B.1

Radiation from Stars

IB PHYSICS | ASTROPHYSICS

Luminosity vs Brightness

B.1

Luminosity	L	Brightness	b
Power Emitted		**Intensity**	
Watts [W]		W/m^2 or $W\ m^{-2}$	
		**Depends on the observer distance*	

Luminosity vs Brightness

B.1

B.1 Thermal energy transfers

$$\rho = \frac{m}{V}$$

$$\overline{E_k} = \frac{3}{2} k_B T$$

$$Q = mc\Delta T$$

$$Q = mL$$

$$\frac{\Delta Q}{\Delta t} = kA\frac{\Delta T}{\Delta x}$$

$L = \sigma A T^4$ ← Luminosity

$b = \frac{L}{4\pi d^2}$ ← Brightness

$$\lambda_{max} T = 2.9 \times 10^{-3} \text{mK}$$

Stefan-Boltzmann Law

B.1

$$L = \sigma A T^4$$

Luminosity (Power) [W]

$5.67 \times 10^{-8}\ W\ m^{-2}\ K^{-4}$

Surface Area [m^2]

Absolute Temperature [K]

Stefan-Boltzmann Constant	σ	$5.67 \times 10^{-8}\ W\ m^{-2}\ K^{-4}$

Surface Area?

The surface area of most objects (like stars) can be approximated as a sphere

$$L = \sigma A T^4$$

Surface Area [m^2]

$A_{sphere} = 4\pi r^2$

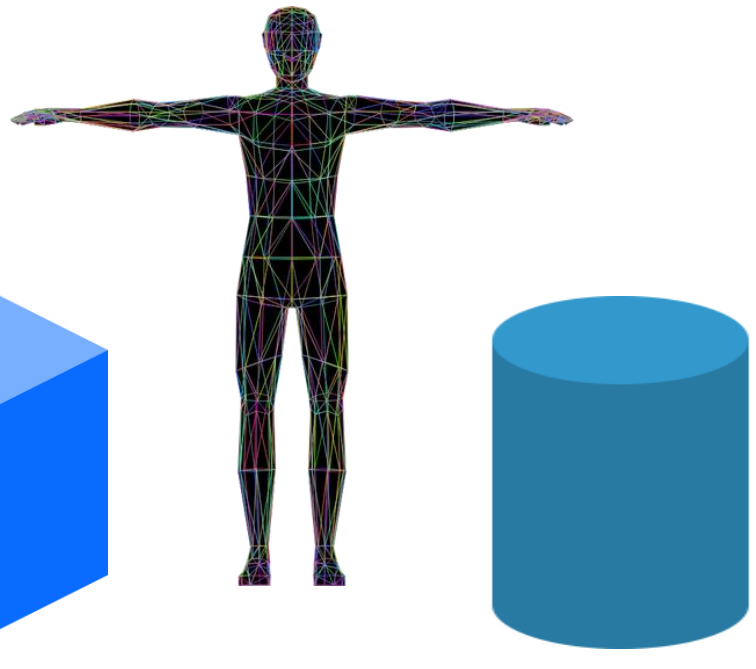
What if it isn't a sphere?

B.1

Any object can radiate energy as described by Stefan-Boltzmann's Law, just substitute in a different formula to calculate surface area ☺

$$L = \sigma A T^4$$

Surface Area [m^2]



Try This... | #1

A star has a radius of 8.3×10^7 m and a surface temperature of 7500°C. Calculate the power (luminosity) it emits.

