Name	Date started	Target end date

GCE AS/A LEVEL — USING RADIATION TO INVESTIGATE STARS QUESTION PACK

1322-01 (Legacy PH2)

PHYSICS — PH2

PH2.5 Using Radiation to Investigate Stars — Wien's law, Stefan's law & stellar spectra

Every stars-and-radiation question from the legacy WJEC PH2 papers (June 2009 – June 2016)

LEGACY 2008 SPECIFICATION

Estimated time for entire question pack: ~2 hours 20 minutes

*Derived from the legacy PH2 paper's pace of **~1 min/mark** (80 marks in 1¼ hours).*

*You are advised to **not** attempt to complete all of this in one sitting.*

For Examiner's use only

Q	Source	Max	Mark
1	Jun 16 Q6	10	
2	Jan 12 Q6	10	
3	Jan 11 Q8	11	
4	Jun 09 Q7	12	
5	Jun 10 Q6	12	
6	Jan 10 Q7	11	
7	Jun 11 Q7	9	

Q	Source	Max	Mark
8	Jun 15 Q7	9	
9	Jun 14 Q7	12	
10	Jan 13 Q6	11	
11	Jun 13 Q7	10	
12	Jun 12 Q8	10	
13	Jan 14 Q7	11	
Total		138	

ABOUT THIS QUESTION PACK

This is a **comprehensive practice question pack**, not a single mock paper. It contains every using-radiation-to-investigate-stars question (black-body radiation, Wien's law, Stefan's law, stellar spectra and luminosity) from the legacy WJEC PH2 papers between June 2009 and June 2016.

Questions are grouped by sub-topic, then ordered roughly by difficulty.

INSTRUCTIONS

Use black ink or black ball-point pen. Answer all questions in the spaces provided.

A calculator is required. The Data Booklet is allowed.

PH2.5 Using radiation to investigate stars — what the legacy spec asks

WJEC GCE AS/A Level Physics (from 2008) · PH2 Assessment Unit *Waves and Particles*. The stars-and-radiation strand — black-body radiation, Wien's law, Stefan's law and stellar spectra — maps directly onto the 2015 Topic 6.

Black-body radiation (A)

- Definition: a black body absorbs *all* radiation falling on it and emits the maximum possible power at every wavelength for its temperature.
- Characteristic continuous spectrum shape — rises from zero, peaks, falls asymptotically to zero again.
- Stars approximate to black bodies.

Wien's displacement law (A)

- $\lambda_{\max} T = W$ where $W = 2.90 \times 10^{-3}$ m·K is Wien's constant.
- Read $\lambda_{\max}$ off a spectral-intensity graph; substitute to find surface temperature.
- Hotter stars peak at shorter (bluer) wavelengths; cooler stars peak at longer (redder) wavelengths.

Stefan's law (B)

- Total radiated power per unit area: $P/A = \sigma T^4$ where $\sigma = 5.67 \times 10^{-8}$ W m^{-2} K^{-4}.
- For a spherical star: total luminosity $L = 4\pi r^2 \sigma T^4$.
- Compare two stars: $\frac{L_1}{L_2} = \left(\frac{r_1}{r_2}\right)^2 \left(\frac{T_1}{T_2}\right)^4$.

Luminosity & the inverse-square law (B)

- Luminosity L = total power emitted in all directions by a star.
- Intensity I at distance d (assuming isotropic emission): $I = \frac{L}{4\pi d^2}$.
- Used to deduce L from measured Earth-bound intensity once distance is known.

Stellar spectra & absorption lines (C)

- Dark (Fraunhofer) lines crossing the continuous spectrum arise when photons from the hot interior are absorbed by cooler atoms in the star's atmosphere.
- Atoms absorb only photons whose energy matches a discrete transition between bound electron energy levels.
- The set of lines identifies the elements present; their relative strength depends on stellar temperature.

Working scientifically

- Always work in SI: T in kelvin, λ in metres, r in metres, L in watts.
- Convert nanometres to metres ($\times 10^{-9}$) before applying Wien's law.
- Sketch black-body spectra with a single peak that approaches but never reaches the axes at the extremes.

Section index for this question pack

Stars in one page

Quick-reference notes — revisit before each section.

Black body — definition

An **idealised** emitter that:

- absorbs *all* radiation incident on it (no reflection, no transmission);
- emits the *maximum possible* power at every wavelength for its temperature.

Stars are a good approximation, especially in the continuous part of their spectrum.

Black-body spectrum shape

A single broad peak. Key features to draw:

- starts at zero at $\lambda = 0$;
- rises steeply to a peak at $\lambda_{\max}$;
- falls more slowly, tailing asymptotically to zero.

Hotter $\Rightarrow$ peak *higher* and *shifted left* (shorter λ).

Wien's displacement law

$$\lambda_{\max} T = 2.90 \times 10^{-3} \text{ m·K}$$

- $\lambda_{\max}$ in metres (convert nm $\times 10^{-9}$).
- T in kelvin (absolute temperature only).
- Re-arrange: $T = W/\lambda_{\max}$ or $\lambda_{\max} = W/T$.

Stefan's law (per unit area)

$$\frac{P}{A} = \sigma T^4$$

- $\sigma = 5.67 \times 10^{-8}$ W m^{-2} K^{-4} (Stefan constant).
- Total power for a sphere: $P = A\sigma T^4 = 4\pi r^2 \sigma T^4$.
- Fourth power — doubling T multiplies emitted power by 16.

