Mark schemes

1 (a) λ_{max} = wavelength at which maximum emission occurs **(1)**

(1)

(b) $\lambda_{max} = 0.30 \times 10^{-6}$ (m) **(1)**

$T = \frac{2.9 \times 10^{-3}}{0.30 \times 10^{-6}} = 9.7 \times 10^3$ K **(1)**

(2)

(c) (i) ≈ 0-0.4 μm **(1)**

(ii) peak of curve shifted to right **(1)**
λ_{max} is greater, **(1)** gives T lower than original temperature **(1)**

(max 3)

[6]

2 (a) (i) Segin: spectral class B is hottest **(1)**

(ii) Shedir: class K is closest towards red end **(1)**

(iii) Shedir: 2.2 is smallest value of apparent magnitude **(1)**

(iv) Achird: apparent magnitude lower (brighter) than absolute magnitude and they are equal when star is 10 pc away **(1)**

4

(b) (i) (use of $m - M = 5 \log(d/10)$ gives) $2.2 - (-4.6) = 5 \log\left(\frac{d}{10}\right)$ **(1)**

$d = 229$ pc **(1)**

(ii) (use of $\lambda_{max}T = 0.0029$ gives) $\lambda_{max} = \frac{0.0029}{12000} = 2.4(2) \times 10^{-7}$ m **(1)**

3

[7]

3 (a) (i) *apparent magnitude:* brightness of star as seen from Earth **(1)**
absolute magnitude: apparent magnitude at a distance of 10 pc **(1)**

(ii) one star is much brighter **(1)**
has lower value of apparent magnitude **(1)**

(4)

(b) (i) correct main sequence **(1)**
correct Giants and White Dwarfs **(1)**

(ii) $m - M = 5 \log \left(\frac{d}{10}\right)$ **(1)**

gives $11 - M = 5 \log \left(\frac{1.3}{10}\right)$ **(1)**

$M = 11 + 4.43 = 15.4$ **(1)**

(iii) correct position on diagram (spectral class M, abs magnitude –5) **(1)**

(6)

(c) (i) same temperature [or temperature less than 3500K] **(1)**
same spectral class **(1)**

(ii) Antares is brightest (and at same temperature) **(1)**
so has largest surface area [diameter] **(1)**

(4)

[14]

4 (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]

5 (a) (i) P has the lowest peak wavelength (λ_{max}) **(1)**
(since) $\lambda_{max}T$ = constant, lowest λ_{max} means highest T **(1)**
[or P has highest peak intensity **(1)**
intensity is power per unit area, or ref to Stefan's law **(1)**]

(ii) $\lambda_{max} = 300 \times 10^{-9}$(m) **(1)**
(use of $\lambda_{max}T = 0.0029$ gives) $T = 9.7 \times 10^{3}$K **(1)** (9.67×10^{3} K)

max 3

(b) (i) A and B **(1)**

(ii) light from the star passes through the atmosphere of the star **(1)**
which contains hydrogen with electrons in $n = 2$ state **(1)**
electrons in this state absorb certain energies and (hence) frequencies of light **(1)**
the light is re-emitted in all directions, so that the intensity of these frequencies is reduced in any given direction,
resulting in absorption lines **(1)**

max 4

[7]

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

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

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]

7 (a) (i) (use of $\lambda_{max}T = 0.0029$ gives) $\lambda = \frac{0.0029}{6000}$ **(1)**

$= 4.8 \times 10^{-7}$ m **(1)**

(ii) values on axis : 0.5 1.0 1.5 2.0 **(1)**

(iii) similar shaped curve with peak shifted to right **(1)**

max 4

(b) (i) difference in absolute magnitude = 5 **(1)**
corresponds to × 100 difference in brightness,
some reference to absolute scale **(1)**
Arcturus lower absolute magnitude, therefore brighter **(1)**

(ii) (use of $P = \sigma AT^4$ gives) $\frac{P_A}{P_S} = 100 = \frac{A_A T_A^4}{A_A T_S^4}$ **(1)**

