Astronomy & cosmology

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25 Astronomy and cosmology

25.1 Standard candles

Candidates should be able to:

1. understand the term luminosity as the total power of radiation emitted by a star
2. recall and use the inverse square law for radiant flux intensity F in terms of the luminosity L of the source $F = L / (4\pi d^2)$
3. understand that an object of known luminosity is called a standard candle
4. understand the use of standard candles to determine distances to galaxies

1. Luminosity:

Concept: All stars emit radiations in all directions. These are transverse unpolarised radiations of multiple wavelengths. So Luminosity is the total Power output of radiations emitted by a star.

Def. Total amount of energy of all wavelengths emitted by a star per unit time.

Symbol: L

Units: Watt (W) , Js^{-1}

P.S. Scalar

Dependance: Luminosity of a star depends upon

(i) temperature at its surface :

(Luminosity) ↑ as (temperature) ↑

i.e. As a star gets hotter, the number of Nuclear reactions increases. So more energy is radiated by it per unit time.

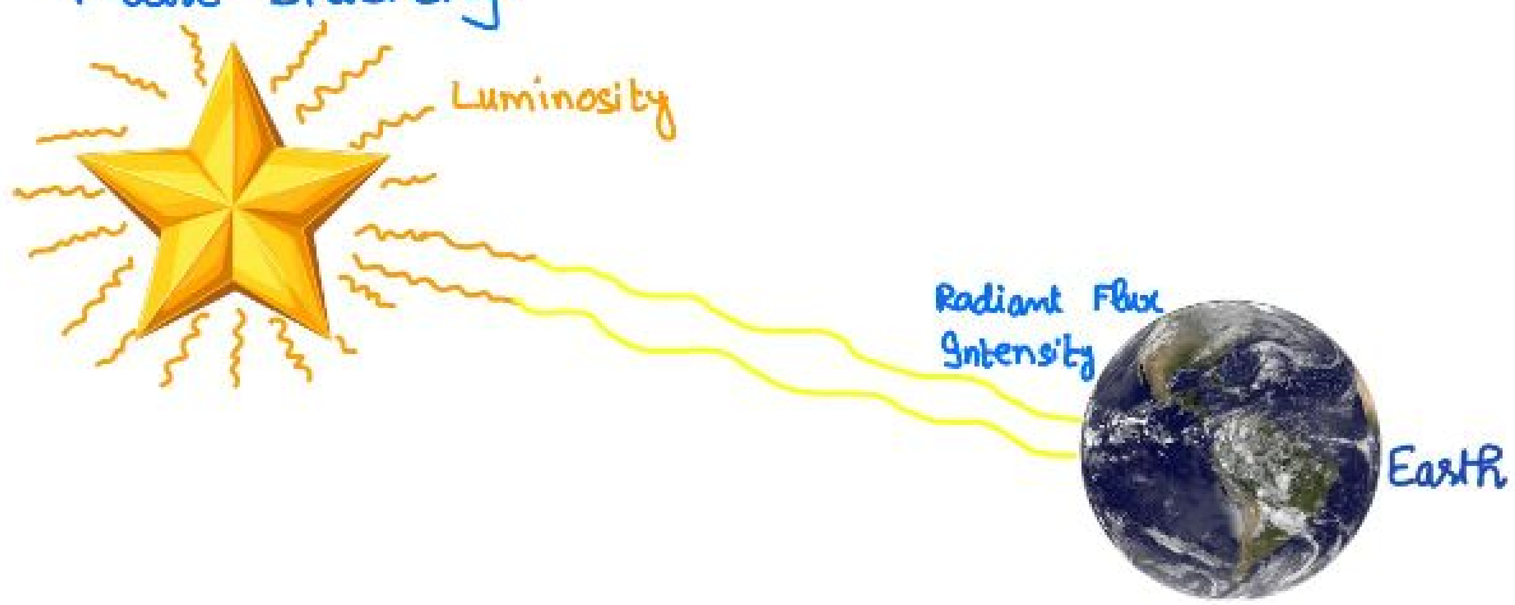
(ii) Physical size / radius / volume :-

(Luminosity) ↑ as (Surface area of star) ↑

i.e. Larger star has more area which allows more light and energy to be emitted per unit time.