Luminosity

L = total power output of a star (W), radiated equally in all directions.

- For a spherical black body: $L = 4\pi r^2 \sigma T^4$.
- Sun: $L_\odot \approx 3.85 \times 10^{26}$ W.
- Use $L_{\text{star}}/L_\odot$ to express luminosity in solar units.

Inverse-square law

$$I = \frac{L}{4\pi d^2}$$

- I = intensity at distance d from the star (W m^{-2}).
- Treat the star as a point source emitting isotropically.
- Re-arrange: $L = 4\pi d^2 I$ — gives the star's power from a measurement at Earth.

Strategy — finding stellar radius

1. From the spectrum, find $\lambda_{\max}$.
2. Apply Wien's law to get T.
3. From distance and intensity, get luminosity L via inverse-square.
4. Apply Stefan's law $L = 4\pi r^2 \sigma T^4$ to solve for r.

Comparing two stars

For two stars with luminosities L_1, L_2, radii r_1, r_2, temperatures T_1, T_2:

$$\frac{L_1}{L_2} = \left(\frac{r_1}{r_2}\right)^2 \left(\frac{T_1}{T_2}\right)^4$$

Cancel solar units when comparing to the Sun — ratios are clean and dimensionless.

Star colour & temperature

- Visible band: ~400 nm (violet) – 700 nm (red).
- $\lambda_{\max}$ in red ($\sim$700 nm) $\Rightarrow T \approx 4100$ K (red giants, e.g. Aldebaran).
- $\lambda_{\max}$ in blue/UV ($\sim$300 nm) $\Rightarrow T \gtrsim 10\,000$ K (blue giants, e.g. Rigel).
- Sun: $T \approx 5800$ K, $\lambda_{\max} \approx 500$ nm (green-yellow).

Stellar spectra — absorption lines

The hot stellar interior emits an approximate black-body *continuous* spectrum.

Cooler atoms in the outer atmosphere absorb photons whose energy matches a transition between electron levels.

Result: dark lines superimposed on the continuum at characteristic wavelengths.

Sets of lines identify which elements are present.

Energy of a transition

$$\Delta E = hf = \frac{hc}{\lambda}$$

- Larger $\Delta E \Rightarrow$ shorter wavelength (UV / blue end).
- Smaller $\Delta E \Rightarrow$ longer wavelength (red / IR end).
- Higher temperatures populate higher excited states — so different absorption patterns at different surface temperatures.

Giant vs dwarf

- **Red giant:** low surface T (cool, red) but high L — possible only if r is very large (Stefan).
- **White/blue dwarf:** high surface T but low $L \Rightarrow$ small r.
- **Main sequence:** L rises with T along a diagonal band on the HR diagram.

Questions begin overleaf.

SECTION A

Black-body spectra & Wien's law

Questions 1 – 5 · 55 marks

6. *(a)* Stars emit radiation as *black bodies*. State what is meant by a *black body*. [1]

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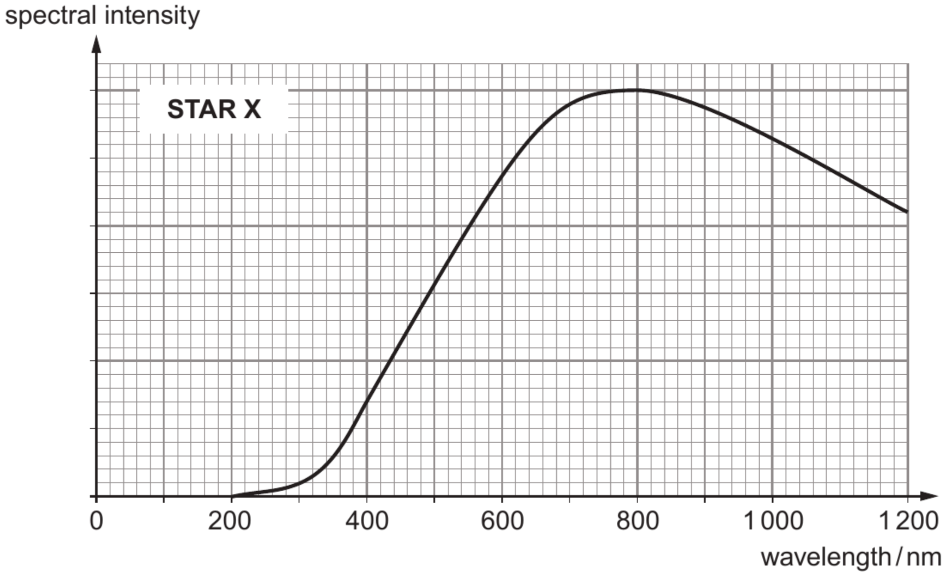
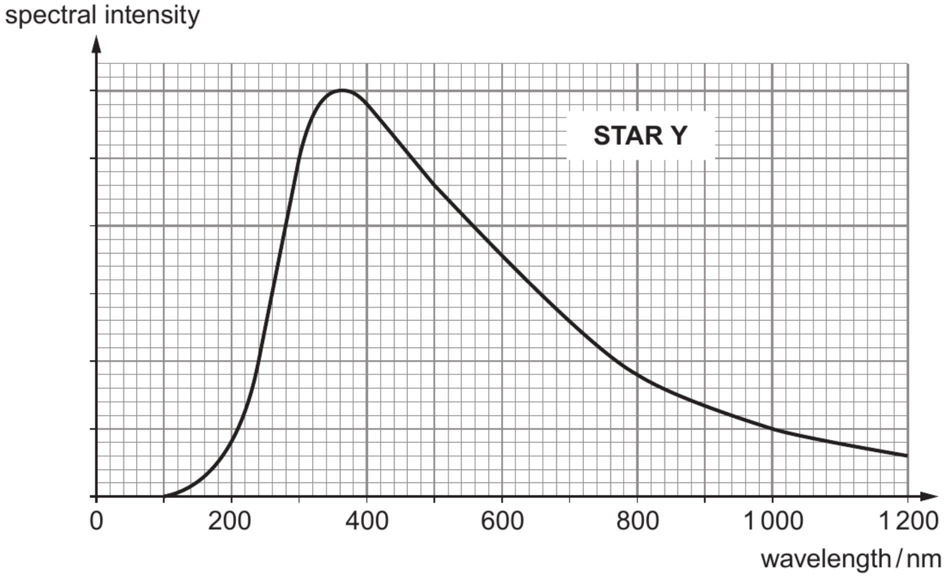
(b) The spectra of two stars, X and Y, are given below. The vertical scales are arbitrary.





