PEARSON EDEXCEL A-LEVEL PHYSICS · 9PH0

PHYSICS



MARK SCHEME

TOPIC 9: THERMODYNAMICS

BLACKBODY RADIATION

SCORE	PERCENTAGE
/115	%

STEMUP

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Mark Scheme

Q1.

Question Number	Answer		Mark
	Use of $\lambda_{max} T = 2.898 \times 10^{-3}$ m K $T = 3400$ (K) Use of $L = 4\pi r^2 \sigma T^4$ $r_B = 6.8 \times 10^{11}$ (m) [8.82×10^{11} m if T = 3000 K, 6.87×10^{11} m if T = 3400 K] $r_B / r_S = 980$ [1270 if $T = 3000$ K, 988 if $T = 3400$ K] Example of calculation $T = \frac{2.898 \times 10^{-3}\,\text{m K}}{850 \times 10^{-9}\,\text{m}} = 3410\,\text{K}$ $r_B = \sqrt{\frac{4.49 \times 10^{31}\,\text{W}}{4\pi \times 5.67 \times 10^{-8}\,\text{W m}^{-2}\text{K}^{-4} \times (3410\,\text{K})^4}} = 6.83 \times 10^{11}\,\text{m}$ $\frac{r_B}{r_S} = \frac{6.83 \times 10^{11}\,\text{m}}{6.95 \times 10^{8}\,\text{m}} = 983$	(1) (1) (1) (1) (1)	5

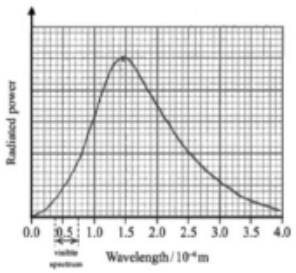
Q2.

Question Number	Acceptable answers	Additional guidance	Mark
	• Use of $\lambda_{max} T = 2.9 \times 10^{-3}$ **(1)** • $T = 5800$ K [accept 5780 K and 6000 K] **(1)** • Use of $L = 4\pi r^2 \sigma T^4$ **(1)** • r = 6.9×10^8 m **(1)**	Example of calculation: $T = \frac{2.9 \times 10^{-3}\,\text{mK}}{5.02 \times 10^{-7}\,\text{m}} = 5780\,\text{K}$ $r = \sqrt{\frac{3.85 \times 10^{26}\,\text{W}}{4\pi \times 5.67 \times 10^{-8}\,\text{Wm}^{-2}\text{K}^{-4} \times (5800\,\text{K})^4}} = 6.91 \times 10^8\,\text{m}$	**4**

Q3.

Question Number	Answer		Mark
	The star cools, so temperature T reduces The star contracts (under gravitational forces), so area A reduces $L = \sigma A T^4$ hence L is reduced (mark dependent upon either mp1 or mp2)	(1) (1) (1)	3

Q4.

Question Number	Acceptable answers	Additional guidance	Mark
(i)	• Use of $\lambda_{max} T = 2.898 \times 10^{-3}$ m K (1) • $\lambda_{max} = 1.4 \times 10^{-6}$ (m) (1) • correct black body radiation shape (1) • peak at correct wavelength (1) • line not zero at long wavelength **and** not positive at 0.0 on wavelength axis (1)	Example of calculation and graph $\lambda_{max} \times 2026$ K $= 2.898 \times 10^{-3}$ m K $\lambda_{max} = 1.43 \times 10^{-6}$ m 	5
(ii)	• Most radiation at infrared **or** λ_{max} isn't in the visible spectrum **or** only a small proportion of radiation/power in visible spectrum (1) • Ratio of useful output/input is therefore very small **Or** so proportion of energy transfer that is useful is small (1)		2

Q5.

