earth is 8.13×10^{13} km.

Calculate the luminosity of Sirius.
Give an appropriate unit for your answer.

luminosity ____________________ unit __________

(3)

(c) State which star in the table is closer to the Earth.
Explain your reasoning.

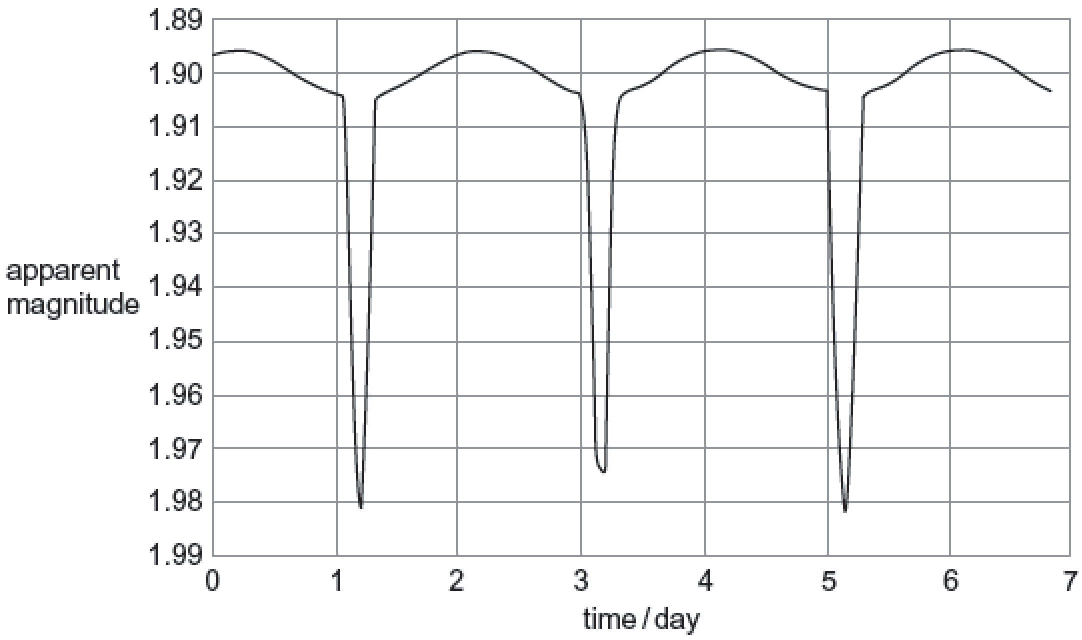
(2)

(Total 7 marks)

Q10.

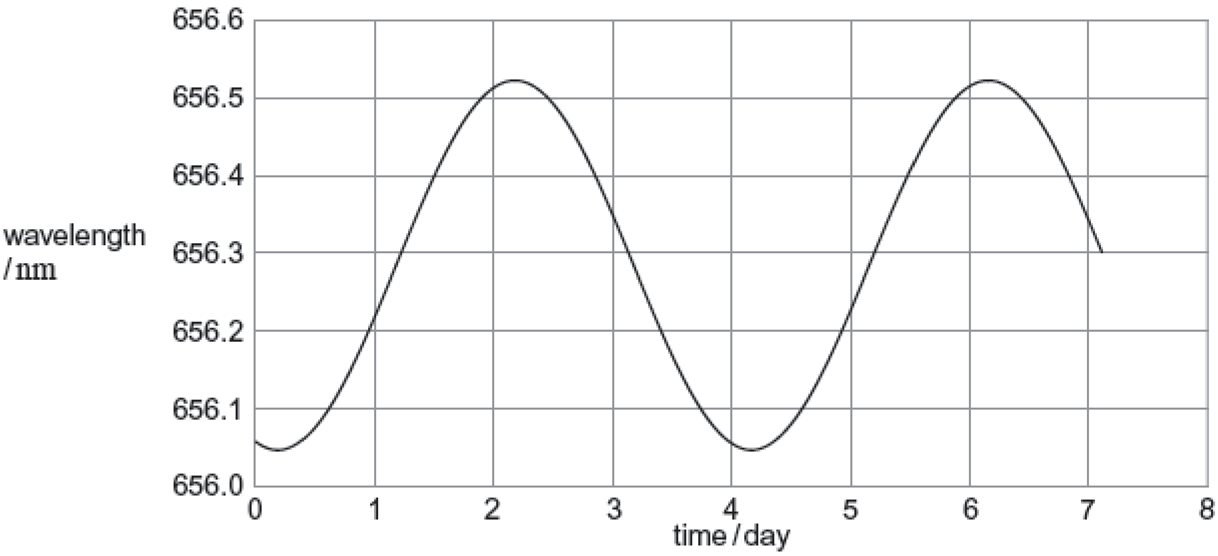
Menkalinan is an eclipsing binary star system in the constellation of Auriga. **Figure 1** shows the variation in apparent magnitude with time (light curve) for Menkalinan.