$\sigma = 5.67 \times 10^{-8}$ W m^{-2} K^{-4}

$A = 4\pi(8.3 \times 10^7)^2 = 8.66 \times 10^{16}$ m^2

$T = 7500 + 273 = 7773$ K

$$L = \sigma A T^4$$

$$L = (5.67 \times 10^{-8})(8.66 \times 10^{16})(7773)^4$$

$$\boxed{L = 1.79 \times 10^{25}\ \mathbf{W}}$$

Proportionality

B.1

How much more heat energy is radiated from a 80°C cup of water than from a 20°C cup of water?

$$L = \sigma A T^4$$

**Careful! Temperature must be converted into Kelvin*

$$T_1 = 80 + 273 = 353\ \text{K}$$

$$T_2 = 20 + 273 = 293\ \text{K}$$

σ and A are all the same before and after…

$$\frac{P_1}{P_2} = \frac{\cancel{\sigma} \cancel{A} T_1^{\,4}}{\cancel{\sigma} \cancel{A} T_2^{\,4}} = \frac{353^4}{293^4} = 2.1\ times\ more$$

Apparent Brightness

B.1

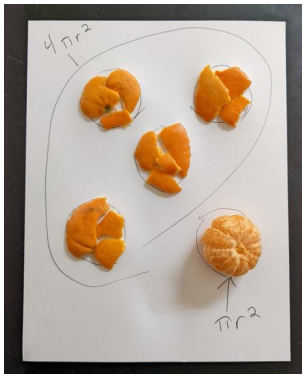
1. Roll up a piece of paper to make a tube that you can shine a cell phone flashlight through.
2. Aim the circle of light at a wall or a table and increase the distance the source is away from the “screen”.
3. Describe how this distance affects the light

- Area of the circle is larger
- Light is dimmer (less intense/bright)

Apparent Brightness

B.1

As light travels away from a point source it spreads out in a sphere in all directions so the area is that of the shell of this sphere with a radius equal to the distance from the source



Remember the surface area of a sphere?

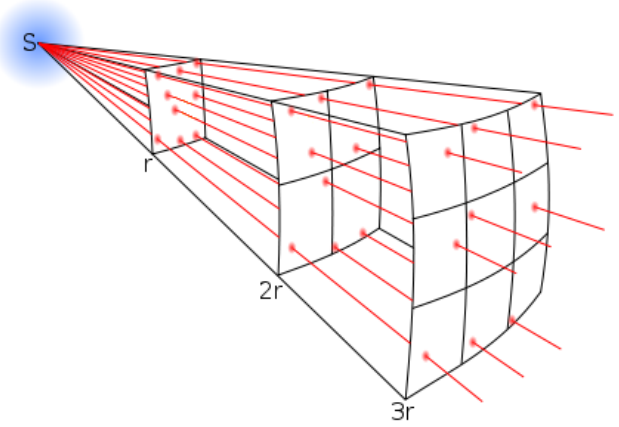
$$A_{sphere} = 4\pi r^2$$

Apparent Brightness

B.1

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

Distance from source



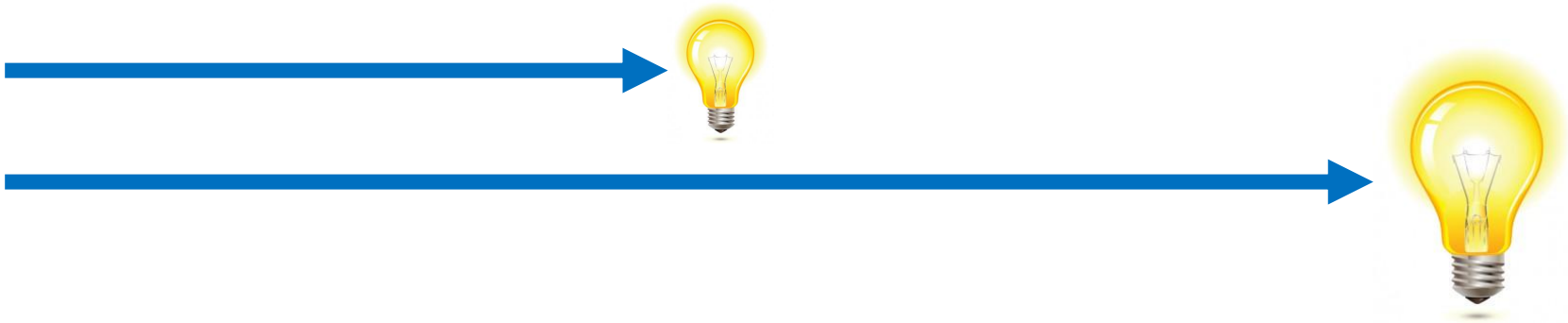
Inverse Square Law

Distance	Brightness
r	b
2r	b/4
3r	b/9
4r	b/16

Same Brightness, Different Stars

B.1

It is possible for stars to have the same brightness but have different distances and luminosities