Question Number	Acceptable answers	Additional guidance	Mark
(i)	An explanation that makes reference to: • quantisation of energy is the idea that energy is emitted/radiated in discrete packets/photons **(1)** • each photon has an energy which is related to frequency OR suitable reference to $E = hf$ **(1)**		2
(ii)	• Model A is successful at long wavelengths because the curve for model A follows the experimental curve **(1)** • But model A breaks down for short wavelengths, since it suggests that the intensity tends to infinity as the wavelength gets shorter **(1)** • Model B is successful for short wavelengths because curve B follows the experimental curve **(1)** • But model B indicates higher than expected intensities at larger wavelengths **(1)**		4

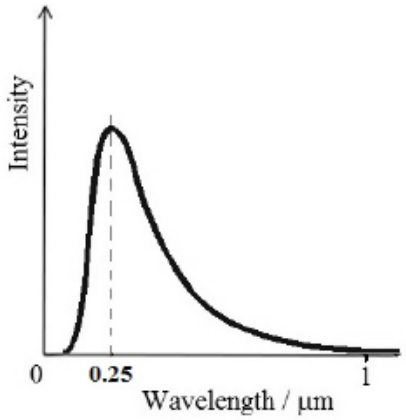
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Q6.

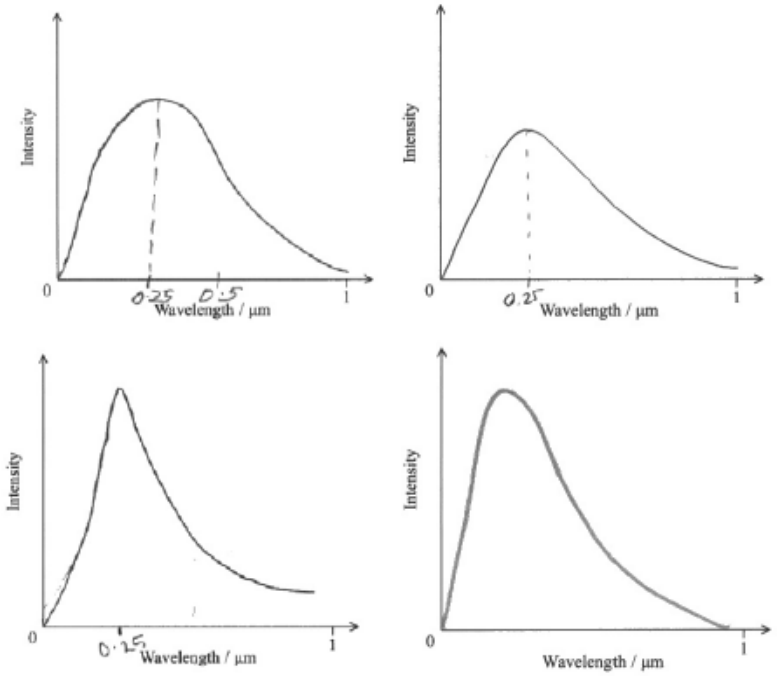
Question Number	Answer		Mark
(a)	(B2 =) 2.9×10^{-3}/A2 **Or** (B2 =) $2.9 \times 10^{-3}/\lambda_{max}$ **Or** (B2=) $2.9 \times 10^{-3}/6.85 \times 10^{-7}$ [Ignore incorrect powers of 10]	**(1)**	**1**
(b)	Use of $L = \sigma T^4 A$ $A = 0.21(48) \times 10^{19}$ (m^2) For max 1 Use of $A = 4\pi R^2$ to give $A = 2.1(1) \times 10^{18}$ (m^2) <u>Example of calculation:</u> $A = \frac{0.392 \times 10^{26}\ \text{W m}^{-2}}{5.67 \times 10^{-8}\ \text{W m}^{-4}\ \text{K}^{-4} \times (4230\ \text{K})^4} = 2.148 \times 10^{18}\ \text{m}^2$	**(1)** **(1)**	**2**
(c)	Flux/brightness/intensity measured and distance to star determined (Luminosity calculated using) $L = 4\pi d^2 F$ **Alternative mark scheme:** Temperature and type of star identified [e.g. main sequence]	**(1)** **(1)** **(1)**	
	Hertzsprung-Russell diagram used to find luminosity	**(1)**	**2**
	Total for question		**5**

Q7.

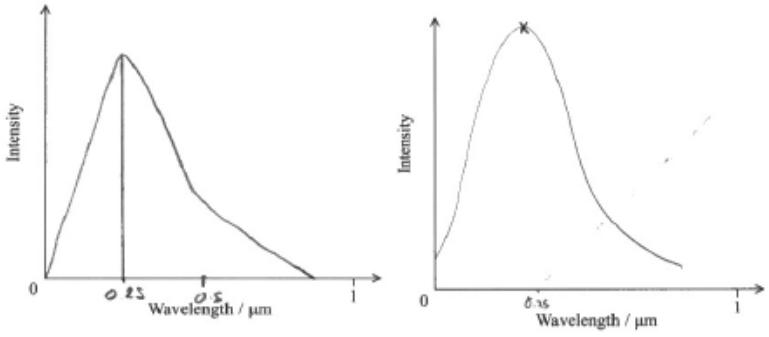
Question Number	Answer	Mark
	Curve with peak at 0.25μm (labelled or in correct position) (1) Shape must be an asymmetric curve and must not have intensity at $\lambda = 0$ (1)	2



Examples of acceptable shapes:



Examples of unacceptable shapes:



Q8.