Figure 1



Analysis of the spectrum of one of the stars shows a periodic variation in wavelength. **Figure 2** shows the results for one of the spectral lines in the Hydrogen Balmer series. The wavelength for this line as measured for a source in a laboratory on the Earth is 656.28 nm.

Figure 2



(a) Describe the physical processes that give rise to the shape of each graph. Go on to show how the information in the graphs can be used to determine properties, such as the speed and period, of the Menkalinan binary system. You should include appropriate calculations in your answer.

The quality of your written communication will be assessed in your answer.

(6)

(b) The black body temperature of each star is approximately 9200 K.

Explain why a Hydrogen Balmer line was chosen for the analysis of wavelength variation.

(2)

(c) The distance from the Earth to Menkalinan is 7.7×10^{17} m.

Calculate the value of the absolute magnitude of Menkalinan when it appears dimmest.

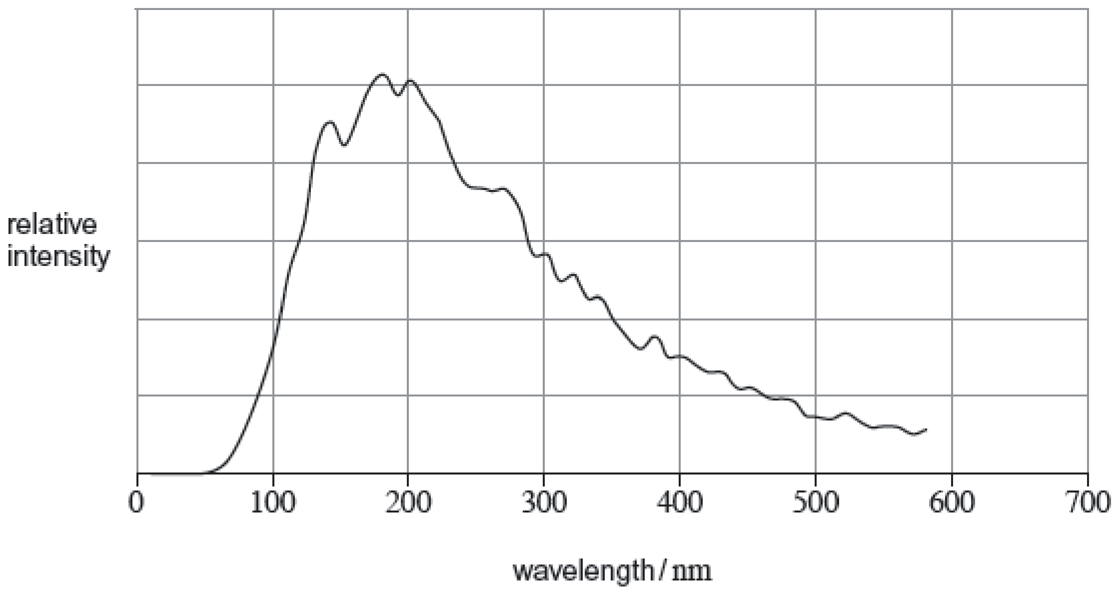
absolute magnitude = ____________________

(3)

(Total 11 marks)

Q11.

The graph shows the variation of intensity with wavelength for the star 40 Eridani B.



(a) (i) Calculate the black body temperature of 40 Eridani B.

State an appropriate unit for your answer.

temperature = ____________________ unit ___________

(3)

(ii) 40 Eridani B has a total power output of 4.2×10^{24} W.

Calculate its radius.

radius = ____________________ m

(2)

(b) (i) Which of the following regions of the Hertzsprung-Russell diagram does 40 Eridani B belong to?
Tick (✓) the correct answer.

main sequence	
dwarf star	
giant star	

(1)

(ii) Give reasons for your answer to part (i).

____

____

____

____

____

____

(2)

(Total 8 marks)

Mark schemes

Q1.

(a) Curve with a single peak ✓

Steepest part of LHS steeper than steepest part of RHS ✓

If multiple curves seen all of them must be correct.

Do not condone curves with negative gradient on LHS.

2

(b) Mention of use of peak wavelength ✓

Quoting use of Wien's law and that wavelength is in metres ✓

Use of $\lambda_{max}T$ = 0.0029 m K ✓ and mention of temperature in kelvin. ✓

This mark may be awarded for a label on the wavelength axis of the graph. Do not condone biggest or maximum.

If no peak in graph 2 max.

Only the first mark can be awarded if there is a suggestion that 'm' in the equation represents 'milli', or K represents Boltzmann's constant.