2. Radiant Flux Intensity:

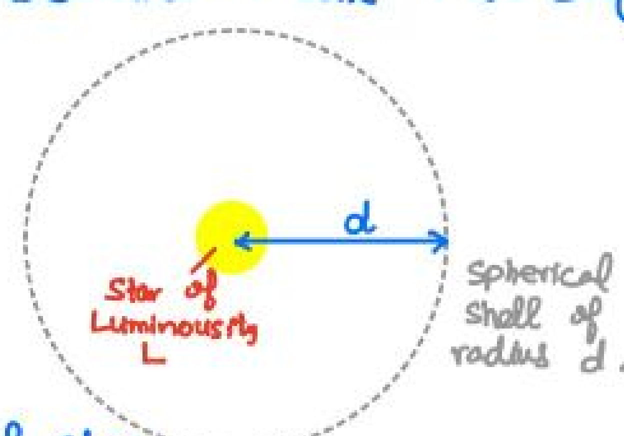
Concept: Luminosity is transmitted from the surface of a star and is received at Earth. The observed amount of intensity received at Earth is Radiant Flux Intensity.



Def. Power per unit perpendicular area received at the surface of Earth is Radiant Flux intensity.

Symbol: F

Formula:



$$\text{Radiant flux intensity} = \frac{\text{Power of star}}{\text{Surface area of sphere}}$$

$$= \frac{\text{Luminosity}}{\text{Surface area of sphere}} \Rightarrow F = \frac{L}{4\pi d^2}$$

Units: $Wm^{-2} = Js^{-1}m^{-2} = kg\,s^{-3}$

P.S: Scalar

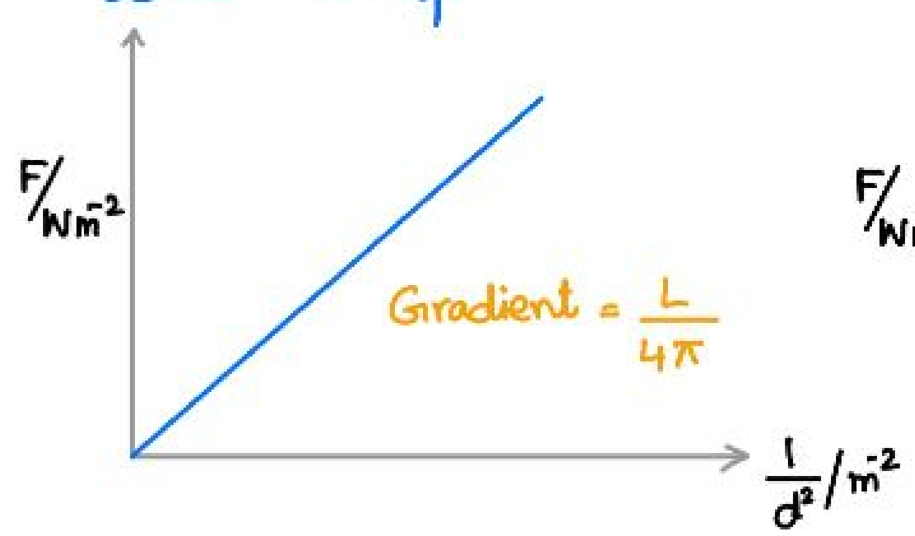
Assumptions: For $F = \frac{L}{4\pi d^2}$, we assume

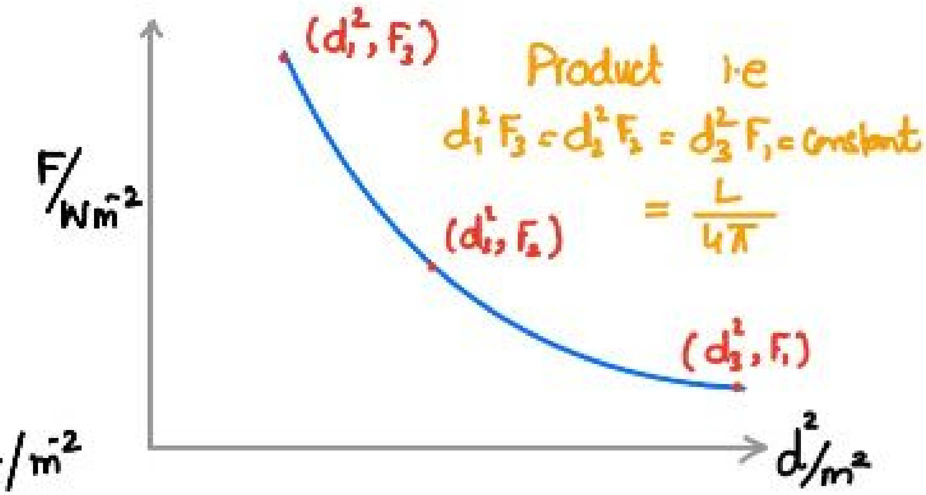
(i) The Power from a star is uniformly radiated through space.

