

Astronomy and cosmology

A-Level Physics 9702 · Topic 25 revision notes · A2

Measuring the Universe: luminosity, flux and standard candles for distance, Wien's and Stefan-Boltzmann laws for stellar radii, and redshift with Hubble's law for an expanding Universe.

9 definitions to learn word for word, 8 equations in their own column, 6 diagrams and graphs. Read it, cover it, test yourself.

1. 25.1 Standard candles
2. 25.2 Stellar radii
3. 25.3 Hubble's law and the Big Bang theory

Definitions (mark-scheme wording) Equations Exam traps

25.1 Standard candles

Definitions

Luminosity (L): the total power of electromagnetic radiation emitted by a star.

Radiant flux intensity (F): the radiant power passing normally through unit area (at the observer).

Standard candle: an astronomical object of known luminosity (e.g. a Cepheid variable star or a type Ia supernova).

Equations

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

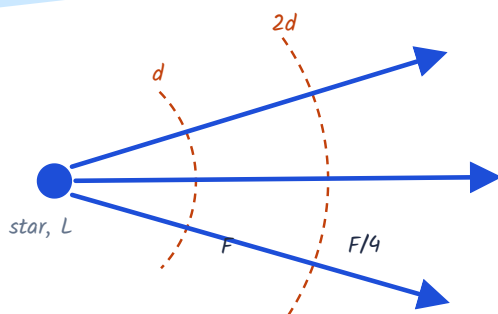
radiant flux intensity at distance d
 W m^{-2}

$$d = \sqrt{L / 4\pi F}$$

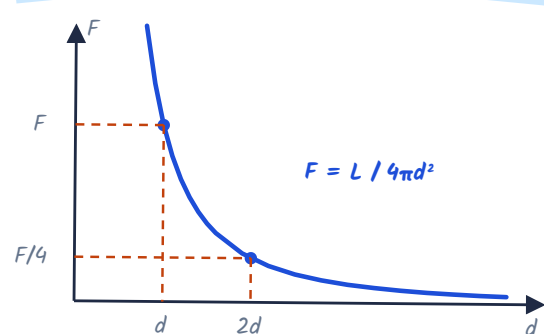
distance to a standard candle
 m

Key points

- ✓ Radiation spreads out over a sphere of area $4\pi d^2$, so flux obeys an **inverse-square law**.
- ✓ Luminosity is **intrinsic** to the star; flux depends on luminosity **and** distance.
- ✓ Distance method: know L (standard candle), measure F , then $d = \sqrt{L / 4\pi F}$.
- ✓ **Cepheid variables:** pulsation period is linked to luminosity; useful to $\sim 10^7$ pc (nearby galaxies).
- ✓ **Type Ia supernovae:** very bright, nearly equal peak luminosity; reach distant galaxies.
- ✓ Assumes no absorption of radiation between the star and Earth.



Inverse-square law: the same power L spreads over spheres of area $4\pi d^2$, so doubling d quarters F .



Flux against distance: $F \propto 1/d^2$ for a source of fixed luminosity.

Watch out!

- ! A dim star may be **distant**, not low-luminosity: F depends on both L and d .
- ! Use $4\pi d^2$ (sphere area), not πd^2 , and d in metres.

25.2 Stellar radii

Definitions

Wien's displacement law: the wavelength at which a black body emits maximum power is inversely proportional to its thermodynamic temperature: $\lambda_{\max} \propto 1/T$.

Stefan-Boltzmann law: the power radiated by a black body is proportional to its surface area and to the fourth power of its thermodynamic temperature.

Black body: an idealised object that absorbs all incident radiation and emits a continuous spectrum depending only on its temperature.

Equations

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

Wien's displacement law

m K

$$L = 4\pi\sigma r^2 T^4$$

Stefan-Boltzmann law for a star; $\sigma = 5.67 \times 10^{-8} \text{ W m}^{-2} \text{ K}^{-4}$

