Blackbody Radiation

Q1.

A black body radiator has a temperature of 300°C.

What is the wavelength corresponding to the peak intensity of the emitted radiation?

☒ **A** 5.1×10^{-6} m

☒ **B** 9.7×10^{-5} m

☒ **C** 1.7×10^{0} m

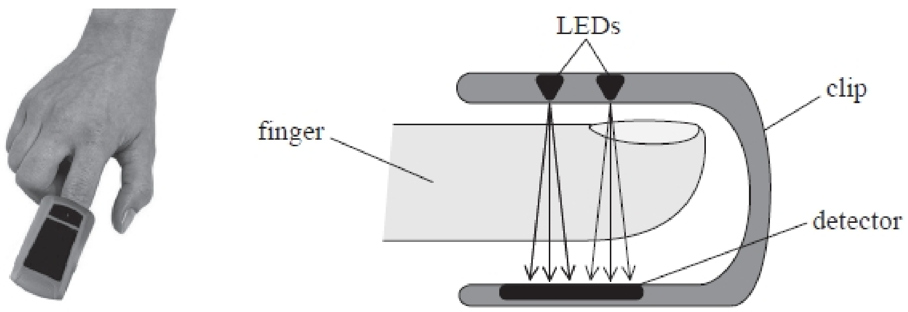
☒ **D** 2.0×10^{5} m

(Total for question = 1 mark)

Q2.

An oximeter is a device used in hospitals to monitor the oxygen level in a patient's blood.

In an oximeter, two light-emitting diodes (LEDs) are mounted opposite light sensors in a clip and attached to the patient's finger. One of the LEDs produces red light and the other produces infrared.



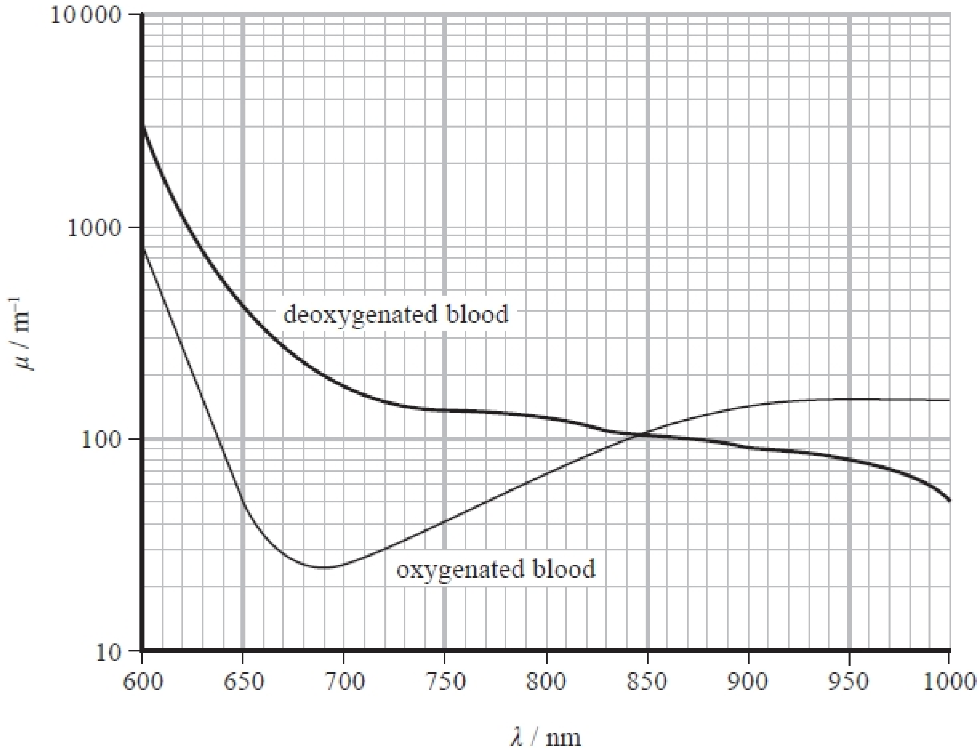
The intensity I of electromagnetic radiation received by the detector, after passing through a thickness x of blood, is given by

$$I = I_0^{e-\mu x}$$

where I_0 is the intensity that would have been received if the blood were not present and μ is the attenuation coefficient of blood.

The red LED emits visible light of wavelength 650 nm and the infrared LED emits infrared of wavelength 950 nm.

The graph shows how μ varies with wavelength λ for oxygenated blood and deoxygenated blood.



It is suggested that ambient light could affect the readings produced by the oximeter.

Halogen lamps have a filament temperature of 3200 K.