Ignore references to Stefan's Law.

3

(c) **The mark scheme gives some guidance as to what statements are expected to be seen in a 1 or 2 mark (L1), 3 or 4 mark (L2) and 5 or 6 mark (L3) answer. Guidance provided in section 3.10 of the 'Mark Scheme Instructions' document should be used to assist in marking this question.**

Level	Criteria	QoWC
6 marks	Correct calculations of power output. Comparison of brightness. Leading to similar distance away and therefore binary (or not if supported).	The student presents relevant information coherently, employing structure, style and sp&g to render meaning clear. The text is legible.
5 marks	There may be an error in the calculations but POT errors can be condoned.	
4	Attempt to calculate power outputs or quantitative analysis of brightness, with some relevant comment. Condone some errors including POT, missing "4" or use of "4/3". Do not condone more serious errors in calculation. If the brightness is the wrong way round (B>A) ignore brightness comparison.	The student presents relevant information and in a way which assists the communication of meaning. The text is legible. Sp&g are sufficiently accurate not to obscure meaning.
3	Only a qualitative response.	

	Reference to r and T suggesting that Power output of A greater than B. This can be seen in an (incorrect) equation. OR straight forward comparison of brightness. (eg A is about twice as bright).	
2	Two aspects of star correct – eg A brighter than B, both appear orange (do not accept red), B redder than A.	The student presents some relevant information in a simple form. The text is usually legible. Sp&g allow meaning to be derived although errors are sometimes obstructive.
1	Only one aspect statement comparing stars correct. eg A brighter than B, both appear orange (do not accept red), B redder than A.	
0	Unsupported evaluation or no relevant analysis	The student's presentation, spelling, punctuation and grammar seriously obstruct understanding.

Stars compared for colour:

Cygnus B will appear more red than Cygnus A as it is cooler

Or both stars orange. (L1)

Ignore calculation of λ_{max} unless linked correctly to colour.

Stars compared for brightness.

Cygnus A will appear (approximately 2 times) brighter than Cygnus B, as the apparent magnitude is approximately 1 less than that of Cygnus B. (L2)

Difference in magnitude = 0.9

ratio in brightness = $2.51^{0.9} = 2.3$

Distance discussed

Powers compared: (L2)

Using $P=\sigma AT^4$

Gives

For A: $P = 5.67 \times 10^{-8} \times 4\pi \times (4.7 \times 10^8)^2 \times 4500^4 = 6.45 \times 10^{25}$ W (L2/3)

For B: $P = 5.67 \times 10^{-8} \times 4\pi \times (4.1 \times 10^8)^2 \times 4100^4 =$

3.38×10^{25} W (L2/3)

*As power output of **A** is about twice that of **B**, and **A** appears about twice as bright, they must both be about the same distance away.(L2/3)*

Evaluation

Being about the same distance away is consistent with idea that they form a binary system. (L2/3)

6

(d) K ticked

1

[12]

Q2.

(a) Distance at which 1AU ✓ subtends an angle of 1/3600th degree ✓

or

Diagram with 1AU, 1pc and 1/3600th degree labelled ✓

Allow 1 arc second for angle

1AU can be shown as Sun Earth distance

1pc can be either long side

2

(b) They are the same spectral class and therefore have similar temperatures. ✓

No mark for the answer on its own.

First mark for identifying same T

They have the same apparent magnitude, but K is significantly further away, therefore K has a greater power output (P)/ brighter absolute magnitude ✓

Second mark for identifying greater P

Condone greater for brighter

Condone luminosity for absolute magnitude

As $P=\sigma AT^4$

to have a greater power output than R at the same temperature, K must have a greater area, and therefore be bigger. ✓

Third mark for use of Stefan's Law to obtain the answer.

3

(c) Substitution into $\lambda_{max}T = 0.0029$ mK ✓

To give $T = 2.9 \times 10^{-3} / 1.0 \times 10^{-6} = 2.9 \times 10^{3}$ K ✓

Condone power of ten errors in first mark

2

(d) The spectral class is related to the temperature✓

So the star is in spectral class M

Allow ecf from (c) – see spec for table of spectral class and temperature

And is therefore Rasalgethi ✓

The second mark is for the correct class and therefore star identified

2

(e) Rasalgethi

1

(f) Use of m-M = 5 log (d/10)

To give

3.1 – M = 5 log(2.3) ✓

3.1 – M = 1.8 ✓

First two marks are for the substitution of M, m and unit of d and correct log.

Detect one mark for each error; more than two errors give 0/3

M = 1.3 ✓

Third mark for the correct calculation: allow ecf for up to two errors

3

[13]

Q3.