Question Number	Answer	Mark
	B	**1**

Mark Scheme

Q1.

Question Number	Answer	Mark
	A	1

Q2.

Question Number	Answer		Mark
	Use of $\lambda_{max} T = 2.898 \times 10^{-3}$ m K $T = 3400$ (K) Use of $L = 4\pi r^2 \sigma T^4$ $r_B = 6.8 \times 10^{11}$ (m) [8.82×10^{11} m if T = 3000 K, 6.87×10^{11} m if T = 3400 K] $r_B / r_S = 980$ [1270 if $T = 3000$ K, 988 if $T = 3400$ K] Example of calculation $T = \frac{2.898 \times 10^{-3}\,\text{m K}}{850 \times 10^{-9}\,\text{m}} = 3410\,\text{K}$ $r_B = \sqrt{\frac{4.49 \times 10^{31}\,\text{W}}{4\pi \times 5.67 \times 10^{-8}\,\text{W m}^{-2}\text{K}^{-4} \times (3410\,\text{K})^4}} = 6.83 \times 10^{11}\,\text{m}$ $\frac{r_B}{r_S} = \frac{6.83 \times 10^{11}\,\text{m}}{6.95 \times 10^{8}\,\text{m}} = 983$	(1) (1) (1) (1) (1)	5

Q3.

Question Number	Acceptable answers	Additional guidance	Mark
	• Use of $\lambda_{max}T = 2.9\times10^{-3}$ **(1)** • T = 5800 K [accept 5780 K and 6000 K] **(1)** • Use of $L = 4\pi r^2\sigma T^4$ **(1)** • r = 6.9×10^8 m **(1)**	Example of calculation: $T = \frac{2.9\times10^{-3}\,\text{mK}}{5.02\times10^{-7}\,\text{m}} = 5780\,\text{K}$ $r = \sqrt{\frac{3.85\times10^{26}\,\text{W}}{4\pi\times5.67\times10^{-8}\,\text{Wm}^{-2}\text{K}^{-4}\times(5800\,\text{K})^4}} = 6.91\times10^8\,\text{m}$	**4**

Q4.

Question Number	Answer		Mark
	The star cools, so temperature T reduces	**(1)**	
	The star contracts (under gravitational forces), so area A reduces	**(1)**	
	$L = \sigma AT^4$ hence L is reduced (mark dependent upon either mp1 or mp2)	**(1)**	**3**

Q5.

Question Number	Acceptable Answer		Additional Guidance	Mark
(i)	• All the stars are in the main sequence • In an older cluster there would be red giant stars	**(1)** **(1)**		**2**
(ii)	**MAX 4** • The most massive stars experience much greater gravitational forces • So core temperature and density is greatest • The rate of fusion in the core is greatest **Or** the power generated in the core is greatest • The (surface) temperature is greatest • The surface area of these stars is greatest • So according to Stefan's Law the power radiated from these massive stars is greatest	**(1)** **(1)** **(1)** **(1)** **(1)** **(1)**		**4**

Q6.

Question Number	Acceptable Answer	Additional Guidance	Mark
	• Use of $L = 4\pi r^2 \sigma T^4$ (1) • Use of $I = \frac{L}{4\pi d^2}$ (1) • $I = 1.37$ (kW m^{-2}) (1) • This is less than 2 (kW m^{-2}) and so the claim is false. (1)	Example of calculation: $L = 4\pi(6.96\times10^{8}\text{m})^2 \times 5.67\times10^{-8}$ W r $L = 3.88 \times 10^{26}$ W $I = \frac{3.88\times10^{26}\text{W}}{4\pi(1.50\times10^{11}\text{m})^2} = 1372$ W m^{-2}	4

Q7.