$\frac{A_A}{A_S} = 100 \times \left(\frac{6000}{5000}\right)^4$ **(1)** (= 200)

max 4

[8]

8 (a) Spectral class A✓

1

The temperature range for A class is 7500 K to 11 000 K✓

1

(b) Lowest value of apparent magnitude indicates the brightest star. ✓

1

Vega has the lowest apparent magnitude (so is brightest) ✓

1

(c) Closest of three stars is Altair✓ **1**

Using $m - M = 5 \log (d / 10)$

To give $0.77 - 2.21 = -1.44$✓ **1**

And $d = 5.2$ pc✓

Allow ce for calculation of wrong star **1**

(d) Deneb is the largest✓

No mark for unsupported answer **1**

It has approximately the same temperature, but has a much brighter absolute magnitude and therefore greater power ouput✓ **1**

To have a much greater power output for a similar temperature, it must have a greater area✓

As $P = \sigma A T^4$ **1**

Allow alternative:
from position on HR diagram, from T and M,
Altair and Vega are main sequence stars
Deneb is a giant star
so Deneb largest.

(e) Using $\lambda_{max} T = 0.0029$ **1**

To give $\lambda_{max} = 0.0029 / 7700$✓

$= 3.8 \times 10^{-7}$ m✓ **1**

[12]

9 (a) (i) Similarity both would appear the same brightness
As the apparent magnitudes are the same ✓
Description and explanation needed for mark.
Any references to same size gets zero for 1st mark.

Difference Kocab would appear orange / red, Polaris yellow / white
Due to their spectral classes / different temperatures ✓
Allow different colours + ref to spectral class for second mark
If colour named, should be correct. **2**

(ii) Polaris is further from Earth:

Alternative:

Polaris hotter and same size

Both stars same size and Polaris is hotter ✓

As $P = \sigma AT^4$

Hence, Polaris has brighter absolute magnitude / is intrinsically brighter

Same A, would mean that Polaris has greater power output. ✓

Polaris must be further from Earth to appear same brightness as Kocab. ✓

Same apparent brightness, therefore Polaris is further away.

3

(b) (i) $v = Hd$

$v = 0.025 \times 3 \times 10^5 = 7.5 \times 10^3$ km s^{-1} ✓

1st mark is for calculating v

$d = 340 \times 10^6$ l yr = 340 / 3.26 Mpc = 104 Mpc ✓

2nd mark is for working out d in Mpc

$H = 7.5 \times 10^3 / 104 = 72$ kms^{-1} Mpc^{-1} ✓

3rd mark is for calculating H in the correct unit.

3

(ii) Age of Universe = 1 / H

1st mark is for the equation

$= 0.014 \times 10^6 \times 3.26 \times 9.5 \times 10^{15} / 1000$

2nd is for the answer with working

$= 4.3 \times 10^{17}$ seconds

(= 13.6 billion years)

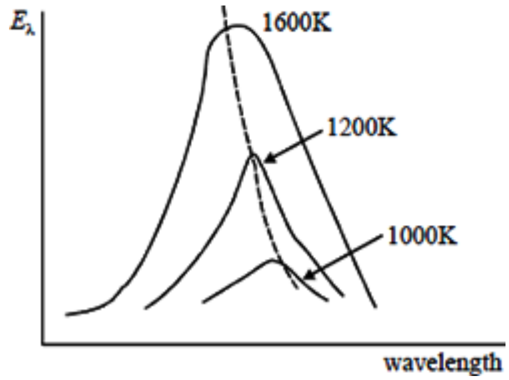
Unit consistent with calculation.