(i) The range of visible wavelengths is roughly 400 nm - 700 nm. Identify the likely *colours* of the two stars, giving your reasoning. [2]

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(ii) Show clearly that the ratio:

$$\frac{\text{Kelvin temperature of surface of Y}}{\text{Kelvin temperature of surface of X}}$$ is approximately 2,

giving your own value for the ratio to two significant figures. [3]

(iii) Calculate the ratio:

$$\frac{\text{Power of electromagnetic radiation emitted by Y } \textbf{per m}^{\mathbf{2}} \text{ of surface}}{\text{Power of electromagnetic radiation emitted by X } \textbf{per m}^{\mathbf{2}} \text{ of surface}}$$ [1]

(iv) Measurements show that:

$$\frac{\text{Total power of electromagnetic radiation emitted by Y}}{\text{Total power of electromagnetic radiation emitted by X}} = 9.0$$

The diameter of X is 1.5×10^9 m. Calculate the diameter of Y. [3]

6. *Neutron stars* are very small, dense 'dead' stars. Sometimes they can acquire an outer layer of 'active' material which becomes very hot and radiates as a *black body*. One such star has a **radius** of 11 km, and radiates at a temperature of 2.5×10^7 K.

(a) (i) Show that the wavelength of greatest spectral intensity is approximately 1×10^{-10} m. [2]

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(ii) Name the region of the electromagnetic spectrum in which this wavelength lies. [1]

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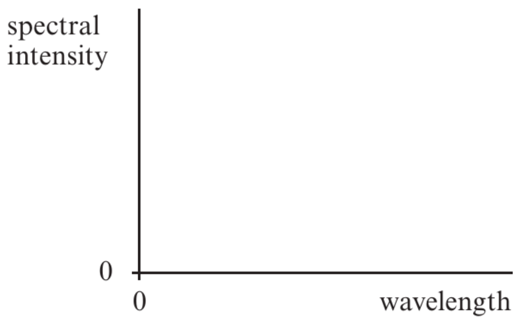
(iii) Sketch a black body spectrum on the axes provided. [1]



(iv) Discuss briefly whether the star in question emits any **visible** radiation. [1]

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(b) Calculate the total *power* emitted as electromagnetic radiation by the star. [3]

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(c) The outer layer of the star expands rapidly and cools. The total power emitted remains roughly constant. Estimate the temperature of the outer layer when its **surface area** has doubled. [2]

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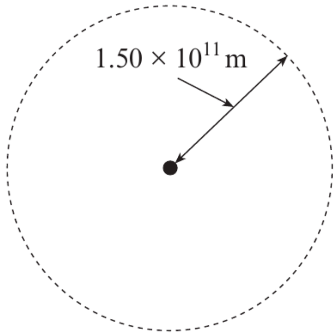
8. *(a)* (i) The *intensity* of the Sun's electromagnetic radiation at a distance of 1.50×10^{11} m from its centre is $1.36\,\text{kW}\,\text{m}^{-2}$.

Show that the power the Sun emits is approximately 4×10^{26} W. Give your answer to 3 significant figures. [2]



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(ii) 1.50×10^{11} m is the radius of the Earth's orbit. Suggest why the intensity of radiation, as measured on the Earth's surface, is less than $1.36\,\text{kW}\,\text{m}^{-2}$. [1]

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(b) The temperature of the Sun's surface is 5780 K.

(i) Use Stefan's Law to calculate the *surface area* of the Sun. [2]

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(ii) The Sun's ***diameter*** is measured, by optical methods, to be 1.4×10^{9} m. Show clearly whether or not your answer to *(b)*(i) is consistent with this. [2]

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(c) A biologist claims that our eyes are sensitive to the region of the Sun's spectrum of greatest intensity. Use Wien's law to support this claim, and sketch the Sun's spectrum on the axes provided. [4]

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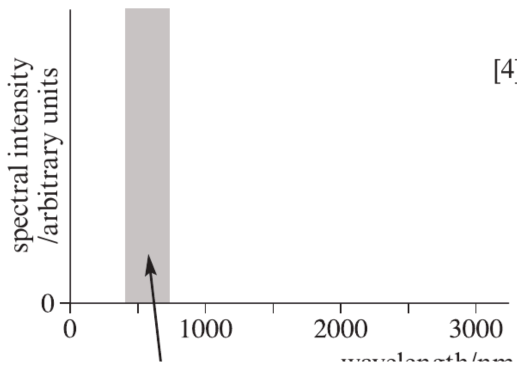

