Edexcel International A Level (IAL) Physics

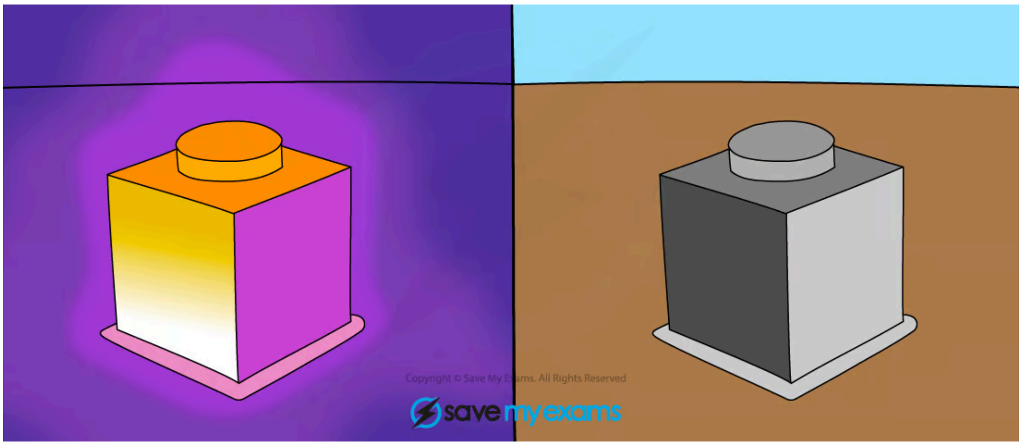
Black Body Radiation

Your notes

Contents

Black Body Radiation

- Black body radiation is the name given to the **thermal radiation** emitted by all bodies (objects)
- All objects, no matter what temperature, emit black body radiation in the form of electromagnetic waves
- These electromagnetic waves usually lie in the **infrared** region of the spectrum but could be emitted in the form of visible light or other wavelengths, depending on the temperature
- The **hotter** object, the **more** infrared radiation it radiates in a given time



The infrared emitted from a hot object can be detected using a special camera

- A perfect black body is defined as:

  An object that absorbs (or emits) all of the radiation incident on it and does not reflect or transmit any radiation

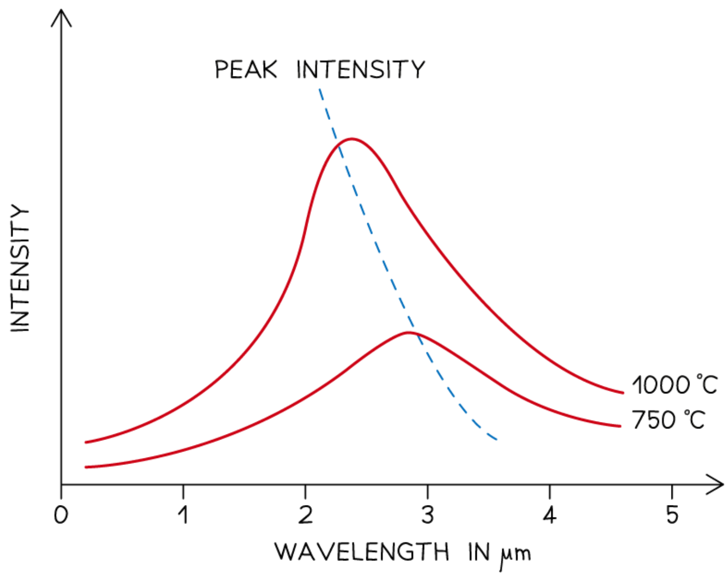
- Since a good absorber is also a good emitter, a perfect black body would be the best possible emitter too
- As a result, an object which perfectly absorbs all radiation will be black
  - This is because the colour black is what is seen when **all** colours from the visible light spectrum are absorbed

Absorption and Emission For Different Colours Table

Colour	Absorbing	Emitting
Black	Good absorber	Good emitter
Dull/Dark	Reasonable absorber	Reasonable emitter
White	Poor absorber	Poor emitter
Shiny	Very poor absorber (Therefore a good reflector)	Very poor emitter