Deduce whether the light from such a lamp would have a significant effect on the oximeter readings.

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(Total for question = 3 marks)

Q3.

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

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

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

(4)

longest wavelength of visible red light ≈ 700 nm

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(Total for question = 4 marks)

Q4.

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

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

☐ **A** $\frac{L}{4}$

☐ **B** *L*

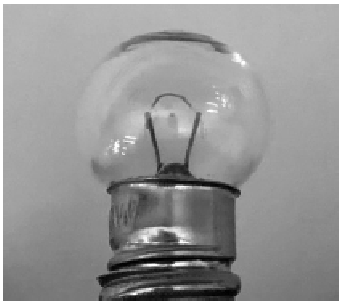
☐ **C** 4*L*

☐ **D** 16*L*

(Total for question = 1 mark)

Q5.

The photograph shows a filament bulb.



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

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

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

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

Your answer should include a calculation.

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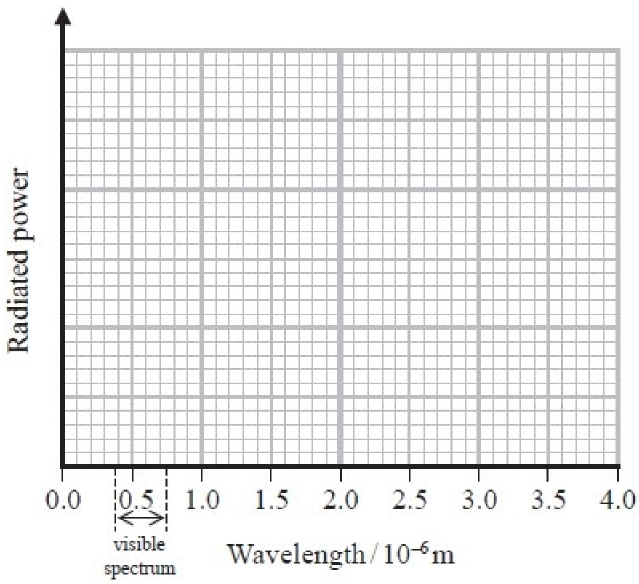

(ii) Use your graph to explain why filament light bulbs are considered inefficient.

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(Total for question = 7 marks)

Q6.

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

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

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

surface temperature of Sun = 5780 K
luminosity of Sun = 3.85×10^{26} W
radius of Sun = 6.96×10^{8} m

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

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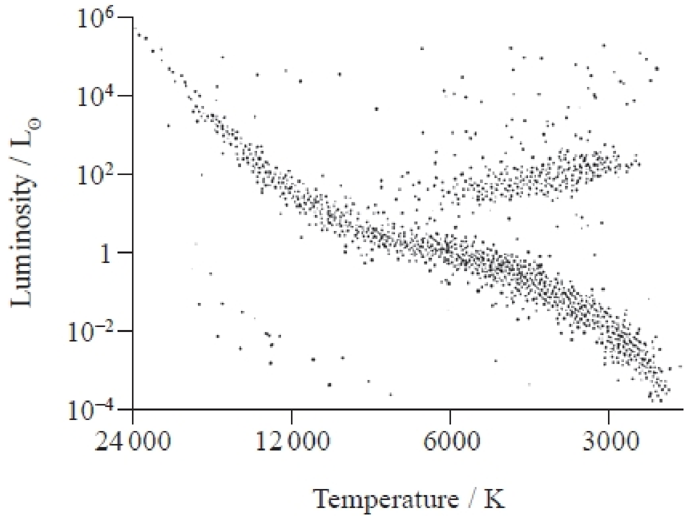
Wavelength = ...

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

(2)



Type of star ....

(Total for question = 7 marks)

Q7.

The light emitted from a star is due to the energy released by fusion reactions taking place in the core of the star. Our Sun is a main sequence star with a luminosity of 3.85×10^{26} W.

An analysis of the Sun's spectrum gives λ_{max} = 502 nm

Use the data provided to calculate the radius of the Sun.

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Radius of the Sun = ...

(Total for question = 4 marks)

Q8.

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

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

Assess the validity of this claim.

radius of Sun = 6.96×10^{8} m

surface temperature of Sun = 5790 K

distance from Sun to Earth = 1.50×10^{11} m

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(Total for question = 4 marks)

Q9.