7. (a) A star's continuous spectrum approximates to that of a black body. What is meant by a black body? [1]

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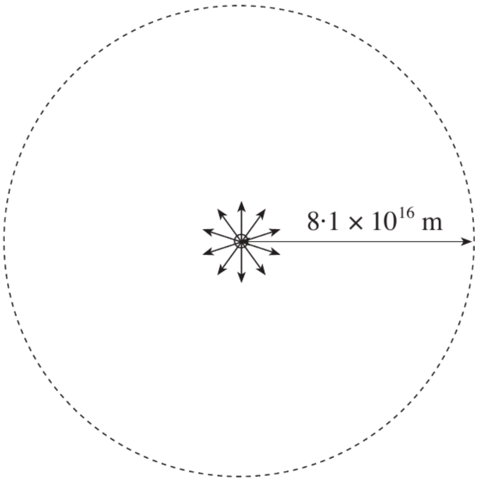
(b) The star Sirius is estimated to be $8{\cdot}1 \times 10^{16}$ m away. The intensity of its electromagnetic radiation reaching the Earth is measured to be $1{\cdot}2 \times 10^{-7}$ Wm^{-2}.



(i) Sirius emits radiation equally in all directions. Show that the information above leads to a value of $9{\cdot}9 \times 10^{27}$ W for the power output from the surface of Sirius. [2]

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(ii) Suggest why the actual emitted power will, in fact, be more than this. [1]

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(iii) The surface temperature of Sirius is measured to be 9900 K. Using Stefan's Law, estimate the effective radius of Sirius. [3]

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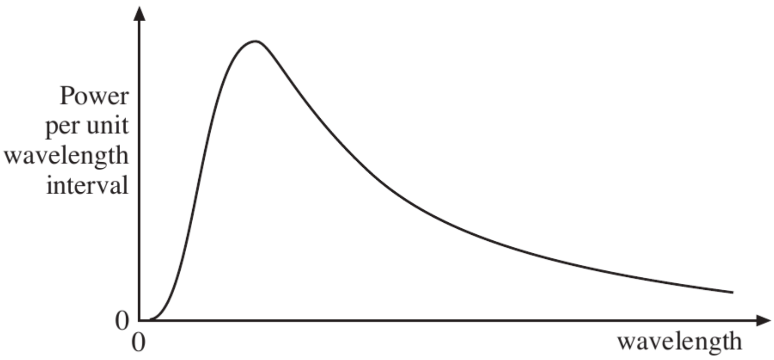
(iv) The (continuous) spectrum of Sirius is sketched below. On the same axes, sketch the spectrum of the Sun. The sun's temperature is 5800 K. [Assume that the surface areas of the Sun and Sirius are approximately equal.] [2]



(c) Dark lines are seen crossing the continuous spectrum of a star. Explain how these lines arise. [3]

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Examiner only

6. *(a)* In this question, stars may be assumed to radiate as *black bodies.* Define a *black body.*[1]

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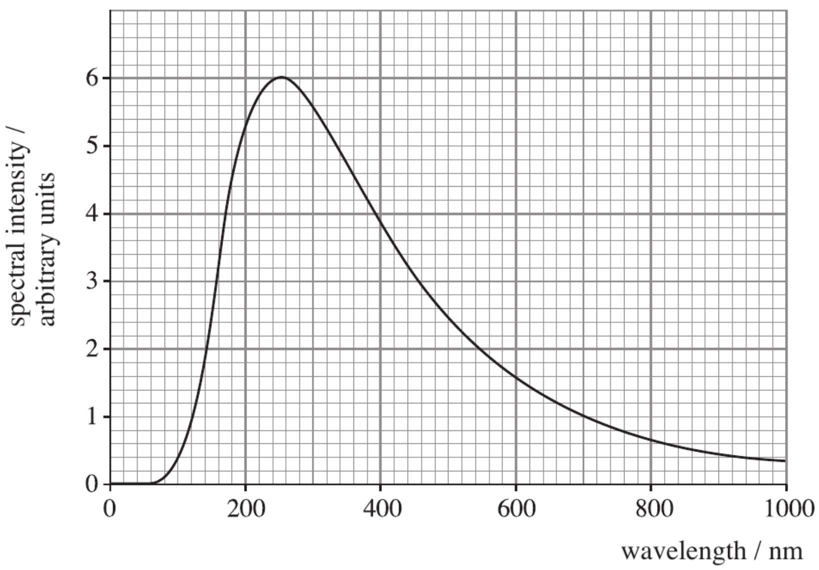
(b) The diagram shows the spectrum of *Rigel* (one of the brightest stars in the night sky).



Show that the surface temperature of Rigel is 10 000 K to one significant figure. [3]

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(c) The *power* emitted by Rigel is found to be 2.53×10^{31} W.