(a) Absolute magnitude scale gettingg more negative going up

and

Time scale with 0 along axis, going up to between 10 and 400 ✓

The first mark is for the scales

Line drawn going up and down, with LHS steeper than steepest part of RHS ✓

The second is for the curve

Line drawn increasing quickly with peak at absolute magnitude between -18 and -20 ✓

The third is for the value of the peak

3

(b) Object whose absolute magnitude is known (and whose apparent magnitude can be measured.) ✓

Do not allow fixed or constant for 'known'

But condone predictable

Do not allow 'directly measured'

Condone intrinsic or inherent brightness, or luminosity for absolute magnitude

1

(c) Measurements of supernovae do not agree with predictions (from Hubble's Law) ✓

1

So Universe must be expanding at increasing rate/accelerating ✓

1

(Controversial as) no known energy source for expansion or reference to dark energy ✓

1

[7]

Q4.

(a) Principal axis drawn and principal foci shown to coincide on it ✓

three non-axial rays drawn correctly with final virtual image shown ✓

PA needs to be drawn

2

(b) Mirrors do not suffer from chromatic aberration, ✓

Mirrors can be larger and therefore have greater collecting powers ✓

Mirrors can be larger and therefore have smaller minimum angular resolution ✓

Parabolic mirrors with axial rays do not suffer from spherical aberration ✓

4

(c) **The mark scheme gives some guidance as to what statements are expected to be seen in a 1 or 2 mark (L1), 3 or 4 mark (L2) and 5 or 6 mark (L3) answer. Guidance provided in section 3.10 of the *Mark Scheme Instructions* document should be used to assist marking this question.**

L3 5−6 marks	clear description of what is meant by apparent magnitude, with discussion of logarithmic scale; explanation of Hipparcos scale in terms of visibility of stars	The student presents relevant information coherently, employing structure, style and sp&g to render meaning clear. The text is legible.
L2 3−4 marks	Either apparent magnitude or Hipparcos scale discussed in detail, with other not discussed fully or containing errors	The student presents relevant information and in a way which assists the communication of meaning. The text is legible. Sp&g are sufficiently accurate not to obscure meaning.
L1 1−2 marks	Either one discussed fully and other not at all, or both discussed with some errors.	The student presents some relevant information in a simple form. The text is usually legible. Sp&g allow meaning to be derived although errors are sometimes obstructive.
0 marks	Little or no discussion of relevant content.	The student's presentation, spelling, punctuation and

		grammar seriously obstruct understanding.

(d) **The following statements could be present**

- *apparent magnitude is based on how bright a star appears on the Earth*
- *this depends on how bright a star actually is and how far away it is*
- *larger values of apparent magnitude are given to dimmer stars*
- *the difference of 1 on the apparent magnitude scale is associated with a difference in brightness of a factor of 2.51.*

The Hipparcos scale assumed the brightest stars have a magnitude of 1 and the dimmest a magnitude of 6.
Magnitude 1 stars are 100 times brighter than magnitude 6 stars.

Applying apparent magnitude to the Hipparcos scale means that some stars (the brightest) have a negative apparent magnitude.

6

[12]

Q5.

(a) Main sequence shown correctly ✓

Dwarf star region shown correctly ✓

(red) giant star region shown correctly ✓

3

(b) Temperature scale 50 000 to 2 500 ✓

Absolute magnitude scale 15 to −10 ✓

2

(c) B ticked ✓

1

(d) Temperature of stars used as discriminator ✓

class B is in range 11 000 K to 25 000 K ✓

2

(e) The white dwarf must have the lowest (dimmest) absolute magnitude due to position on HR diagram (or ref to size) ✓

Omicron 2 has the dimmest apparent magnitude, and is the closest so must have dimmest absolute magnitude (or ref to m-M) ✓

Hence Omicron 2 is the white dwarf ✓

3

[11]

Q6.

(a) The collapse of a (super) massive star into a neutron star or black hole ✓

Allow lowering in value of absolute magnitude

1

(b) Use of $z = \frac{v}{c}$ to give

$v = 0.34 \times 3 \times 10^8$

$= 1.0 \times 10^8$ m s^{-1} $= 1 \times 10^5$ km s^{-1} ✓

Use of v = Hd

To give $d = \frac{v}{H} = \frac{1 \times 10^5}{65}$ = 1 600 Mpc ✓

$= 1\,600 \times 1 \times 10^6 \times 3.26$

$= 5.1 \times 10^9$ lyr ✓

2sf ✓

1 mark for calculating v
1 mark for calculating d in Mpc
1 mark for converting to l yr
1 mark for 2 sf

4

(c) Use of $E = mc^2$

To give

$E = 2 \times 10^{30} \times (3 \times 10^8)^2$ ✓

$= 2 \times 10^{47}$ which is the correct order of magnitude ✓

2

[7]

Q8.