Try This... | #2

B.1

The star Betelgeuse has an apparent brightness of 2.0×10^{-7} W m^{-2}. Calculate its luminosity.

d = 4.0×10^{18} m

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

$$L = (\mathrm{b})(4\pi d^2)$$

$$= (2.0 \times 10^{-7})(4\pi(4.0 \times 10^{18})^2)$$

$$= 4.0 \times 10^{31} \text{ W}$$

Number of Suns??

B.1

When quantifying the luminosity of a star it can be useful to describe the value by comparing it to the luminosity of the sun

Solar Luminosity	L_{sun}	$L_\odot$

$$L_\odot = 3.84 \times 10^{24}\ W$$

Try This… | #3

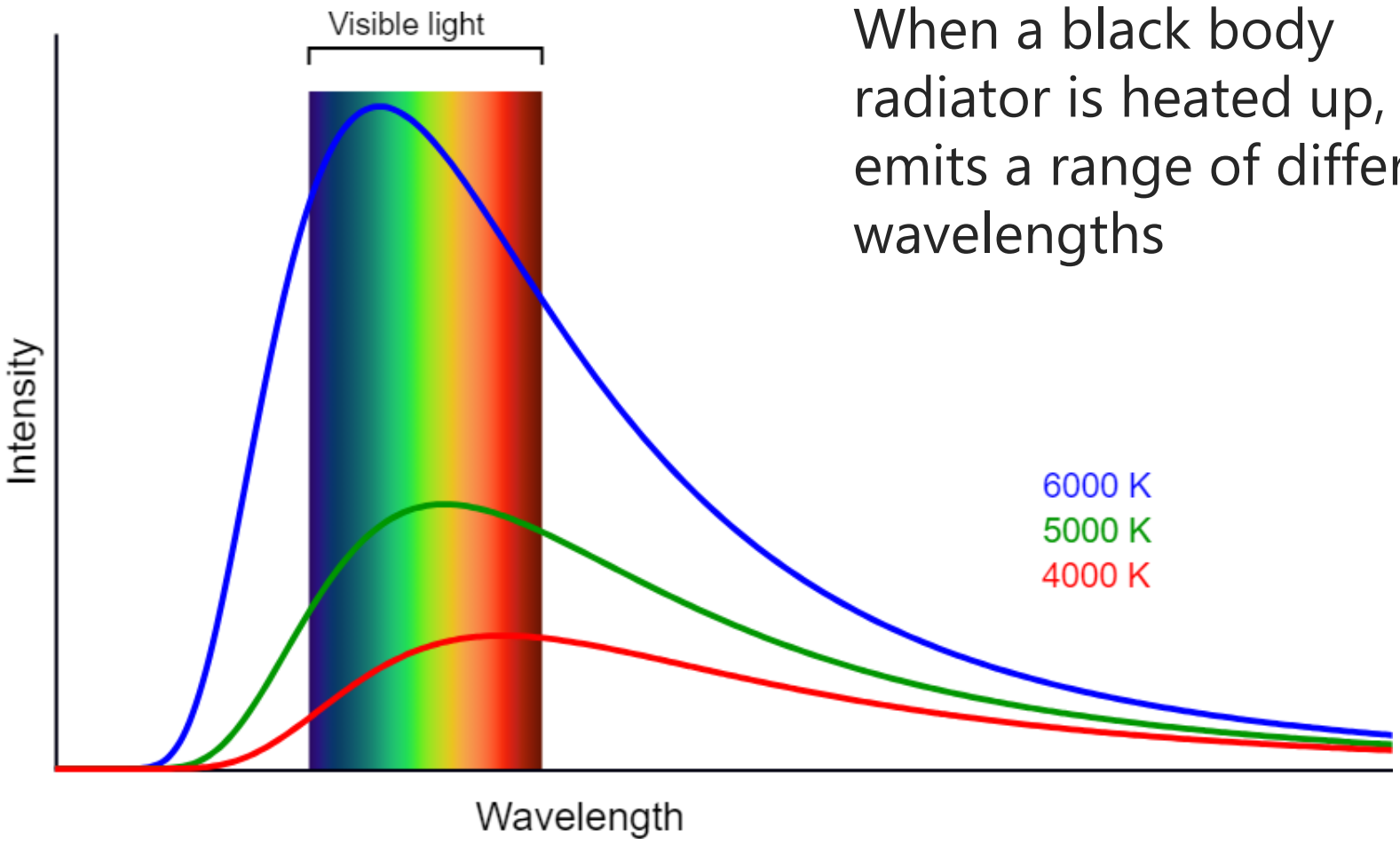
If the luminosity of Betelguese is 4.0×10^{31} W, what is the luminosity in terms of numbers of suns?