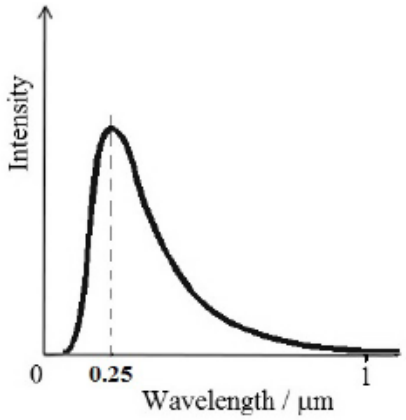
Question Number	Acceptable Answers	Additional Guidance	Mark
(i)	• use of $I = L / 4\pi d^2$ (1) • $L = 6.53 \times 10^{23}$ W (1) • = 0.17% of Sun (1)	Example of calculation 3.25×10^{-11} W m$^{-2} = L / 4\pi(4.00 \times 10^{16}$ m$)^2$ $L = 6.53 \times 10^{23}$ W 6.53×10^{23} W / 3.85×10^{26} W = 0.17%	3
(ii)	• use of $L = \sigma A T^4$ (1) • $T = 3124$ (K) (1) • Statement relating calculated values of T and L to main sequence on H-R diagram (1)	Example of calculation 6.53×10^{23} W = 5.67×10^{-8} W m^{-2} K$^{-4} \times 4\pi$ (9.81 $\times 10^{7}$ m$)^2 \times T^4$ $T = 3124$ K	3

Q8.

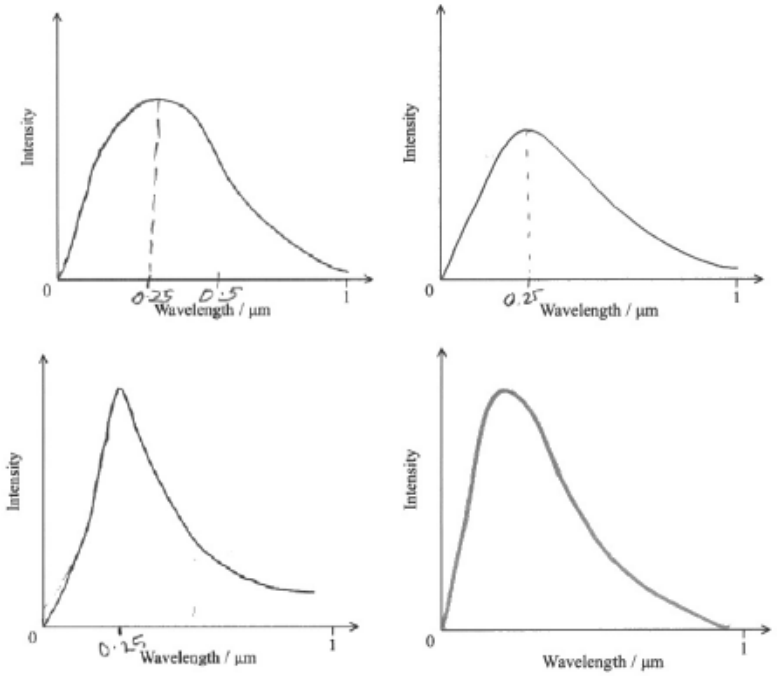
Question Number	Answer		Mark
(a)	(B2 =) 2.9×10^{-3}/A2 **Or** (B2 =) $2.9 \times 10^{-3}/\lambda_{max}$ **Or** (B2=) $2.9 \times 10^{-3}/6.85 \times 10^{-7}$ [Ignore incorrect powers of 10]	**(1)**	**1**
(b)	Use of $L = \sigma T^4 A$ $A = 0.21(48) \times 10^{19}$ (m^2) For max 1 Use of $A = 4\pi R^2$ to give $A = 2.1(1) \times 10^{18}$ (m^2) <u>Example of calculation:</u> $A = \frac{0.392 \times 10^{26}\ \text{W m}^{-2}}{5.67 \times 10^{-8}\ \text{W m}^{-4}\ \text{K}^{-4} \times (4230\ \text{K})^4} = 2.148 \times 10^{18}\ \text{m}^2$	**(1)** **(1)**	**2**
(c)	Flux/brightness/intensity measured and distance to star determined (Luminosity calculated using) L= $4\pi d^2 F$ **Alternative mark scheme:** Temperature and type of star identified [e.g. main sequence]	**(1)** **(1)** **(1)**	
	Hertzsprung-Russell diagram used to find luminosity	**(1)**	**2**
	Total for question		**5**

Q9.