Black Body Radiation Curves

- All bodies (objects) emit a spectrum of thermal radiation in the form of electromagnetic waves
- The **intensity** and **wavelength** distribution of any emitted waves depends on the **temperature** of the body
- This is represented on a black body radiation curve
    - As the temperature increases, the peak of the curve moves

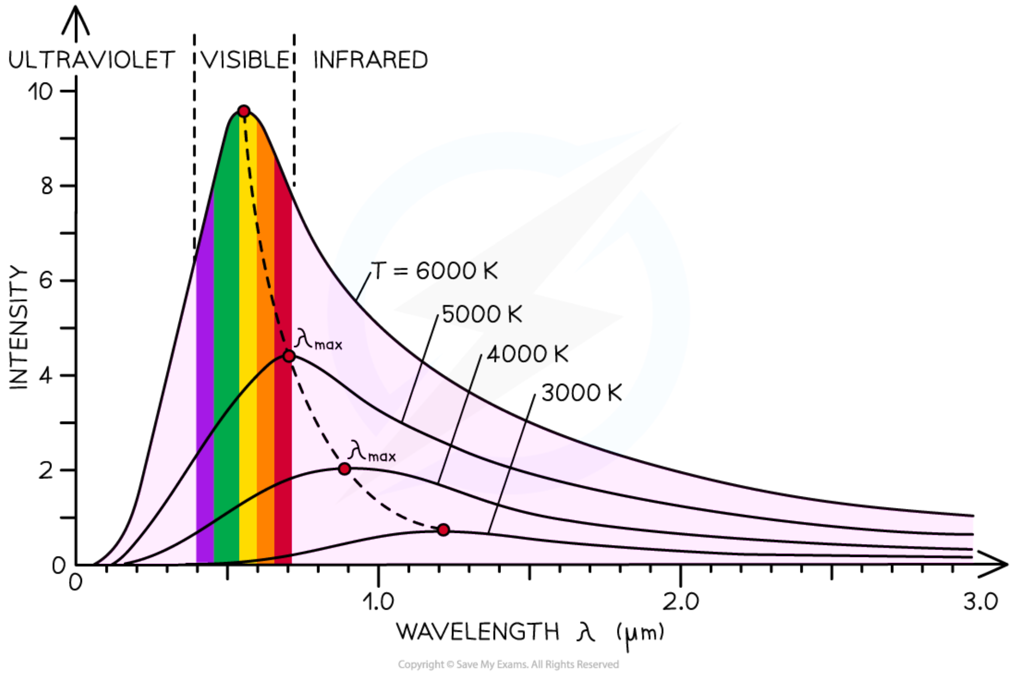


Black body spectrum for objects of different temperatures

- From the electromagnetic spectrum, waves with a **smaller** wavelength have **higher** energy (e.g. UV rays, X-rays)
- When an object gets hotter, the amount of **thermal radiation** it emits increases

- This increases the thermal energy emitted and therefore the **wavelength** of the emitted radiation **decreases**

- An ideal black body radiator is one that **absorbs and emits all wavelengths**
  - This idealised black body is a theoretical object
  - However, **stars** are the best approximation there is
- The radiation emitted from a black body has a **characteristic spectrum** that is determined by the temperature alone



The intensity–wavelength graph shows how thermodynamic temperature links to the peak wavelength for four different bodies

Your notes

Stefan-Boltzmann Law

- An objects luminosity depends on two factors:
  - Its surface temperature
  - Its surface area
- The relationship between these is known as the **Stefan-Boltzmann Law**, which states:

  The total energy emitted by a black body per unit area per second is proportional to the fourth power of the absolute temperature of the body

- So, $L \propto AT^4$
- The Stefan-Boltzmann Law equation is:

$$L = \sigma AT^4$$

- Where:
  - L = luminosity of the star (W)
  - A = surface area of the star
  - σ = the Stefan-Boltzmann constant
  - T = surface temperature of the star (K)
- The surface area of a star (or other spherical object) can be calculated using:

$$A = 4\pi r^2$$

- Where:
  - r = radius of the star

Worked Example

A camel has a body temperature of 40°C and a surface area of 16 m^2. The peak wavelength of the emitted spectrum from the camel is $\lambda_{max} = 8.6 \times 10^{-6}$ m. Calculate the total power radiated by the camel.