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

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

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

(3)

distance to Proxima Centauri = 4.00×10^{16} m
$L_{\odot}$ = 3.85×10^{26} W

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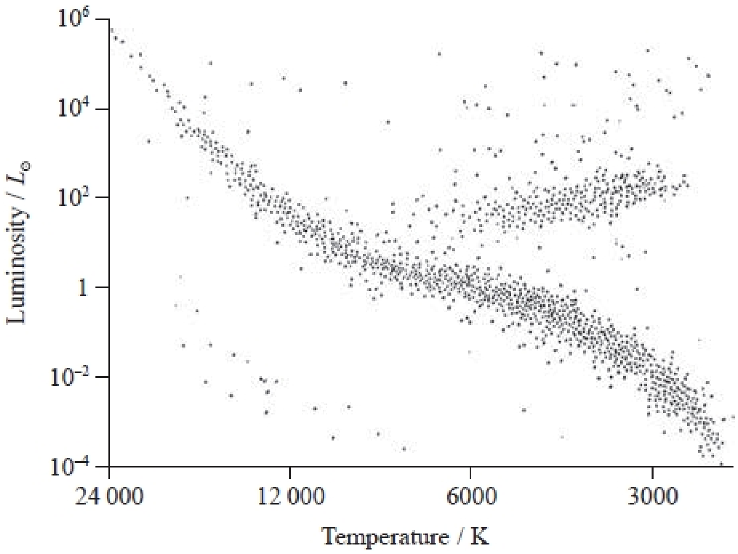
(ii) Proxima Centauri is described on a website as a main sequence star.

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

(3)

radius of Proxima Centauri = 9.81×10^7 m



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(Total for question = 3 marks)

Q10.

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

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

(1)

☐ **A** $\frac{L}{2}$

☐ **B** L

☐ **C** $4L$

☐ **D** $8L$

(Total for question = 1 mark)

Q11.

The photograph shows a filament bulb.

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

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

surface area of filament = 3.9×10^{-6} m^2

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Temperature = ...

(Total for question = 3 marks)

Mark Scheme – Blackbody Radiation

Q1.

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

Q2.

Question Number	Acceptable Answer		Additional Guidance	Mark
	• Use of $\lambda_{max}T = 2.898 \times 10^{-3}$ m K	(1)	Ignore references to the wavelength of red light	
	• $\lambda_{max} = 910$ nm	(1)		
	• Yes, because peak emission occurs at a wavelength close to 950 nm	(1)	Example of calculation: $\lambda_{max} = \frac{2.898 \times 10^{-3} \text{ m K}}{3200 \text{ K}} = 9.06 \times 10^{-7}$ m	3

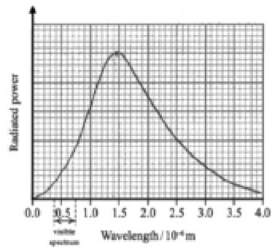
Q3.

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	
	• … with sensible temperature expressed in Kelvin	(1)		
	• E.g. $\lambda_{max} = 9.89 \times 10^{-6}$ m for 293 K	(1)	MP4 consistent with calculation	4
	• 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			

Q4.

Question Number	Acceptable answer	Additional guidance	Mark
	C	The only correct answer is C: luminosity is proportional to temperature^4 which means a 16-fold increase, and luminosity is proportional to area, which is proportional to diameter^2, and so means a 4-fold decrease, so there is a 4-fold increase overall A is not the correct answer because this only accounts for the decrease due to decreasing diameter B is not the correct answer because this is the answer obtained if the power applied to temperature is 2 instead of 4 D is not the correct answer because the effect of area is not included	1

Q5.

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)	<u>Example of calculation and graph</u> $\lambda_{max} \times 2026$ 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

Q6.

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 × 270 000 = 4 × π × 5.67×10^{-8} × $(1420 \times 6.96 \times 10^{8}\ \text{m})^2 \times T^4$ 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

Q7.

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

Q8.

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

Q9.

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} × 4π (9.81 × 10^7 m$)^2$ × T^4 $T = 3124$ K	3

Q10.

Question Number	Answer	Mark
	D - 8L	1
	Incorrect Answers: Correct method: ÷ 2 for area change and × 24 for temperature change A – only applies ÷ 2 for area change B – applies ÷ 2 for area change and × 2 for temperature change C – applies ÷ 1/2 for area change and × 2 for temperature change Or applies ÷ 2 for area change and × (2 × 4) for temperature change	

Q11.

Question Number	Acceptable answers	Additional guidance	Mark
	• Use of $P = IV$ (1) • Use of $L = A\sigma T^4$ (1) • $T = 1800$ K (1)	Example of calculation $P = 2.0$ V × 0.37 A = 0.74 W 0.74 W = 0.35 × 3.9 × 10^{-6} m^2 × 5.67 × 10^{-8} Wm^{-2}K^{-4} W × T^4 $T^4 = 9.56 \times 10^{12}$ K^4 $T = 1758$ K	3