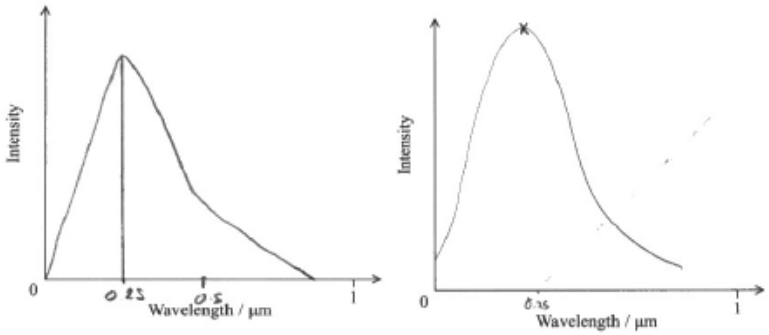
Question Number	Answer	Mark
	Curve with peak at 0.25μm (labelled or in correct position) (1) Shape must be an asymmetric curve and must not have intensity at $\lambda = 0$ (1)	2



Examples of acceptable shapes:



Examples of unacceptable shapes:



Q10.

Question Number	Answer	Mark
	B	**1**

Mark Scheme

Q1.

Question Number	Acceptable Answer	Additional Guidance	Mark
	• Use of $\lambda_{max}T = 2.898\times10^{-3}$ m K (1) • $\lambda_{max} = 910$ nm (1) • Yes, because peak emission occurs at a wavelength close to 950 nm (1)	Ignore references to the wavelength of red light Example of calculation: $\lambda_{max}=\frac{2.898\times10^{-3}\text{ m K}}{3200\text{ K}}=9.06\times10^{-7}$ m	3

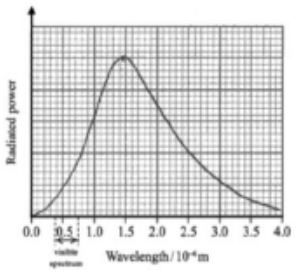
Q2.

Question Number	Answer	Mark
	D	1

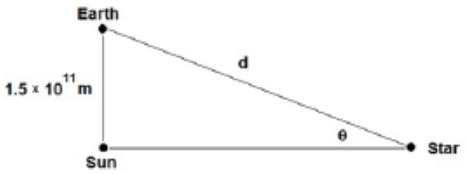
Q3.

Question Number	Answer		Mark
	Use of $\lambda_{max}T = 2.898\times10^{-3}$ m K $T = 3400$ (K) Use of $L = 4\pi r^2\sigma T^4$ $r_B = 6.8\times10^{11}$ (m) [8.82×10^{11} m if T = 3000 K, 6.87×10^{11} m if T = 3400 K] $r_B/r_S = 980$ [1270 if $T = 3000$ K, 988 if $T = 3400$ K] Example of calculation $T=\frac{2.898\times10^{-3}\text{ m K}}{850\times10^{-9}\text{ m}}=3410\text{ K}$ $r_B=\sqrt{\frac{4.49\times10^{31}\text{ W}}{4\pi\times5.67\times10^{-8}\text{ W m}^{-2}\text{K}^{-4}\times(3410\text{ K})^4}}=6.83\times10^{11}\text{ m}$ $\frac{r_B}{r_S}=\frac{6.83\times10^{11}\text{ m}}{6.95\times10^{8}\text{ m}}=983$	(1) (1) (1) (1) (1)	5

Q4.

Question Number	Acceptable answers	Additional guidance	Mark
(i)	• Use of $\lambda_{max}\ T = 2.898 \times 10^{-3}$ m K (1) • $\lambda_{max} = 1.4 \times 10^{-6}$ (m) (1) • correct black body radiation shape (1) • peak at correct wavelength (1) • line not zero at long wavelength **and** not positive at 0.0 on wavelength axis (1)	Example of calculation and graph $\lambda_{max} \times 2026$ K $= 2.898 \times 10^{-3}$ m K $\lambda_{max} = 1.43 \times 10^{-6}$ m 	5
(ii)	• Most radiation at infrared **or** λ_{max} isn't in the visible spectrum **or** only a small proportion of radiation/power in visible spectrum (1) • Ratio of useful output/input is therefore very small **Or** so proportion of energy transfer that is useful is small (1)		2

Q5.