(a) (i) Spectral class axis correct: OBAFGKM ✓

Ignore bunching of labels.
Do not condone letters beyond O and M

1

(ii) Main sequence correct ✓

Dwarf and giant stars correct ✓

Bands not lines.
Main sequence must have correct curvature
LHS must be above -5 and RHS below 10 on abs mag scale.
Dwarfs in bottom left quadrant, below abs mag 5, not touch Main sequence.

Giants in top right quadrant, can extend left, above abs mag 0, not touch Main sequence.

2

(b) (i) Marks awarded for this answer will be determined by the Quality of Written Communication (QWC) as well as the standard of the scientific response. Examiners should apply a 'best-fit' approach to the marking. The candidate's writing should be legible and the spelling, punctuation and grammar should be sufficiently accurate for the meaning to be clear. The candidates answer should be assessed holistically. The answer will be assigned to one of 3 levels according to the following general criteria:

Higher Level (5 or 6 marks)

The information conveyed by the answer is clearly organised, logical and coherent using appropriate specialist vocabulary correctly. The form and style of writing is appropriate to answer the question. Appearance: Student gives a coherent description the relative brightness and of the three stars, linked to their apparent magnitude.

For 6 marks, they go on to describe the colour of each star related to the temperature and spectral class

Spectrum: The student further describes the spectrum of each of the three stars in terms of the major absorption lines, again related to the spectral class from their temperatures.

Position on HR. There is some discussion of the position of the stars. For example it is pointed out that 41 Arieti cannot be a dwarf star as it is too large.

Intermediate Level (3 or 4 marks)

The information conveyed by the answer may be less well organised and not fully coherent. There is less use of specialist vocabulary, or specialist vocabulary may be used incorrectly. The form and style of writing is less appropriate.

Appearance: Student gives a coherent description the relative brightness and of the three stars, linked to their apparent magnitude.

Spectrum: There may be some less accurate comparison of colour based on temperature **or** description of the spectra of the stars.

Position: There is some attempt to discuss the position of the stars on the HR diagram.

Low Level (1 or 2 marks)

The information conveyed by the answer is poorly organised and may not be relevant or coherent. There is little correct use of specialist vocabulary. The form and style of writing may be only partly appropriate.

Appearance: The apparent magnitude scale is identified as the one that indicates brightness, but it may be interpreted the wrong way round by the student.

Incorrectly, there may be some reference to how big the stars appear based on the radius. References to colour may be missing altogether.

Spectrum: little or no relevant detail related to the spectrum of each star is given.

Position: on the HR diagram: there may be no attempt.

Summary of relevant information about each star

Property	**41 Arieti**	**Sharatan**	**Hamal**
Brightness	Dimmest	Middle	Brightest
Colour	Blue	Blue / white	Orange / red
Spectra **class**	He and H B	H and ionised metals A	Neutral metals K
type of star	Main sequence Not dwarf.	Main sequence	Main sequence
Position on HR	Top left	Middle / left	Middle / right

extra information

Answers that suggest that the size of the stars can be compared visually are unlikely to be awarded marks in the top half of a band.

max 6

(ii) d = 66 /3.26 = 20 pc ✓

Use of m-M = 5 log (d/10)

To give 2 – M = 5 log (20/10) ✓

M = 2 – 1.5 = 0.5 ✓

The first mark is for the conversion of d into parsec

Allow CE for two marks.

If M and m wrong way round, treat as physics error: only the first mark can be awarded

The second mark is the correct substitution

The third mark is for the final answer; allow 0.46 to 0.5; no sf penalty

3

(iii) 41 Arietis has the largest radius and temperature, ✓

and therefore the greatest power output / brightest abs mag / greatest intrinsic brightness (ref to $P = \sigma AT^4$) ✓

But appears dimmest in the sky (as it has the greatest apparent magnitude.)

so 41 Arietis must be furthest away. ✓

No mark for an unsupported answer.

Allow area for radius

The first two marks can be awarded for a correct calculation of the power of 41 Arietis.

3

[15]

Q9.

(a) App magnitude is how bright object appears in sky

Abs magnitude is how bright object would appear if 10 parsecs away

Magnitude must be related to brightness or max 1

2

(b) Use of $I = P / 4\pi r^2$

9.8×10^{27}

W

3

(c) Sirius (is closer)

Sirius is 10 pc from Earth or apparent magnitude = absolute magnitude

Explains that data shows that Regel would appear (much) brighter if at 10 pc but is seen to be much dimmer (so must be further away)

OR

Appears brighter

Even though it has a lower luminosity / even though it has a lower surface temperature

2

[7]

Q10.