$L_\odot = 3.84 \times 10^{24}$ W

$$\frac{4.0 \times 10^{31}}{3.84 \times 10^{24}} = \mathbf{1.0 \times 10^{7} L_\odot}$$

Radiated Energy

B.1

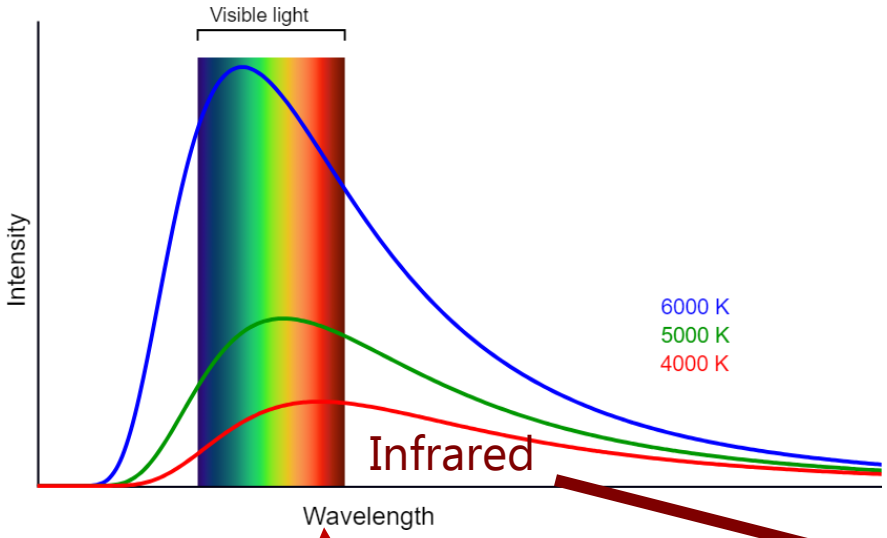


When a black body radiator is heated up, it emits a range of different wavelengths

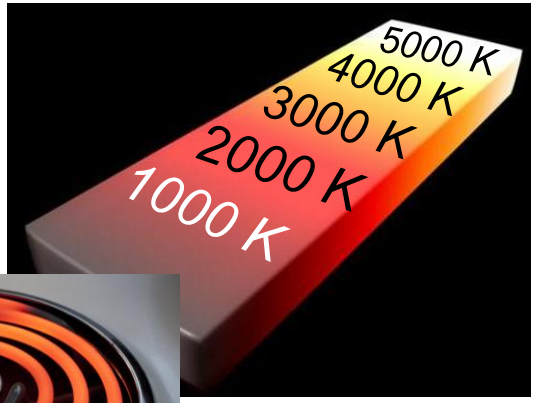
Glowing Hot

B.1

If the temperature is high enough the radiation that is emitted is in the visible spectrum