(i) Use Stefan's law to calculate the effective surface area of Rigel. [3]

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Examiner only

(ii) The **radius** of the **Sun** is 6.96×10^8 m. Supporting your explanation with a calculation, explain why Rigel is called a *giant* star. [2]

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(iii) Referring again to the spectrum given in part *(b)*, discuss whether or not Rigel should be classed as a *red* giant. [3]

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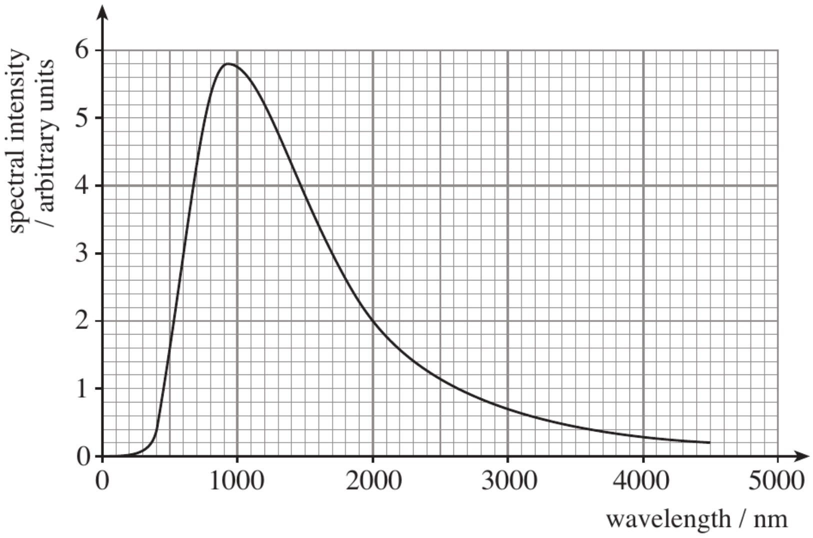
QUESTION 7 IS ON PAGE 12

SECTION B

Stefan's law — size, luminosity & spectra

Questions 6 – 11 · 62 marks

7. The nearest star to the Sun is a 'red dwarf', *Proxima Centauri*. The graph shows its spectrum.



(a) Use *Wien's law* to show clearly that the temperature of the star is about 3000 K. [3]

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(b) The range of visible wavelengths is 400 nm – 700 nm.

(i) Explain why *Proxima Centauri* is described as 'red'. [1]

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(ii) Name the region of the electromagnetic spectrum containing most of the power radiated. [1]

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(iii) (I) Where, apart from at the extremes, is the graph gradient zero? [1]

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(II) Astrophysicists believe that *Proxima Centauri* will become hotter in the distant future. Estimate the temperature it would have to reach in order for the intensity of its radiation to be roughly the same at each end of the **visible** region of the spectrum (so the star appears white). Show your working clearly. [2]

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(c) Use *Stefan's law* to calculate the total power of electromagnetic radiation emitted from *Proxima Centauri* (at its present temperature) if its effective radius is 1.01×10^8 m. [3]

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7. *(a)* (i) The spectrum of the star *Rigel* in the constellation *Orion* peaks at a wavelength of 260 nm. Calculate the temperature of the surface of Rigel. [2]

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(ii) What assumption were you making about the way the star's surface radiates? [1]

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(b) To a good approximation the Kelvin temperature of Rigel's surface is twice that of the Sun, and the **radius** of Rigel is 70 times the radius of the Sun. Use *Stefan's Law* to estimate the ratio

$$\frac{\text{total power of electromagnetic radiation emitted by Rigel}}{\text{total power of electromagnetic radiation emitted by the Sun}}\ .$$ [3]

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(c) We can discover the presence of particular atoms in the atmosphere of a star by measuring the wavelengths of dark lines in the star's spectrum.

Explain how the lines arise, and why they occur at specific wavelengths. [3]

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7. A website gives the following data for the star Aldebaran:

radius = 44.2 $R_\odot$ luminosity = 518 $L_\odot$

in which $R_\odot$ = radius of Sun = 6.96×10^8 m
and $L_\odot$ = luminosity of Sun = 3.85×10^{26} W

(a) Use Stefan's law to calculate a value for the surface temperature of Aldebaran. [4]

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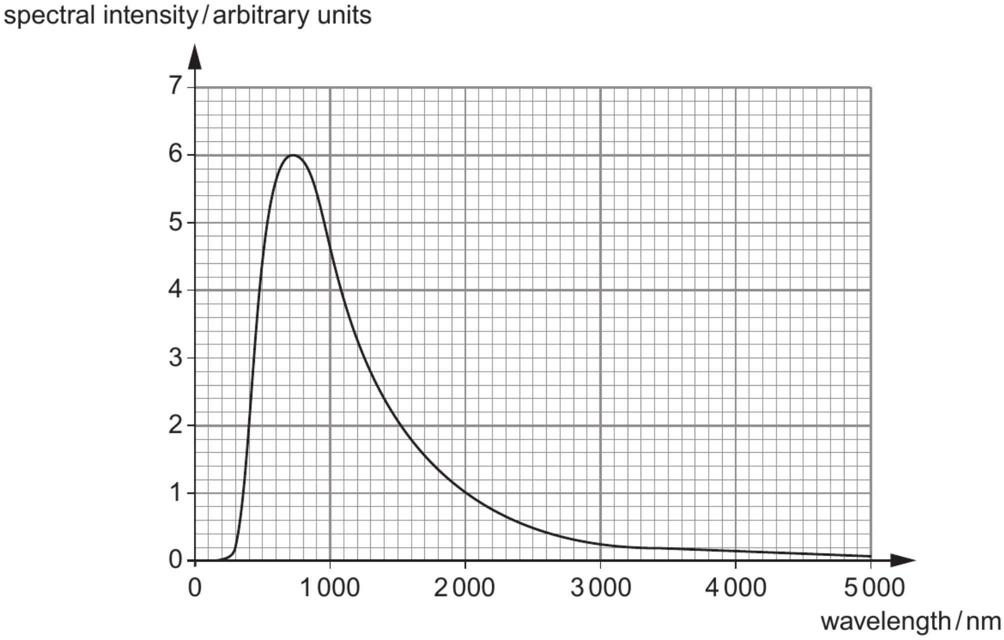
(b) The continuous spectrum of Aldebaran is given.