(a) Marks awarded for this answer will be determined by the Quality of Written Communication (QWC) as well as the standard of the scientific response. The candidate's writing should be legible and the spelling, punctuation and grammar should be sufficiently accurate for the meaning to be clear. The candidates answer should be assessed holistically. The answer will be assigned to one of 3 levels according to the following criteria:

0 marks

Level 1 (1-2 marks)

Lower level (Poor to limited): 1 or 2 marks

The information conveyed by the answer is poorly organised and may not be relevant or coherent. There is little correct use of specialist vocabulary. The form and style of writing may be only partly appropriate.

Calculations:

No relevant calculations. At 1 mark the time period may be quoted as 2 days rather than four.

Discussion

Only one graph discussed (or both very poorly).

At 1 mark there may some attempt to discuss eclipsing or going towards / away.

At 2 marks one discussion will be more correct.

Level 2 (3-4 marks)

Intermediate level (Modest to adequate): 3 or 4 marks

The information conveyed by the answer may be less well organised and not fully coherent. There is less use of specialist vocabulary, or specialist vocabulary may be used incorrectly. The form and style of writing is less appropriate.

Calculations:

Some attempt to use Doppler equation. At four marks there may be only a couple of minor errors.

Discussion:

Correctly links at least one graph to the movement of the two stars in terms of eclipsing or movement relative to each other and the Earth.

Level 3 (5-6) marks
High level (good to excellent): 5 or 6 marks.
The information conveyed by the answer is clearly organised, logical and coherent using appropriate specialist vocabulary correctly. The form and style of writing is appropriate to answer the question.
Calculations:
Doppler equation applied correctly (perhaps a minor error at 5 marks).
At the highest level, the use of 4 days and velocity to give the radius may be seen.
Discussion:
2 graphs discussed. Mostly correct. At 5 marks there may be some minor incorrect statements − e.g. referring to red shift rather than Doppler shift.

Examples of the points made in the response
The explanations expected in a good answer should include most of the following physics ideas:
The time period, T, is the time from the first dip in the light curve to the third dip. (I)
This is approximately 4 days. (L)
This is one full cycle for the wavelength graph. (I)
One full cycle is approximately 4 days. (I)
When one star passes in front of the other the amount of light received changes. (L)
The brightest (lowest value of) apparent magnitude occurs when both stars can be seen. (I)
The dips occur when one star is in front of the other. (I)
The similarity in the dips suggests that both stars have similar temperatures / sizes. (H)
The variation in wavelength is due to the Doppler effect. (I)
The peaks and troughs occur when the stars are moving at their greatest velocity away from / towards us. (H)
The biggest change in wavelength is 656.52 nm - 656.28 nm = 0.24 nm. (I)
The orbital speed, v, is therefore $\Delta\lambda \times c / \lambda$ (I)

= 0.24 × 3 × 108 / 656.28 = 1.1 × 10^5 ms−1. (H)

The orbital radius is therefore v / (2π / T) = 6.1 × 10^9 m. (H)

The letter next to each statement suggests the minimum level of answer the statement may be seen in.

6

(b) The temperature (9200K) indicates that the star is in spectral class A. ✓

Hydrogen Balmer lines are strongest in A class stars and therefore would be more easily measured. ✓

Reference to class A not essential if it is clear that stars contain hydrogen in n = 2 state.

2

(c) m – M = 5 log (d / 10)
d (in parsec) = 7.7 × 10^{17} / 3.08 × 10^{16} = 25 pc ✓
dimmest m = 1.981 ✓
dimmest M = 1.981 – 5 log (25 / 10)

= −0.009 ✓

Allow range 1.980 to 1.982 for m.

Allow c.e. for either d or m.
If both incorrect, no marks are awarded.

3

[11]

Q11.

(a) (i) $\lambda_{max} T = 0.0029$

$\lambda_{max} = 180 \times 10^{-9}$ m ✓

T $= 0.0029 / 180 \times 10^{-9}$

$= 1.6 \times 10^{4}$ K ✓

Allow range for wavelength.

170nm to 190nm correct.

150nm to 200nm incorrect but treat as a.e.

Anything else treat as PE –first two marks not awarded.

Allow kelvin for unit. But not degrees kelvin.

3

(ii) P $= \sigma A T^4$

$A = P / \sigma T^4 = 4.2 \times 10^{24} / (5.67 \times 10^{-8} \times (1.6 \times 10^{4})^{4})$ ✓

$= 1.1 \times 10^{15}$ m^2

$r = \sqrt{(A / 4\pi)} = 9.5 \times 10^{6}$ m ✓

Allow c.e. for T from ai.

If formula wrong treat as PE – no marks awarded. Note: this is true if the incorrect equation for A is used within the power equation.

2

(b) (i) dwarf ticked

1

(ii) it has a high temperature ✓

Allow low power output for small.