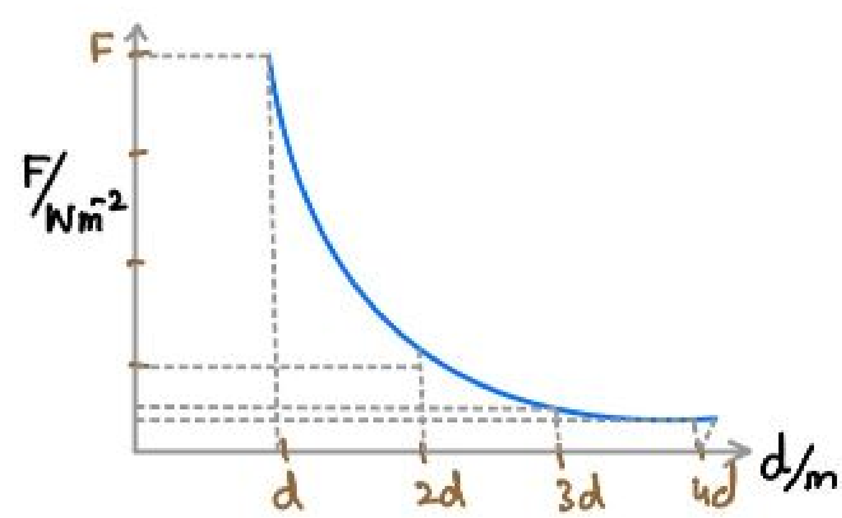
(ii) there is negligible absorption of this radiated power between Earth and star.

Dependance: $F = \frac{L}{4\pi d^2} \Rightarrow F \propto \frac{1}{d^2}$ as L is constant for a star.

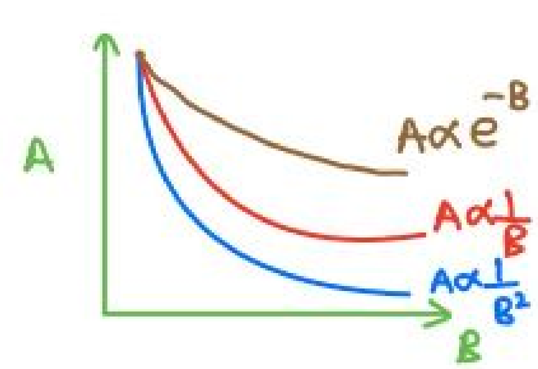
Radiant flux intensity follows the inverse square relationship.







d	2d	3d	4d	5d
F	$\frac{F}{4}$	F/9	F/16	F/25
	0.25F	0.11F	0.0625F	



1 The radius of the Sun is 6.96×10^8 m and its luminosity is 3.83×10^{26} W.
The orbital radius of the Earth is 1.50×10^{11} m.
Calculate the radiant flux intensity at the surface of the Sun and at the position of the Earth.

Sol.

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

Radiant flux intensity at surface of sun:

$$F = \frac{3.83 \times 10^{26}}{4(3.14)(6.96 \times 10^8)^2} = \_\_\_\_\_\_ \ W m^{-2}$$

Radiant flux intensity at surface of Earth:

$$F = \frac{3.83 \times 10^{26}}{4(3.14)(1.50 \times 10^{11})^2} = \_\_\_\_\_\_ \ W m^{-2}$$

3. Standard Candle:-

It is an astronomical object of known luminosity due to special characteristic quality (brightness, colour, heat etc) possessed by that class of object.

Example:

(a) Cepheid Variable stars: A type of pulsating star whose brightness varies (increases and decreases) over a set time period. This variation has a well defined relationship to the luminosity.

(b) Tye 1A Supernovae:- The Supernova explosion occurs when a red star of sufficient mass has reached the end of sequence of thermonuclear reactions; the star is then very bright for a short time.

4. Use of Standard Candle :- It is used to measure large distance by measuring the intensity of the electromagnetic radiations arriving at the Earth.

By collecting information of distances over a range, Astronomer can build up a large picture of universe, also called "cosmic distance ladder.