Determine a value for the temperature of Aldebaran without using Stefan's law giving your working. [2]

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(c) Agreement between the temperatures found in *(a)* and *(b)* would help to confirm that Aldebaran is emitting as a black body. What is a black body? [1]

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(d) Explain, using the data in this question, why 'red giant' is an appropriate description of Aldebaran. [2]

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Examiner only

7. The star Sirius A has a surface temperature of 9 900 K and a luminosity (total power output of electromagnetic radiation) of 1.00×10^{28} W.

(a) (i) Calculate the star's wavelength of peak spectral intensity. [2]

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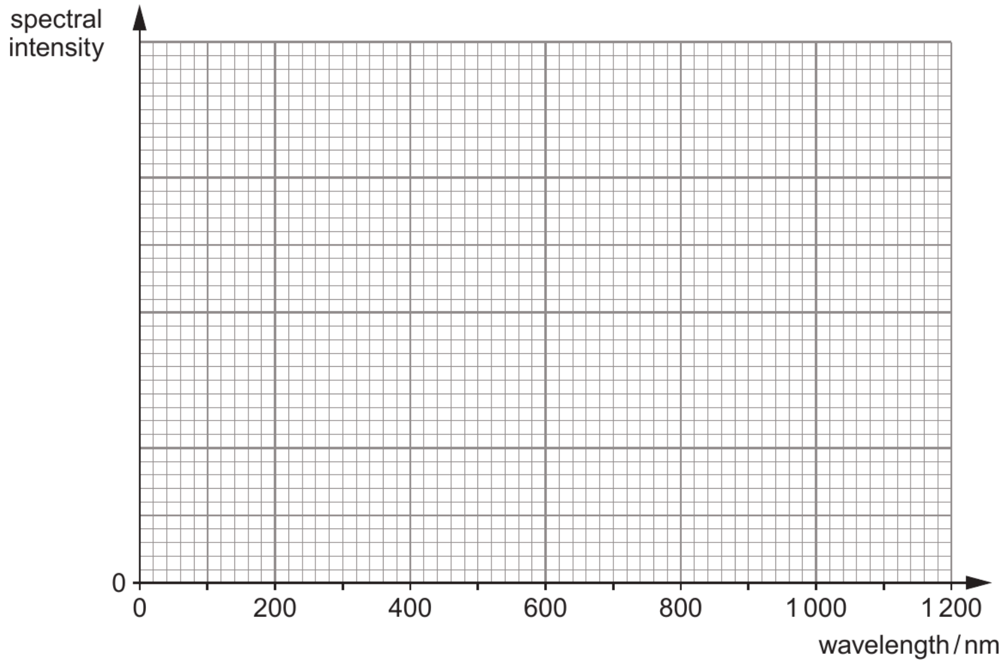
(ii) Sketch on the axes a graph of spectral intensity against wavelength for the continuous spectrum of Sirius A. *(Note: make the peak spectral intensity three or four large squares above the wavelength axis.)* [2]



(iii) What colour would you expect Sirius A to be? [1]

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(b) Use Stefan's Law to calculate the diameter of Sirius A. [3]

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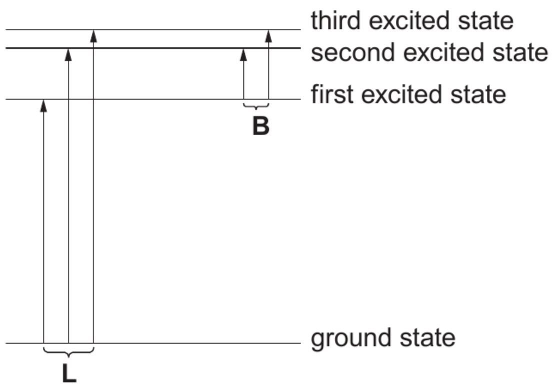
(c) The diagram shows the lowest energy levels of a hydrogen atom, and five possible transitions between these levels.



(i) Name the process (involving photons) which is responsible for the transitions. [1]

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(ii) Briefly describe the observed feature of the spectrum of a star which this process explains. [1]

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(iii) All the transitions shown in the diagram take place in the atmosphere of Sirius A. State which group of transitions, **L** or **B**, is almost completely absent in a much cooler star, giving a reason for your answer. [2]

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TURN OVER FOR QUESTION 8

Examiner only

6. *(a)* A table of astronomical data includes the following about the star *Alpha Centauri A*: Radius = 8.54×10^{8} m, Temperature = 5790 K, Luminosity = 5.83×10^{26} W.

