A LEVEL PHYSICS 9702 · A LEVEL · TOPIC 25 · ~4 MIN READ

Astronomy and cosmology

Luminosity and radiant flux intensity, standard candles, Wien's displacement law and the Stefan–Boltzmann law to find stellar temperatures and radii, redshift, Hubble's law and the evidence for an expanding universe.

Luminosity | Radiant flux intensity $F = L/4\pi d^2$ | Standard candles | Wien's law | Stefan–Boltzmann law | Stellar radius | Redshift $\Delta\lambda/\lambda = v/c$ | Hubble's law

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Paper tag = **where it is examined** DATA & FORMULAE given in the exam C1 A1 B1 how marks are awarded

highlight = comes up again and again Test yourself at the end

IN 30 SECONDS

- **Luminosity L** is the total power a star emits. At distance d, the radiant flux intensity is $F = L/(4\pi d^2)$: an inverse-square law.
- **Standard candles** (Cepheid variables, type 1a supernovae) have known luminosity, so measuring F gives d.
- **Wien's law $\lambda_{max}T = 2.9 \times 10^{-3}$ m K gives T; Stefan–Boltzmann $L = 4\pi\sigma r^2T^4$ then gives the radius r.**
- **Redshift $\Delta\lambda/\lambda \approx v/c$.** Distant galaxies are receding, and Hubble's law $v = H_o d$ shows the universe is expanding: evidence for the Big Bang.

BY THE END YOU CAN

- Define luminosity and radiant flux intensity, and use $F = L/(4\pi d^2)$.
- Understand standard candles and use them to find distances.
- Use Wien's law and the Stefan–Boltzmann law to find surface temperatures and radii of stars.
- Use $\Delta\lambda/\lambda \approx \Delta f/f \approx v/c$ and Hubble's law, and explain the evidence for an expanding universe.

1 Luminosity and distance

The inverse-square law

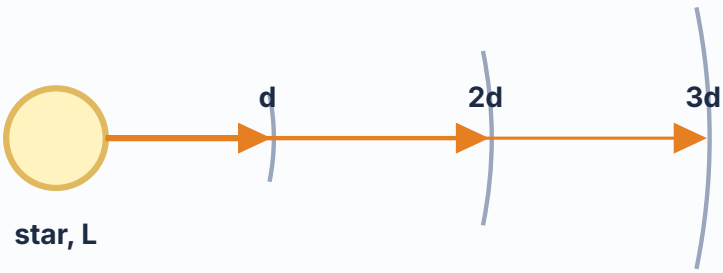
Luminosity — the total radiant power emitted by a star.

Radiant flux intensity — the radiant power passing normally through unit area.

Standard candle — an astronomical object of known luminosity.

$$F = L/(4\pi d^2)$$

d from a standard candle: $d = \sqrt{(L/(4\pi F))}$



$b = L/(4\pi d^2)$

double d:

b falls to ¼

triple d: 1/9

The same power spreads over a sphere of area $4\pi d^2$.

WORKED EXAMPLE

The Sun's luminosity is 3.83×10^{26} W and it is 1.50×10^{11} m away. Find the radiant flux intensity at the Earth.

1. $F = 3.83 \times 10^{26}/(4\pi \times (1.50 \times 10^{11})^2)$ C1
2. **$F = 1.35 \times 10^{3}$ W m^{-2}** A1

WORKED EXAMPLE

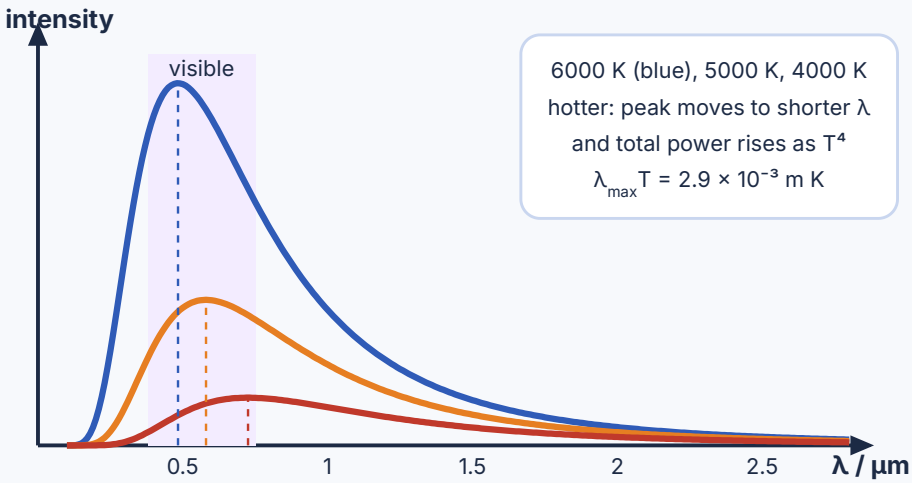
A Cepheid of luminosity 1.0×10^{30} W gives $F = 2.0 \times 10^{-12}$ W m^{-2} at the Earth. Find its distance.