2 The radiant flux intensity, measured at the Earth, from a Cepheid variable star in Andromeda is 1.4 × 10^{-16} W m^{-2}. The luminosity of the star is 1.0 × 10^{30} W.

Calculate the distance of this star.

$$F = \frac{L}{4\pi d^2} \Rightarrow d = \sqrt{\frac{L}{4\pi F}}$$

$$d = \sqrt{\frac{1.0 \times 10^{30}}{4(3.14)(1.4 \times 10^{-16})}} \Rightarrow d = \_\_\_\_\_\_ m$$

25.2 Stellar radii

Candidates should be able to:

1 recall and use Wien's displacement law $\lambda_{max} \propto 1/T$ to estimate the peak surface temperature of a star

2 use the Stefan–Boltzmann law $L = 4\pi\sigma r^2 T^4$

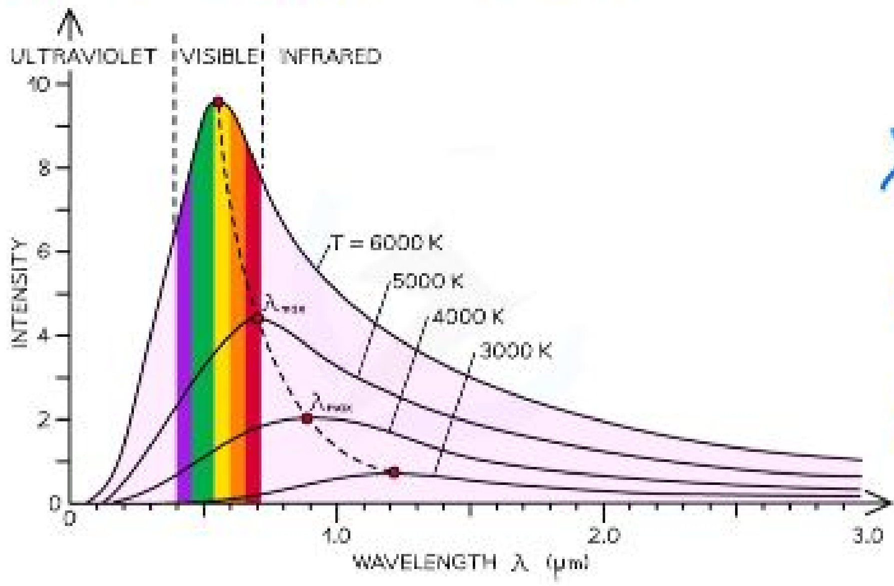
3 use Wien's displacement law and the Stefan–Boltzmann law to estimate the radius of a star

Wien's displacement law:-

This law defines a relationship between the observed colour of a star and its temperature. The observed colour changes with the temperature

Example: The observed colour of a filament lamp vary by increasing its temperature due to increase of current in it. Initially, filament glows dull red when cold, then reddish-orange, and eventually white as it gets hotter.

Explanation: A hot star can be regarded as a black body (An idealised object which absorbs all e.m. radiations incident on it). It has a characteristic emission spectrum and intensity that depends only on its thermodynamic temperatur is shown below.



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

$$(\lambda_{max})(T) = \text{Constant}$$

$$(\lambda_{max})(T) = 2.9 \times 10^{-3}\, mK$$

The broken lines show how the peak intensity, and the wavelength at which this occur, vary with temperature. The overall intensity is represented by the area under the graphs.

Result: The higher the temperature of a body:

(i) the shorter the wavelength at the peak (maximum) intensity.

(ii) the greater the intensity of the electromagnetic radiation at each wavelength.

Statement: Maximum wavelength emitted by a star (black body) at peak intensity is inversely proportional to thermodynamic temperature

Mathematical form:

$$(\lambda_{max})(T) = \text{Constant}$$

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

Here λ_{max} is the maximum wavelength emitted by the star at the peak intensit

Signifance of wien's displacement law:- Astronomers can tell how hot the surface of a star is by the colour (wavelength) of light it emits.

Q) The surface temperature of Sun is 5800 K.

(a) Calculate the wavelength that appears from it.

$$\lambda_{max} = \frac{2.9 \times 10^{-3}}{5800}$$

$$\lambda_{max} = 5.0 \times 10^{-7} m$$

$$= 500\ nm$$

(b) Calculate the surface temperature of a star with wavelength 350nm at peak intensity.

$$[(\lambda_{max})(T)]_{sun} = [(\lambda_{max})(T)]_{star}$$

$$(500 \times 10^{-9})(5800) = (350 \times 10^{-9})T$$

$T = 8286K$

(c) Using information from table given below, state the colour of star.