3rd is for a time unit consistent with their answer / working

3

[11]

10 (a)



peaks displaced towards increasing wavelength **(1)**
steeper slope on left hand side **(1)**
correct temperatures **(1)**

3

(b) (i) λ_{max} is wavelength at which maximum intensity occurs **(1)**

(ii) constant = 2.9×10^{-3} mK **(1)**
for T = 1600K, gives λ_{max} = 1800 nm **(1)**

(iii) $\lambda_{max} \approx 550$ nm **(1)**

$$T = \frac{2.9 \times 10^{-3}}{550 \times 10^{-9}}$$ = 5272K **(1)** (accept 5300K)

5

(c) (i) E is the area under one of the curves in the graph **(1)**

(ii) $P = A\sigma T^4$ **(1)**

2

(d) (i) (total power output from Sun = E)

power arriving at Earth = $\frac{E}{4\pi R^2}$ **(1)**

= 1400 (W m^{-2}) **(1)**
$E = 1400 \times 4\pi \times (1.5 \times 10^{11})^2 = 4.0 \times 10^{26}$ (W) **(1)**

(ii) ($P = A\sigma T^4$) gives $T^4 = \frac{4.0 \times 10^{26}}{4\pi(7 \times 10^8)^2 \times 5.7 \times 10^{-8}}$ **(1)** (= 1.12×10^{15})

T = 5800 K **(1)**

max 4

[14]

Examiner reports

2 This question was very well answered with a large number of candidates obtaining maximum marks. The type of question in part (a) has been set several times before and it was good to see that many candidates understand spectral class and magnitudes sufficiently well to identify the correct stars, and explain their answers in detail. Some candidates failed to get the mark in part (i) despite having correctly identified Segin as the hottest star through its spectral class, because they added that its absolute magnitude also showed that it was the hottest. It should be emphasised that a bright star does not need to be very hot, as shown by the giant stars in the H-R diagram. In part (ii), several candidates incorrectly suggested that Achird would be orange, linking it to the colour of the Sun, which is in fact yellow. The most common error in part (iii) was due to the reverse nature of the apparent magnitude scale. In part (iv), several candidates calculated the distance to each star, obtaining the correct answer. Many correctly stated, without calculation, that Achird was less than 10 pc away because its absolute magnitude was greater (dimmer) than its apparent magnitude. A common incorrect answer was Ruchbah, justified because the difference between M and m was the smallest.

In past papers, the calculation in part (b) has often given rise to many difficulties. This year was no different. There were many errors, particularly when working out the inverse logarithm. Other errors were confusing natural logs and base 10 logs, confusing m and M, and producing errors in units with the answer given in metres or light years rather than parsecs. The clearest answers showed the equation, the values substituted correctly, and then the algebraic steps to yield the correct answer. It was gratifying to see in part (ii) that although there have been problems in the past with the units of Wien's constant (although it is given in the Data sheet), it was rare this year to see answers which interpreted the m in mK as 'milli' rather than 'metre'. Most candidates answered this question successfully.

3 This question generally produced high marks. In part (a)(i) the meaning of *apparent magnitude* and *absolute magnitude* were known well and there were comparatively few explanations which referred to magnitude. luminosity or intensity - none of which were acceptable. Answers to part (a)(ii) were slightly disappointing in that many candidates failed to realise that Antares would appear to be the brighter of the two stars. Candidates got side-tracked with the distance factor and assumed that Proxima Centauri would be the brighter because it was much closer to us.

Some very good Hertzsprung-Russell diagrams were drawn in answer to part (b)(i), although the correct form of the main sequence band again caused problems for a minority of candidates. Attention had to be given to the direction of curvature at both ends of the band. The calculation of absolute magnitude in part (b)(ii) provided weaker candidates with some easy marks. It was significant that errors arose not from dealing with the logarithmic values but from rearranging the equation and failing to transpose the signs properly. Labelling the position of Antares on the Hertzsprung-Russell diagram in part (b)(iii) was done very carelessly and many candidates lost the mark by labelling the position of the star either to the right or to the left of spectral class M.

Part (c)(i) produced many correct answers and did not prove to be difficult. In part (c)(ii) candidates tended to ignore the word 'hence' and made reference to star type, such as red giants, in order to prove their point. It was interesting to try to follow the logic of candidates who tried to prove that Proxima Centauri was the larger star. Since the question had referred to larger diameter. Examiners were expecting candidates to refer to a larger surface area.

4 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.