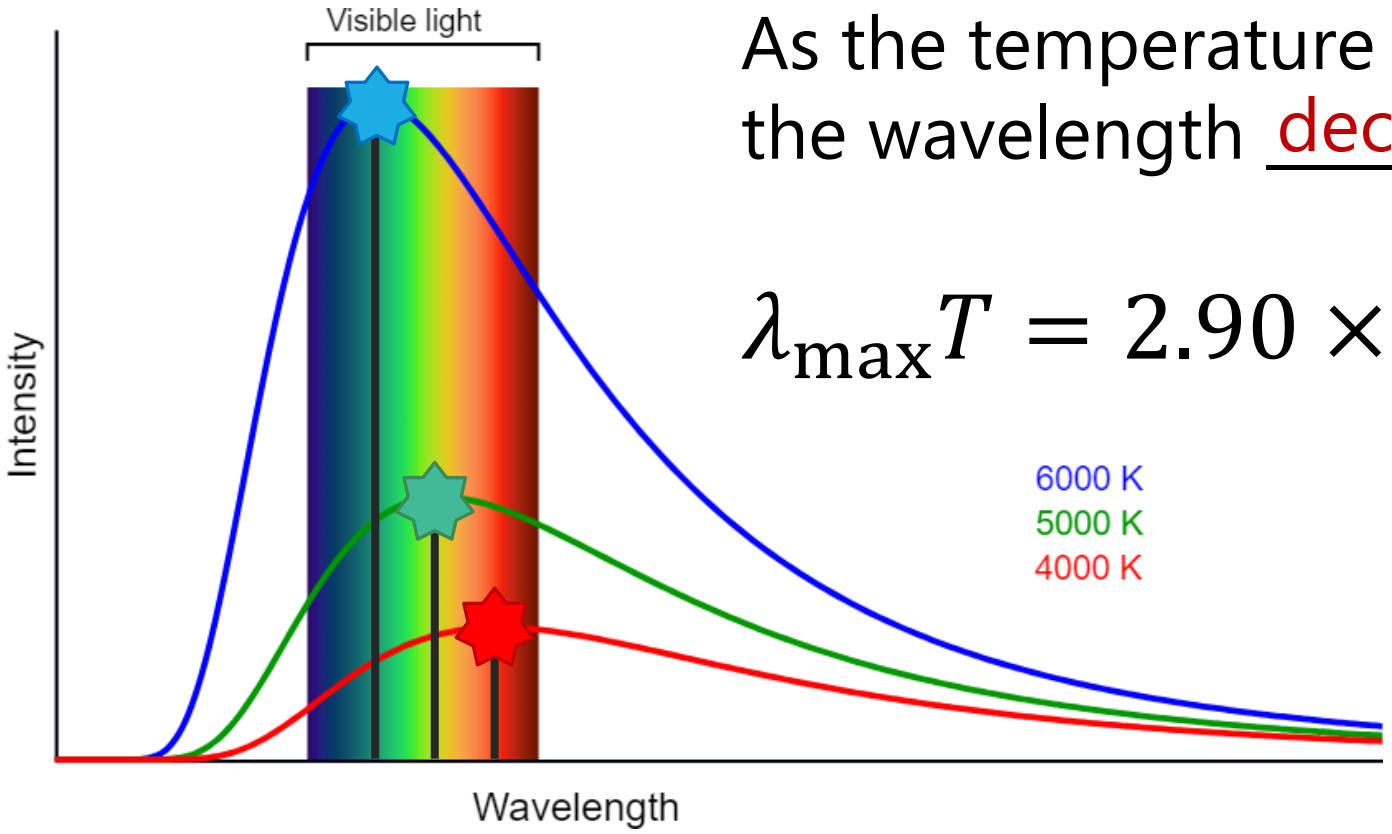


Visible
Red Light



Wien's Displacement Law

B.1



As the temperature increases, the wavelength decreases

$$\lambda_{\max} T = 2.90 \times 10^{-3}\ \mathrm{mK}$$

"meter Kelvin"