Question Number	Answer	Mark
(a)	**Max 6** The young star cluster consists (mainly) of main sequence stars (1) The old star cluster has a truncated main sequence (1) The old star cluster has lost its heaviest main sequence stars (1) The old star cluster has (many) red giant stars (1) The old star cluster has (some) white dwarf stars (1) Massive main sequence stars are the first stars (to deplete sufficient hydrogen in their core) to evolve into red giant stars. (1) Some red giant stars have evolved into white dwarf stars in the old cluster (1)	6
(b)(i)	Star A is closer to Earth than Star B (1)	1
(b)(ii)	 Use of appropriate trigonometric relationship (1) $d = 4.0 \times 10^{16}$ m (1) Example of calculation: $\sin\theta = \frac{1.5\times10^{11}\text{m}}{d}$ $d = 4.01 \times 10^{16}$ m	2

(c)	$\lambda_{max} = 1.0 \times 10^{-6}$ m (1) Use of $\lambda_{max} T = 2.9 \times 10^{-3}$ (1) $T = 2900$ K (1) Example of calculation: $T = 2.9 \times 10^{-3}$ m K/1.0×10^{-6} m = 2900 K	3
	Total for question	12

Q6.

Question Number	Answer	Additional guidance	Mark
	A	(5.1×10^{-6} m)	**(1)**

Q7.

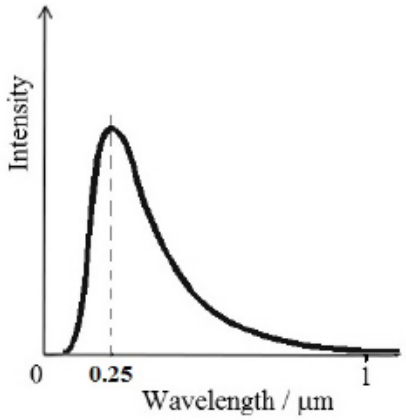
Question Number	Acceptable answers		Additional guidance	Mark
	• Use of $\lambda_{max}T = 2.898 \times 10^{-3}$ m K	(1)	Example of calculation $\lambda_{max}T = 2.898 \times 10^{-3}$ m K $\lambda_{max} = 2.898 \times 10^{-3}$ m K / 293 K $\lambda_{max} = 9.89 \times 10^{-6}$ m MP4 consistent with calculation	4
	• … with sensible temperature expressed in Kelvin	(1)		
	• E.g. $\lambda_{max} = 9.89 \times 10^{-6}$ m for 293 K	(1)		
	• Value is greater than max wavelength of red light so is in IR region	(1)		
	Or (if starting from 700 nm)			
	• Use of $\lambda_{max}T = 2.898 \times 10^{-3}$ m K			
	• $T = 4100$ K			
	• Comparison with stated sensible temperature (°C or K)			
	• Temperature is too high so wavelength greater than max wavelength of red light so is in IR region			

Q8.