5 Most candidates performed satisfactorily on this question and part (a) was answered well by most candidates. Those who could not explain clearly why P was the hottest star in part (i), often picked up full marks by using the correct equation in part (ii). It was pleasing to note that, especially as the point has been emphasised many times in previous reports, only the very occasional candidate wrongly interpreted the unit of the constant in Wien's Law (m K) as the milli Kelvin, rather than the metre Kelvin.

Most candidates correctly identified the two spectral classes in part (b) (i) but the description in part (ii) was generally very poorly answered. Many candidates described the production of emission spectra, rather than absorption spectra, and very few mentioned that the $n = 2$ state is needed for the production of the Balmer series. Further marks were lost because answers implied that the absorption took place in our atmosphere, or the atmosphere of the Sun, rather than in the atmosphere of the star. Several questions on the production of the Balmer series have been set in this series of examination papers, and it is hoped that candidates will become more familiar with the process in the future by studying these past questions and their mark schemes.

6 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).

7 The calculation in part (a)(i) was performed correctly by many candidates although there was some confusion with the unit of m in Stefan's constant, a significant number assuming it represented milli. It was pleasing to note that most candidates were aware that the calculated wavelength was the peak value in the black body radiation curve, and not the maximum value on the wavelength axis. Many candidates did not spot that the peak wavelength did not coincide with the first required value on the wavelength axis in part (ii), or else ignored the zero at the start of the axis. The black body curve for Arcuturus was well drawn, even by the weaker candidates.

In part (b) many candidates understood the relationship between brightness and the absolute magnitude scale, both in general terms and using the mathematical relationship. Any mention of temperature was penalised and candidates were also not rewarded for simply repeating the information in the table. Whilst many candidates calculated the surface area of both the Sun and Arcturus, several did not make their answer explicit by dividing these values to give the correct ratio of 207.

9 Many students could state the differences required for the answers to part (a) (i), but made no attempt to link them to the properties of the stars. Answers which simply stated same brightness and different colours obtained no marks.

There were some difficulties encountered by students answering (a) (ii). The best answers made it clear that Polaris is hotter and, as it has the same radius and therefore surface area, emits more power, from Stefan's Law. The majority of candidates that failed to get all three marks made no reference to the radius. Other incorrect answers simply stated that hotter stars must be further away without any reference to brightness. Other answers were seen that referred to the magnitude of the stars without making it clear whether it was the absolute or apparent magnitude. Similarly, students who referred to bigger magnitudes often failed to state whether they meant more positive or brighter. It would be much less ambiguous if students could be encouraged to refer to *brighter* and *dimmer* magnitudes rather than just bigger and smaller.

Part (b) (i) was correctly answered by the majority of students. Some students had difficulties converting the distance into megaparsecs. There was also evidence that students attempted to work backwards from the accepted value of 65, rather than calculate the value from the data.

Part (b) (ii) proved to be more challenging. Although the majority of students knew that the age of the universe could be calculated from 1 / H, there were many answers seen where the student could not convert the Hubble's constant to s $_{-1}$. Credit was given to answers that used the Hubble's constant to calculate a size for the Universe, and calculated its age from the speed of light. This question included the unit mark and it was only awarded if it was clear that the unit quoted was consistent with the calculation.

10 It is pleasing to report that the majority of candidates gained very high marks on this, the long question. The graphs in part (a) were generally well drawn, although there were a significant number which showed the curves drawn symmetrically, instead of having a steeper slope on the left hand side. A significant number of candidates also lost marks by giving λ_{max} the same value at the three temperatures.

In part (b) there were no outstanding problems, except that too many candidates still think of λ_{max} the maximum wavelength and many are not too sure of the wavelength range in the visible spectrum. The examiners were conscious of incorrect usage of significant figures in this section.

The majority of candidates were not aware, in part (c), that the value of E was given by the area under the curve.

The calculation in part (d) posed no problem for the better candidates. Weaker candidates sometimes started from *power a distance*^{2}, not realising that the energy was spread over the surface of a sphere. Surprisingly, many of these candidates in the final part used the area formula correctly.