Synoptic link

You can refresh your memory by looking back to Topic 18.2, Newton's law of gravitation.

Wien's displacement law and Stefan's law can be used together to estimate the radius of a distant star. Once the radius is known, the mass and density of the star can be determined using Newton's law of gravitation. It is amazing what you can do just by analysing starlight.

Worked example: Radius of a star

The peak wavelength of radiation emitted by our Sun is about 500 nm, its surface temperature is 5800 K, and its luminosity is 3.85×10^{26} W. The peak wavelength emitted by a nearby star with a luminosity 10 times that of our Sun is 310 nm. Show that the radius of this star is approximately 840 000 km.

Step 1: To determine the surface temperature of the star use Wien's displacement law.

$\lambda_{max} T = \text{constant}$

$$\underbrace{500 \times 10^{-9} \times 5800}_{\text{Sun}} = \underbrace{310 \times 10^{-9} \times T_{Star}}_{\text{Star}}$$

Therefore

$$T_{Star} = \frac{500 \times 10^{-9} \times 5800}{310 \times 10^{-9}} = 9355\,\text{K}$$

Step 2: Use Stefan's law to determine the radius of the star.

$L = 4\pi r^2 \sigma T^4$, therefore $r = \sqrt{\frac{L}{4\pi\sigma T^4}}$

The luminosity L of the star is $10 \times 3.85 \times 10^{26}$ W

$$r = \sqrt{\frac{10 \times 3.85 \times 10^{26}}{4\pi \times 5.67 \times 10^{-8} \times 9355^4}}$$

$r = 8.399... \times 10^8$ m = 840 000 km (2 s.f.)

Summary questions

1 State the SI unit for the luminosity of a star. *(1 mark)*

2 Use the data in Table 1 to show that $\lambda_{max} \propto \frac{1}{T}$. *(3 marks)*

3 The peak wavelength emitted by a red supergiant is 0.94 μm. Determine the surface temperature of the star. *(3 marks)*

4 Using Stefan's law, compare the luminosity of one star with another that has:
   a double the surface temperature and the same radius;
   b double the radius and half the surface temperature;
   c half the mass, the same density, and three times the surface temperature. *(6 marks)*

5 The Sun has a radius of approximately 700 000 km and a surface temperature of 5800 K. Calculate the energy radiated by the Sun during one year. *(3 marks)*

6 The peak wavelength emitted by a distant star with a luminosity of 4.85×10^{31} W is measured as 305 nm using a diffraction grating. Calculate the radius of this star. *(5 marks)*