(i) Investigate whether the data above is consistent with the star radiating as a black body. Show your working clearly, and give your conclusion. [3]

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(ii) The star is 4.1×10^{16} m from the Earth. Calculate the intensity (energy per second per m^2) of electromagnetic radiation reaching the Earth from the star. [2]

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(iii) Calculate the wavelength of the star's peak spectral intensity, and sketch the spectrum on the axes provided. [4]

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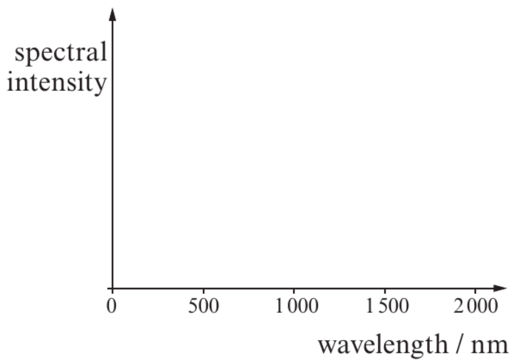
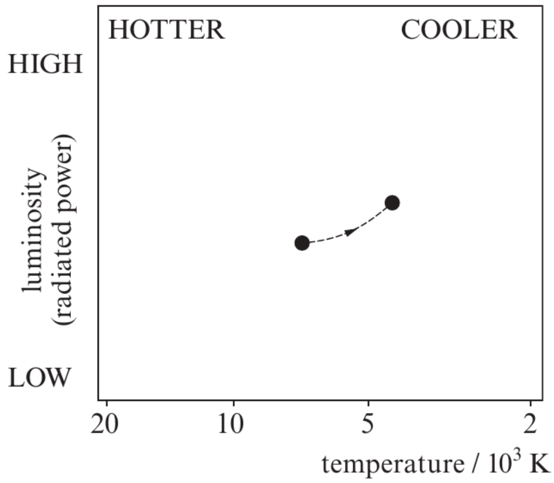


Examiner only

(b) Astronomers assign to each star a position on a chart, according to the star's luminosity and temperature.

During one stage in the life of *Alpha Centauri A*, its position on the chart will move as shown by the dotted line.

Use Stefan's law to show clearly what happens to the *size* of the star during this stage. [**Numerical calculations are not needed.**] [2]



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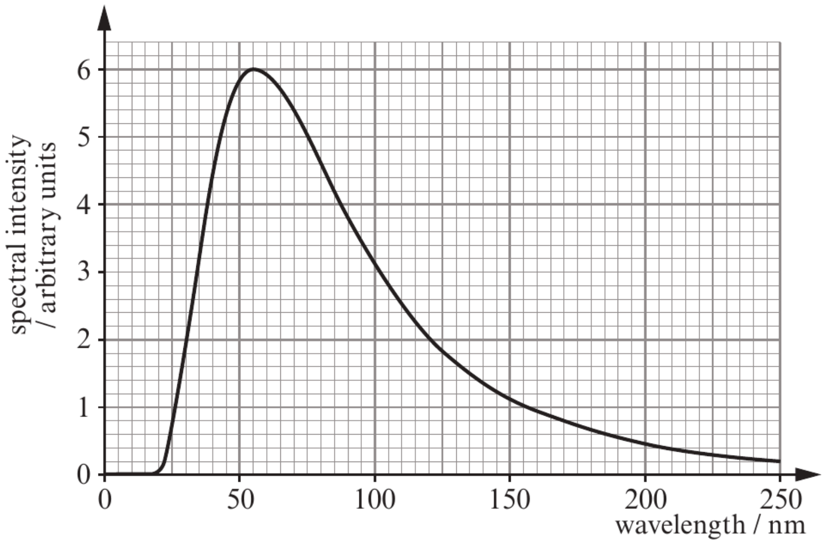
7. One of the hottest stars known is HD93129A in the Carina nebula. Its continuous spectrum is shown.



(a) (i) Name the region of the electromagnetic spectrum in which the wavelength of peak emission lies. [1]

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(ii) Show that the star's temperature is approximately 50 000 K. [2]

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(iii) The star is blue. Explain how this could be deduced from the spectrum. [1]

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Examiner only

(b) (i) The star is 7.10×10^{19} m away, and the intensity of its electromagnetic radiation reaching the Earth is $3.33 \times 10^{-8}\,W\,m^{-2}$. Show that its luminosity is approximately $5 \times 10^{6} P_{sun}$, in which P_{sun} is the Sun's luminosity (3.84×10^{26} W). [3]

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(ii) Use Stefan's law to calculate the star's **diameter.** [3]

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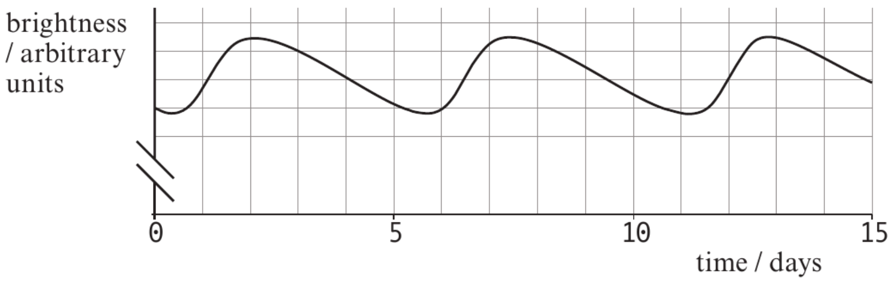
TURN OVER FOR QUESTION 8

SECTION C

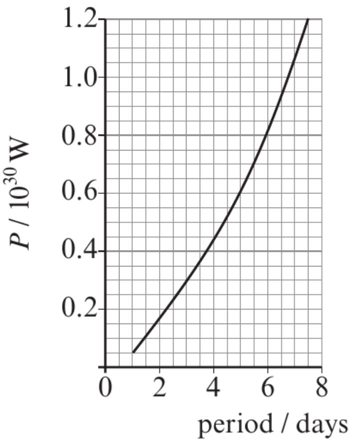
Variable stars

Questions 12 – 13 · 21 marks

8. *Cepheid variables* are stars whose brightness varies in a characteristic, regular way. The variation is shown below for one such star.