1. $d = \sqrt{(L/(4\pi F))} = \sqrt{(1.0 \times 10^{30}/(4\pi \times 2.0 \times 10^{-12}))}$ C1
2. **$d = 2.0 \times 10^{20}$ m** A1

Riyaz Sir

2 Stellar temperatures and radii

Wien and Stefan–Boltzmann



Hotter bodies peak at shorter wavelengths and emit much more power.

$$\lambda_{max}\, T = 2.9 \times 10^{-3}\ \text{m K} \ ; \ L = 4\pi\sigma r^2 T^4$$ DATA & FORMULAE

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

WORKED EXAMPLE

A star's spectrum peaks at 350 nm and its luminosity is 4.0×10^{28} W. Find its surface temperature and radius.

1. $T = 2.9 \times 10^{-3} / 350 \times 10^{-9} =$ **8300 K** C1 A1
2. $r = \sqrt{(L/(4\pi\sigma T^4))} = \sqrt{(4.0 \times 10^{28}/(4\pi \times 5.67 \times 10^{-8} \times 8290^4))}$ C1
3. **$r = 3.5 \times 10^9$ m** A1

COMMON MISTAKE

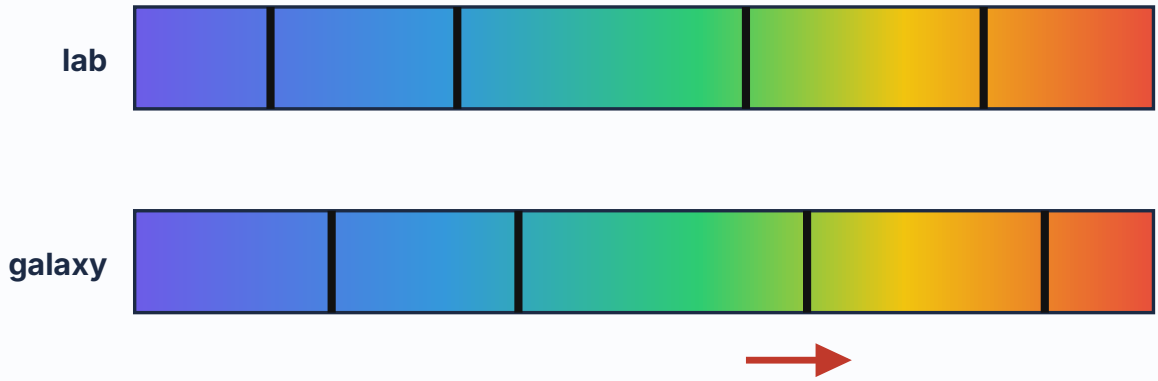
Using the Celsius temperature or forgetting the fourth power. A small error in T is magnified four times in L.

3 The expanding universe

Redshift and Hubble's law

$$\Delta\lambda/\lambda \approx \Delta f/f \approx v/c \ ; \ v = H_0 d$$

for v much less than c



Lines shifted to longer wavelength: the galaxy is moving away (redshift).

Absorption lines from a receding galaxy are shifted to longer wavelengths.

WORKED EXAMPLE

A hydrogen line emitted at 656.3 nm is observed at 669.4 nm from a galaxy. Find its recession speed and its distance ($H_o = 2.3 \times 10^{-18}$ s^{-1}).

1. $v = c\,\Delta\lambda/\lambda = 3.00 \times 10^8 \times 13.1/656.3 =$ **6.0×10^6 m s^{-1}** C1 A1
2. **$d = v/H_o = 2.6 \times 10^{24}$ m** A1

- **Evidence for the Big Bang:** all distant galaxies are redshifted, and $v \propto d$, so the universe is expanding; running it backwards suggests it began from a very hot, dense state.
- **Age estimate:** $1/H_o \approx 4.3 \times 10^{17}$ s ≈ 14 billion years (ignoring changes in the expansion rate).

COMMON MISTAKE

"Galaxies move away from us because we are at the centre". Every observer sees the same recession: space itself is expanding.

LINKING QUESTION

Photons and spectra are in Quantum physics; the Doppler effect for sound is in Waves; and gravity is in Gravitational fields.

Test yourself — cover the answers first

QUICK CHECK

1. Define luminosity.
2. What is a standard candle?
3. A star's temperature doubles at the same radius. By what factor does L change?
4. Does redshift mean a source is approaching or receding?
5. State Hubble's law.

EXAM-STYLE

6. Two stars have the same luminosity; star A appears 9 times brighter than B. Compare their distances.
7. Find λ_max for a star at 3500 K.
8. Estimate the age of the universe in years if $H_o = 2.3 \times 10^{-18}$ s^{-1}.

Show answers

1. the total power radiated by a star
2. an object of known luminosity
3. 16
4. receding
5. recession speed is proportional to distance, $v = H_o d$
6. $F \propto 1/d^2$, so B is 3 times as far as A
7. 8.3×10^{-7} m (red/infrared)
8. $1/H_o = 4.3 \times 10^{17}$ s $\approx 1.4 \times 10^{10}$ years

Stuck on a question?

Send it to me on WhatsApp. I read every message.

Want regular help? Send this to your parent →

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