*Note: This assumes perfect blackbody radiation

Luminosity vs Brightness

B.1

B.1 Thermal energy transfers

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$L = \sigma A T^4$ ← Luminosity

$b = \frac{L}{4\pi d^2}$ ← Brightness

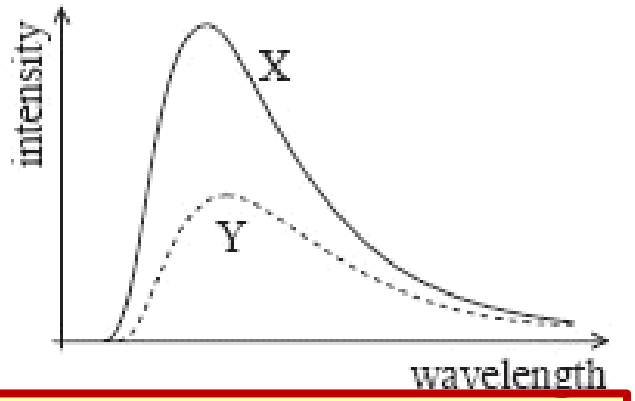
$\lambda_{max} T = 2.9 \times 10^{-3}\,\text{mK}$ ← Temperature

Sample IB Question

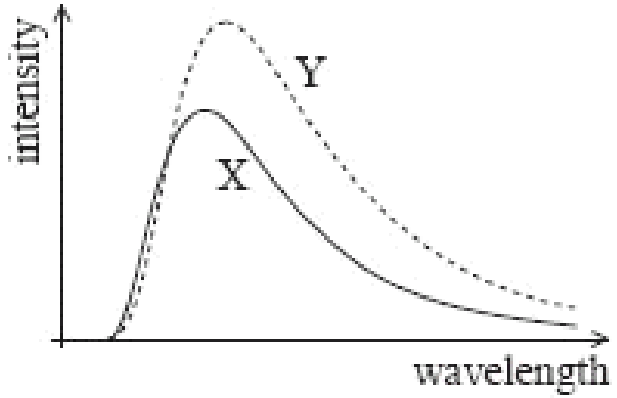
B.1

Two black bodies X and Y are at different temperatures. The temperature of body Y is higher than that of body X. Which of the following shows the black body spectra for the two bodies?

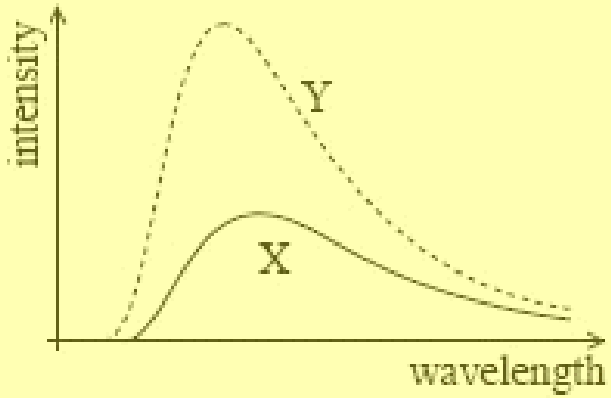
A.



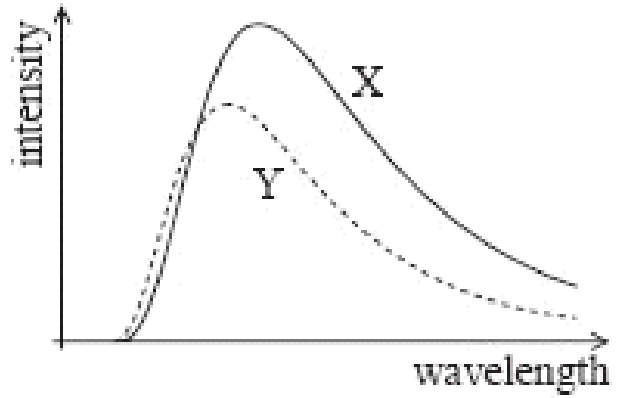
B.