The mean power, P, emitted as electromagnetic radiation from a Cepheid variable is related to the period of its brightness variation, as shown alongside.



(a) (i) Use the graphs to determine P for the star, showing briefly how you obtained your answer. [2]

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(ii) The mean *intensity* of the radiation from the star, as measured at the Earth is $8.0 \times 10^{-13}\,\mathrm{W\,m^{-2}}$. Using your answer to *(a)*(i), calculate the distance, r, between the star and the Earth. [2]

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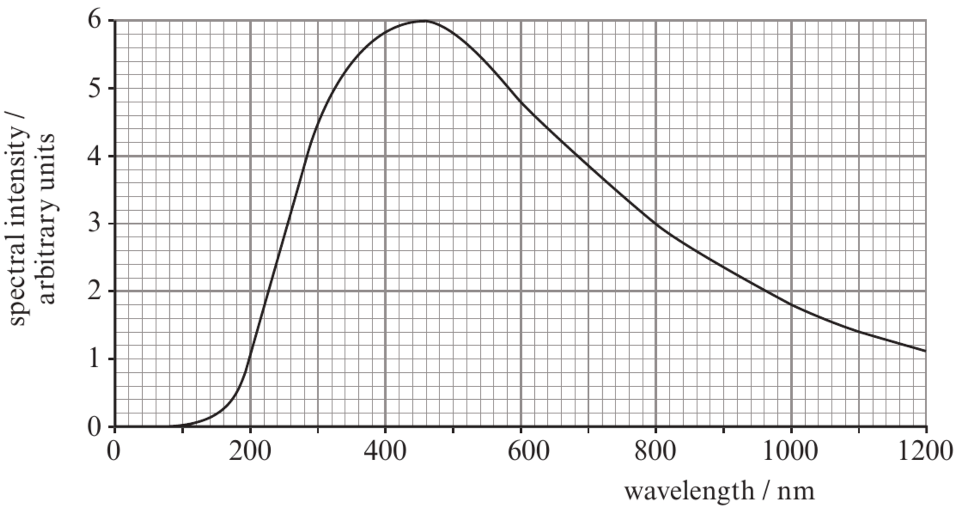
(b) The maximum power emitted by the star during its cycle of variation is estimated to be 9.5×10^{29} W, and the spectrum of its radiation corresponding to this point in its cycle is given below.



(i) Use Wien's law to calculate the temperature of the star. [2]

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(ii) Calculate the **diameter** of the star. [4]

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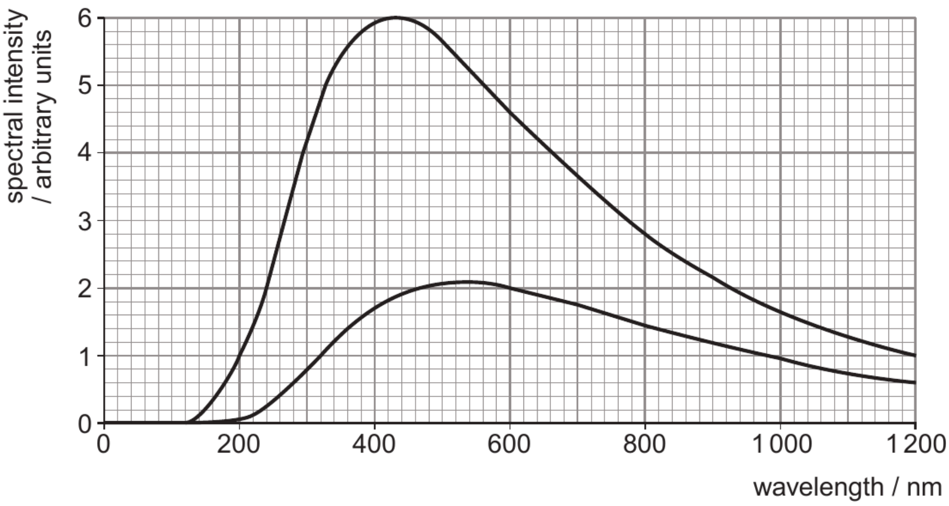
7. Delta Cephei is a variable star, whose surface temperature varies between fixed maximum and minimum values. Its continuous spectrum is given below for the maximum temperature and minimum temperature.



(a) (i) Show that the star's maximum temperature is approximately 7 000 K. [2]

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(ii) Calculate the star's minimum temperature. [1]

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(iii) State the difference you would expect to see in the star's colour at the maximum and minimum temperatures. [1]

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(b) The star's luminosity (total power emitted as e-m radiation) at its maximum temperature is 1.46×10^{30} W. Calculate its diameter. [4]

(c) Calculate the **percentage** decrease in the star's luminosity as its temperature goes from maximum to minimum. [Assume its diameter does not change.] [3]

TURN OVER FOR QUESTION 8

END OF QUESTION PACK

13 questions · 138 marks · ~2 h 20 min

Mark schemes available from WJEC and Physics & Maths Tutor.