W

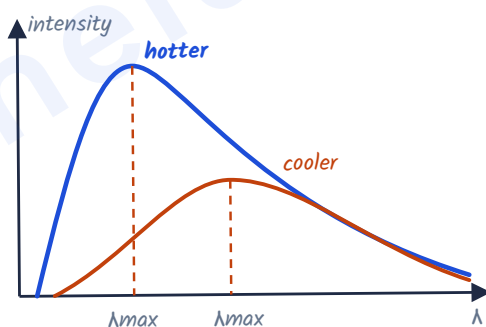
$$r = \sqrt{L / 4\pi\sigma T^4}$$

radius of a star

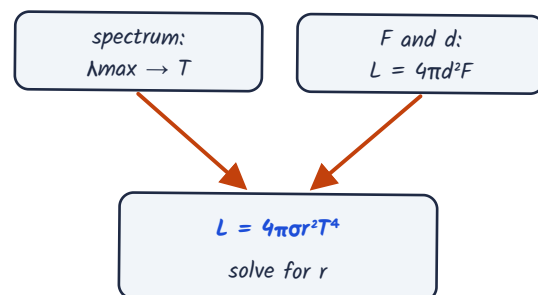
m

Key points

- ✓ Treat stars as **black bodies**: the spectrum shape depends only on surface temperature.
- ✓ Hotter star: peak at **shorter λ** (bluer), and more power at every wavelength.
- ✓ Step 1: measure $\lambda_{\max}$ from the spectrum, use Wien's law to find T .
- ✓ Step 2: find L (e.g. from F and d). Step 3: $r = \sqrt{L / 4\pi\sigma T^4}$.
- ✓ Two stars of the same T but different L : the more luminous one is **larger** (e.g. red giant vs red dwarf).
- ✓ T must be in **kelvin**.



Black-body curves: the hotter star is higher at every λ and peaks at a shorter $\lambda_{\max}$ (Wien's law).



Finding a stellar radius: spectrum gives T (Wien), flux and distance give L , then Stefan-Boltzmann gives r .

Watch out!

- ! $L \propto T^4$: doubling T multiplies L by **16** (same radius).
- ! Temperature in **kelvin**; $\lambda_{\max}$ in metres (not nm) with the $2.9 \times 10^{-3} \text{ m K}$ constant.

25.3 Hubble's law and the Big Bang theory

Definitions

Redshift: the increase in the observed wavelength (decrease in frequency) of electromagnetic radiation from a source moving away from the observer.

Hubble's law: the recession speed of a galaxy is (approximately) proportional to its distance from the Earth.

Big Bang theory: the Universe began from a single point (very hot and dense) and has been expanding ever since.

Equations

$$\Delta\lambda/\lambda \approx \Delta f/f \approx v/c$$

redshift for $v \ll c$

no unit

$$v \approx H_0 d$$

Hubble's law; H_0 = Hubble constant

m s^{-1}

$$t \approx 1/H_0$$

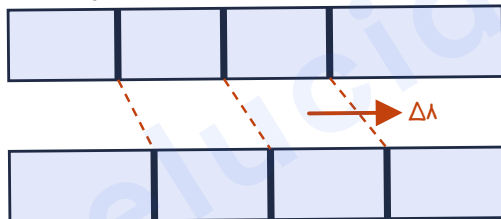
estimated age of the Universe (H_0 in s^{-1})

s

Key points

- ✓ Spectral lines from distant galaxies are shifted to **longer wavelengths** compared with the same lines in the lab.
- ✓ For $v \ll c$, the fractional shift gives the **recession speed** (Doppler effect).
- ✓ Almost all galaxies are redshifted: they are **moving away** from us.
- ✓ Further galaxies show **greater redshift**: $v \propto d$ (Hubble's law).
- ✓ Distances come from **standard candles**; speeds from redshift.
- ✓ Hubble's law implies the **Universe is expanding**; running it backwards gives the Big Bang.
- ✓ Age of the Universe $\approx 1/H_0$ (assumes constant expansion rate), about 1.4×10^{10} years.

laboratory

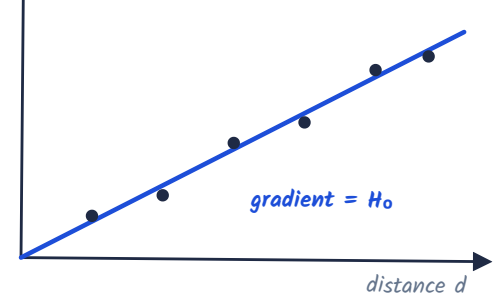


distant galaxy
blue

red

Absorption lines from a receding galaxy (bottom) are shifted towards the red end compared with the laboratory lines (top).

recession speed v



Hubble's law: recession speed against distance is a straight line through the origin; gradient = H_0 .

Watch out!

- ! For the age $1/H_0$, convert H_0 to s^{-1} first (from $\text{km s}^{-1} \text{Mpc}^{-1}$; $1 \text{ Mpc} = 3.09 \times 10^{22} \text{ m}$).
- ! Redshift is an **increase** in wavelength; $\Delta\lambda = \text{observed} - \text{emitted}$, divided by the **emitted** λ .
- ! Galaxies are not flying through space from a centre: **space itself expands**, and every observer sees the same law.