C.



D.



Try This... | #4

B.1

The star Betelgeuse has a max wavelength of 828.6 nm.
What is its surface temperature?

828.6×10^{-9} m

$\lambda_{max} T = 2.90 \times 10^{-3}$ mK

Solve for T

$$T = \frac{2.90 \times 10^{-3}\ \text{mK}}{\lambda_{max}} = \frac{2.90 \times 10^{-3}\ \text{mK}}{828.6 \times 10^{-9}} = \boxed{3500\ \text{K}}$$

Remember Luminosity?

B.1

$$L = \sigma A T^4$$

Stefan-Boltzmann Constant	σ	$5.67 \times 10^{-8}\ W\ m^{-2}\ K^{-4}$

Luminosity
[W]

Temperature
[K]

Surface Area (sphere)
$A = 4\pi r^2$

Review | Calculating Luminosity

B.1

We can use the brightness and distance to determine a star's luminosity

*** We'll talk about where this distance measurement came from in Topic E.5*

Try This… | #2

B.1

The star Betelgeuse has an apparent brightness of 2.0×10^{-7} W m^{-2}. Calculate its luminosity.

d = 4.0×10^{18} m

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

$$L = (\text{b})(4\pi d^2)$$

$$= (2.0 \times 10^{-7})(4\pi(4.0 \times 10^{18})^2)$$

$$= 4.0 \times 10^{31} \text{ W}$$

Try This… | #5

B.1

Knowing the luminosity and temperature of Betelgeuse, calculate the average radius of the star.

L = 4.0×10^{31} W

T = 3,500 K

$$L = \sigma A T^4$$

Solve for r

$$4.0 \times 10^{31} = (5.67 \times 10^{-8})(4\pi r^2)(3500)^4$$

$$r = 6.12 \times 10^{11}$$

All together now!

B.1

Brightness (W m^{-2})	**1.2×10^{-7} W m^{-2}**
Max Wavelength (m)	**292×10^{-9} m**
Distance (m)	**8.14×10^{16} m**
Luminosity (W)	**9.98×10^{27} W**
Temperature (K)	**9930 K**
Radius (m)	**1.2×10^{9} m**

The brightest star in the sky is known as Sirius and has been measured to be approximately 8.14×10^{16} m from earth, has an apparent brightness of 1.2×10^{-7} W m^{-2}, and a max wavelength of 292 nm. Complete this table of stellar properties.

$b = \mathbf{1.2 \times 10^{-7}\ W\ m^{-1}}$

$\lambda = \mathbf{292 \times 10^{-9}\ m}$

$d = \mathbf{8.14 \times 10^{16}\ m}$

$L = (\mathrm{b})(4\pi d^2) = (1.2 \times 10^{-7})(4\pi(8.14 \times 10^{16})^2) = \mathbf{9.98 \times 10^{27}\ W}$

$$\mathrm{T} = \frac{2.90 \times 10^{-3}\ \mathrm{mK}}{\lambda_{\max}} = \frac{2.90 \times 10^{-3}\ \mathrm{mK}}{292 \times 10^{-9}} = \mathbf{9930\ K}$$

$L = \sigma A T^4$ $\quad 9.98 \times 10^{27} = (5.67 \times 10^{-8})(4\pi r^2)(9930)^4$

$r = \mathbf{1.2 \times 10^{9}\ m}$

Lesson Takeaways

B.1

- ❑ I can define and compare the properties of luminosity and brightness
- ❑ I can calculate luminosity using Stefan-Boltzmann's Law
- ❑ I can calculate the surface area of a sphere
- ❑ I can describe and calculate how the brightness changes based on the distance from a source
- ❑ I can determine the temperature of a hot object based on the peak wavelength emitted
- ❑ I can use brightness, peak wavelength, and distance to calculate temperature, luminosity, and radius for a star