Answer:

Step 1: List the known quantities

- Surface area, $A = 16\ m^2$
- Temperature (in K), $T = 40 + 273 = 313$ K
- Stefan-Boltzmann constant, $\sigma = 5.67 \times 10^{-8}\ W\ m^{-2}\ K^{-4}$

Step 2: Write down the Stefan-Boltzmann equation

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

Step 3: Substitute in the values

$$L = (5.67 \times 10^{-8}) \times 16 \times 313^4 = 8707 \text{ W}$$

Step 4: Write the answer to correct significant figures and include units

Luminosity (power emitted) of the camel = 8700 W (2 s.f.)

Your notes

Examiner Tips and Tricks

Remember to convert temperatures into Kelvin.

If you are given the radius of a spherical object then its surface area A can be calculated using $\mathbf{A = 4\pi r^2}$ for the radius of the object r.

Wien's Law

- Wien's displacement law relates the observed wavelength of light from an object to its surface temperature, it states:

  The black body radiation curve for different temperatures peaks at a wavelength that is inversely proportional to the temperature

- This relation can be written as:

$$\lambda_{max} \propto \frac{1}{T}$$

- λ_{max} is the maximum wavelength (m) emitted by an object at the peak intensity
- T is the surface temperature (K) of an object
- Wien's Law equation is given by:

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

- This equation tells us the higher the temperature of a body:
  - The shorter the wavelength at the peak intensity, so **hotter** objects tend to be **white or blue,** and **cooler** objects tend to be **red or yellow**
  - The greater the intensity of the radiation at each wavelength

Table to compare surface temperature and star colour

Colour of star	Temperature / K
blue	> 33 000
blue–white	10 000 – 30 000
white	7 500 – 10 000
yellow–white	6 000 – 7 500
yellow	5 000 – 6 000
orange	3 500 – 5 000
red	< 3 500

Worked Example

The spectrum of the star Rigel in the constellation of Orion peaks at a wavelength of 263 nm, while the spectrum of the star Betelgeuse peaks at a wavelength of 828 nm. Which of these two stars is cooler, Betelgeuse or Rigel?

Answer:

Step 1: Write down Wien's displacement law

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

Step 2: Rearrange for temperature T

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

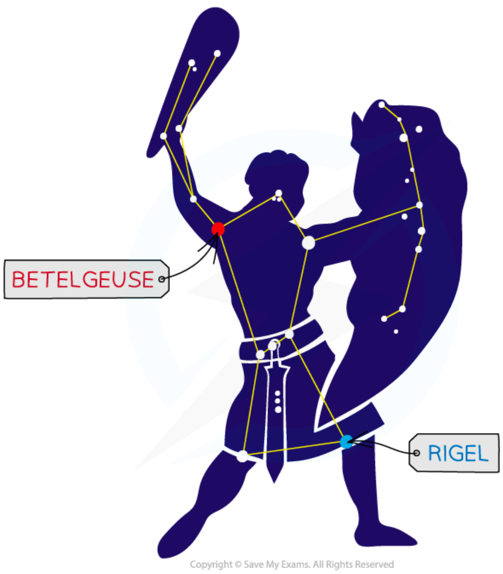
Step 3: Calculate the surface temperature of each star

$$\text{Rigel: } T = \frac{2.9 \times 10^{-3}}{\lambda_{max}} = \frac{2.9 \times 10^{-3}}{263 \times 10^{-9}} = 11026 = \mathbf{11\,000\ K}$$

$$\text{Betelguese: } T = \frac{2.9 \times 10^{-3}}{\lambda_{max}} = \frac{2.9 \times 10^{-3}}{828 \times 10^{-9}} = 3502 = \mathbf{3\,500\ K}$$

Step 4: Write a concluding sentence

Betelgeuse has a surface temperature of 3500 K, therefore, it is much cooler than Rigel



The Orion Constellation; cooler stars, such as Betelguese, appear red or yellow, while hotter stars, such as Rigel, appear white or blue

Your notes

Examiner Tips and Tricks

Note that the temperature used in Wien's Law is in **Kelvin** (K). Remember to convert from °C if the temperature is given in degrees in the question before using the Wien's Law equation.