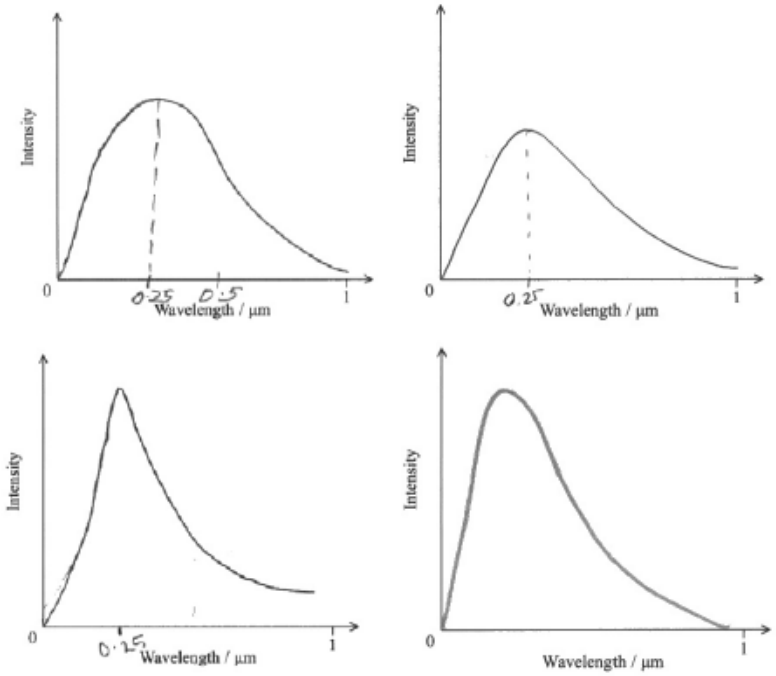
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(a)	(B2 =) 2.9×10^{-3}/A2 **Or** (B2 =) $2.9 \times 10^{-3}/\lambda_{max}$ **Or** (B2=) $2.9 \times 10^{-3}/6.85 \times 10^{-7}$ [Ignore incorrect powers of 10]	**(1)**	**1**
(b)	Use of $L = \sigma T^4 A$ $A = 0.21(48) \times 10^{19}$ (m^2) For max 1 Use of $A = 4\pi R^2$ to give $A = 2.1(1) \times 10^{18}$ (m^2) <u>Example of calculation:</u> $A = \frac{0.392 \times 10^{26}\ \text{W m}^{-2}}{5.67 \times 10^{-8}\ \text{W m}^{-4}\ \text{K}^{-4} \times (4230\ \text{K})^4} = 2.148 \times 10^{18}\ \text{m}^2$	**(1)** **(1)**	**2**
(c)	Flux/brightness/intensity measured and distance to star determined (Luminosity calculated using) $L = 4\pi d^2 F$ **Alternative mark scheme:** Temperature and type of star identified [e.g. main sequence]	**(1)** **(1)** **(1)**	
	Hertzsprung-Russell diagram used to find luminosity	**(1)**	**2**
	Total for question		**5**

Q9.

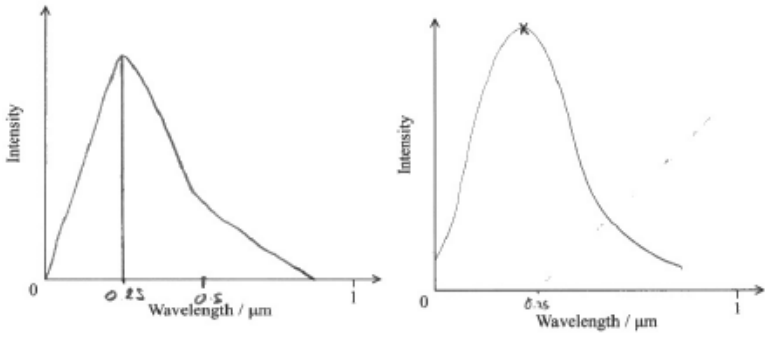
Question Number	Answer	Mark
	Curve with peak at 0.25μm (labelled or in correct position) (1) Shape must be an asymmetric curve and must not have intensity at $\lambda = 0$ (1)	2



Examples of acceptable shapes:



Examples of unacceptable shapes:



Q10.

Question Number	Acceptable answers		Additional guidance	Mark
(a)	• Use of $L = 4\pi r^2 \sigma T^4$ • With 270 000 or 1420 • $T = 3494$ K which is smaller than the temperature of the Sun, so it is not correct • **Or** $T = 0.605\ T_{Sun}$ which is smaller than the temperature of the Sun, so it is not correct	(1) (1) (1)	Example of calculation 3.85×10^{26} W $\times$ 270 000 $= 4 \times \pi \times 5.67 \times 10^{-8} \times (1420 \times 6.96 \times 10^{8}\ \text{m})^2 \times T^4$ $T = 3494$ K	3

Question Number	Acceptable answers		Additional guidance	Mark
(b)	• Use of $\lambda_{max}\ T = 2.898 \times 10^{-3}$ m K • $\lambda_{max} = 8.29 \times 10^{-7}$ m (ecf for T from (a))	(1) (1)	Example of calculation $\lambda_{max} \times 3494\ \text{K} = 2.898 \times 10^{-3}$ m K $\lambda_{max} = 8.29 \times 10^{-7}$ m	2

Question Number	Acceptable answers		Additional guidance	Mark
(c)	• Add to top right • Red giant/supergiant	(1) (1)	Consistent with the answer from (a) for both marking points Accept hypergiant	2