Allow high power output for large.

but is relatively small, so it will have a low absolute magnitude ✓

Marks can be awarded for ruling out other two.

(this puts it into the bottom left region of the HR diagram)

If white dwarf not ticked in bi :–

Giant stars – cool and big.

Main sequence – either cool and small or hot and big for 2 marks.

Or 'middling temperature and size' for 1 mark.

2

[8]

Q1.

This question was concerned with the analysis of the light from stars and some of the information astronomers can obtain from it.

(a) The mark scheme for this question meant that many students were able to score both marks (63.2%), but some very poor lines were seen. Most students knew that a peak was required, but the curvature of the line either side of the peak was not drawn clearly. The AQA support booklet for this topic, and previous question papers, contain versions of the graph that can be used to make it clear to students what is expected. It should be stressed, for example, that the left hand side of the peak is steeper than the right hand side.

(b) This question discriminated well, with a range of marks being awarded. Most students mentioned Wien's Law and identified the wavelength required correctly as the peak rather than maximum. A common error was one of simple algebra, with students incorrectly suggesting that this wavelength should be divided by Wien's constant, rather than the other way round. It was satisfying to note that very few students suggested that the 'm' in the unit of the constant represented milli- rather than metre. This has been a common error in the past.

(c) The 6-mark question has been a feature of this exam for many years and there is evidence to suggest that students are becoming more familiar with what is expected. Many students correctly identified that calculations using Stefan's Law were needed to compare the power output of the two stars, and then related that to the difference in apparent magnitude. There were many examples of students failing to use the correct equation for the area of a sphere or neglecting to use the fourth power of the temperature, however. There was evidence to suggest that many students were familiar with the apparent magnitude scale and correctly calculated a ratio of apparent brightness for the two stars. Students who failed to make much progress simply stated that the values of apparent magnitude, radius and temperature were similar and that, therefore, the two stars were the same distance away. It should be noted that, although the two stars do in fact form a binary system, full credit was given to students who argued that the ratio of the power output and the ratio of the brightness are sufficiently different to suggest that they are too far apart. Pleasingly, just over half of the students were able to gain at least four of the six marks available.

Q2.

This question required students to compare the nature of four stars based on pertinent information.

(a) The definition of the parsec is difficult to express, and therefore most successful students preferred to draw a labelled diagram. Three things needed to be included: the angle of 1 arc second, 1 AU and 1 pc. It was relatively common to see one of these missing or mislabelled. Those students who chose to define in words commonly suggested that it was the distant star that subtended the angle of 1 arc second, rather than the Earth–Sun distance.

(b) The use of Stefan's Law to judge the relative size of a star has been asked in a variety of forms in the previous specification, and many students responded to this question. Many students managed to make some progress by arguing that the absolute magnitude, or power output, of Kornephoros must be greater due to its distance. The use of ‘brightness’ or ‘magnitude’ here did not gain credit as students may have been referring to the apparent magnitude. A more common mistake was the failure to make a reference to the temperature, based on the spectral class. A significant number of students made the classic mistake of not reading the question correctly and discussed the relative size of Rasalgethi.

(c) The vast majority of students had no difficulty determining the temperature based on Wien’s Law. Occasionally answers based on power of ten errors were seen, either related to the micro prefix, or the metres in the unit of the constant being interpreted as milli.

(d) The vast majority of students were also able to use their knowledge of spectral class temperature ranges to identify the correct star.

(e) It was relatively common to see the calculated absolute magnitudes written next to the name of each star. Undoubtedly many students saved time by spotting that all of the stars have a similar apparent magnitude, and yet one is significantly further away than the others.

(f) This calculation was performed correctly by the vast majority of students. Common errors included converting the distance into other units, using natural logs rather than base 10 and confusing m and M.

Q3.

This question gave students an opportunity to demonstrate what they had learned about dark energy and the accelerating universe.

(a) A significant tool in astronomy is related to the use of standard candles, and this specification focuses on type 1a supernovae. Very few students were able to demonstrate sufficient knowledge to gain all three marks. The shape of the graph caused problems, with some confusion with black body radiation curves being apparent. The labelling of the axes also suggested that few students had studied this light curve in sufficient depth.

(b) Lack of clarity cost many students the mark in this question. As has been pointed out earlier, ‘magnitude’ can be either ‘apparent’ or ‘absolute’ and the correct one needs to be used for credit.

(c) It is expected that students are away of some of the significant discoveries in recent astronomy, the idea of an accelerating universe being the relevant one here. Very students were able to relate the surprising nature of the supernovae measurements. It was fairly common to see answers discussing the big bang or gamma ray bursts. Marks were also lost by students who confused dark energy and dark matter.

Q8.

The question looked at the properties of 3 stars in the constellation of Aries, using this context to assess the H-R diagram, and to some extent, Stefan’s Law.

(a) (i) Most students correctly labelled the spectral classes. Some careless errors were seen, and it was sometimes difficult to distinguish which letter was being written eg a K written to look like H. Students should be encouraged to take much more care. Despite the spectral class being asked for, it was fairly common to see the temperature given.

(ii) The H-R diagram takes many different forms and therefore, to make it easier for the students, the one expected in this examination has been laid out clearly in previous examinations and in the online support material. Some students had difficulty with the curvature of the main sequence, or the position of the dwarf and giant stars within appropriate limits.

(b) (i) This question required a comparison of three stars, and answers were judged against the content as well as the quality of the written communication. There was a good spread of marks and clear discrimination. The best answers made it clear that Hamal would appear brightest and 41 Arietis dimmest, referring to the inverse nature of the apparent magnitude scale. They went on to state the spectral class of each star, and therefore the colour they would appear. They used the spectral class to describe the absorption lines within the spectra. Using the temperature and size of the stars, they concluded by discussing where on the H-R diagram the three stars would appear. Whilst the very best answers were able to conclude that all three were main-sequence stars, examiners awarded full marks to students who showed some degree of discussion. Answers obtaining fewer marks tended to reverse the brightness by misinterpreting the apparent magnitude scale, or claim you would be able to see 41 Arietis more clearly because it is bigger. An issue with any extended writing is the quality of the handwriting of the students. Careless writing will inevitably lead to ambiguities that cannot be given credit.

(ii) Most students coped very well with this multistep calculation. There were some answers seen that converted “d” incorrectly but an error was carried forward for this. Answers that mixed up m and M were less likely to gain credit.

(iii) This question produced a spread of marks as some students found it difficult to express themselves clearly or missed important detail. Confusion about bigger and smaller magnitudes can be overcome if students refer to brighter or dimmer magnitudes instead. The best answers used Stefan’s Law to support the idea that 41-Arietis has the brightest absolute magnitude and that appearing dimmest means that it must be furthest away.

Q9.

(a) Relatively few students identified magnitude with brightness and clear coherent responses were rare. Relatively few mentioned 10 pc when they were referring to absolute magnitude. Most who discussed this only referred to them being at the same distance.

(b) Most students identified the correct unit and a good proportion realised that the inverse square law had to be applied but correct answers were rare.

(c) Relatively few were able to give a convincing explanation as to why the data suggested that Sirius was closer. The data clearly suggested that Sirius is 10 pc from Earth and this was identified by some students. Explaining why the data suggested that Rigel was further away proved more difficult.

Q10.

Question (a) gave students an opportunity to show what they know about eclipsing binary stars and the full range of marks were awarded. At the highest level, answers were seen that correctly described how the motion of the two stars gives rise to each graph, with calculations of the time period, orbital speed and, in some cases, orbital radius. Some students incorrectly suggested that the change in apparent magnitude was due to changing distances, rather than one star blocking the other. There was some confusion with students suggesting that low apparent magnitudes means dimmer, and the time period was incorrectly given as 2 days, or 8 days, in some answers. Some students also confused the Doppler shift of the second graph with cosmological red shift and suggested using Hubble's Law to determine the distance to the binary system. The guidance booklet for astrophysics, available on the AQA website, includes an analysis of a binary system that may be helpful to teachers and students unfamiliar with this area.

Many students correctly identified the stars as class A, but fewer went on to say that these stars would have strong Hydrogen Balmer lines and therefore make measurement easier. Many students are clearly well practised in the use of the magnitude-distance equation. Some were confused about the unit of distance to use in the equation, however, and some had difficulty determining the value of the apparent magnitude when the system was dimmest.

Q11.

A range of values were acceptable for the wavelength of the peak in the intensity curve. Many students, however, chose the value on the curve where the wavelength is greatest. This was treated as a physics error and the first two marks were not awarded. The vast majority of students gave the correct unit for temperature. Occasionally °K was seen and this was not accepted. It should also be noted that the unit is K (or kelvin) and not k. On this occasion, benefit of the doubt was given when it was unclear.

Any error in the temperature was carried forward into (a)(ii) allowing full marks to be given. Problems here were mainly due to the incorrect area equation. It was common to see the volume of a sphere, or the area of a circle, used. Many students also failed to use the fourth power of the temperature, even after writing it correctly in the formula.

(b)(i) was automarked and only dwarf star was accepted as the answer.

The error in (b)(i) was carried forward into (b)(ii), so that full marks could be given if the student's answer was consistent with their answer to (b)(i). The best answers made it clear how the radius and temperature of the star supported their answer to (b)(i).