Colour of star	Surface temperature of star / K
blue	Greater than 33 000
blue to blue-white	10 000 – 30 000
white	7500 – 10 000
yellowish white	6000 – 7500
yellow	5200 – 6000
orange	3700 – 5200
red	Less than 3700

Since 828K lies in the range of (7500 to 10000K), so colour of star is white.

The Stefan-Boltzmann law:

This law defines a relationship between luminosity of a star interms of radius of star (black body) and the thermodynamic temperature at its surface.

Statement: The total radiant power emitted from a surface of star (Luminosity) is directly proportional to the fourth power of its absolute temperature.

Mathematical form: $L \propto T^4$

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

where, L - Luminosity of a star in watt (W)

r - Radius of the star in metre (m)

σ - the stefan-Boltzmann constant / $W m^{-2} K^{-4}$

It's value is $5.67 \times 10^{-8} W m^{-2} K^{-4}$.

Signifance of Wien's displacement law and the Stefan - Boltzmann law :- Both are used simultaneously to determine stellar radii as per following steps.

1- Use Wien's displacement law to find the surface temperature of star

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

λ_{max} - Peak wavelength
T - Surface temperature

$$(\lambda_{max})(T) = 2.9 \times 10^{-3}\, mK$$

2- Inverse square relationship is used to find the Luminosity of the star.

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

F- Radiant Flux intensity
d - Distance between the star and Earth

3- Stefan - Boltzmann law is used to get stellar radius.

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

L - Luminosity
r - Radius of star
T - Thermodynamic temperature of star

Q.4) The surface temperature of the Sun is 5800 K and wavelength of light at peak intensity is 500 nm. The wavelength at peak intensity for Sirius-B (a white dwarf star) is 120 nm. The luminosity of this star is 0.056 times that of the Sun. The luminosity of the Sun is 3.83×10^{26} W.

(a) Calculate the radius of Sirius-B.

Step 1: Initially calculate temperature of Sirius -B

$$(\lambda_{max})(T) = \text{Constant}$$

$$\left[(120 \times 10^{-9})(T)\right]_{\text{Sirius-B}} = \left[(500 \times 10^{-9})(5800)\right]_{\text{Sun}}$$

$$T = 2.42 \times 10^{4}\, K$$

Step 2: Luminosity of star Sirius- B (Given)

$$L_{Sirius-B} = (0.056)L_{Sun}$$
$$= (0.056)(3.83\times10^{26})$$
$$= 2.14\times10^{25}\ W$$

Step 3: Radius of Sirius- B by Stefan- Boltzmann Law

$$L = 4\pi\sigma r^2 T^4$$
$$2.14\times10^{25} = 4(3.14)(5.67\times10^{-8})\, r^2 (2.42\times10^{4})^4$$
$$r = \underline{9.36\times10^{6}}\ m$$

(b) The radius of Earth is 6.4×10^{6}m and is not very luminous. State the Luminosity of Sirius-B in comparison to Earth.

Since Radius of Earth and Sirius- B is approximately same, so luminosity of Sirius - B is nearly same as that of Earth.

Q.5) The luminosity of the star Aldebaran is 520 times that of the Sun. The wavelength of light at peak intensity for Aldebaran is 740 nm and the wavelength of light at peak intensity for the Sun is 500 nm.

a Explain whether Aldebaran is cooler or hotter than the Sun.

b Calculate the ratio:

radius of Aldebaran / radius of the Sun.

(a) Luminosity $\propto$ (Temperature)

So temperature of Aldebaran is greater than Sun

(b) $\frac{r_{Ald}}{r_{Sun}}$

Method 1: If value of constant $\{(\lambda_{max})(T) = 2.9\times10^{-3}\}$ is Provided in question.

Temperature of Aldebaran:

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

$$T_{Ald} = \frac{2.9 \times 10^{-3}}{740 \times 10^{-9}} = 3.92 \times 10^{3}\ K$$

Temperature of Sun:

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

$$T_{Sun} = \frac{2.9 \times 10^{-3}}{500 \times 10^{-9}} = 5.80 \times 10^{3}\ K$$

Now use Stefan-Boltzman's law $L = 4\pi\sigma r^2 T^4$

$$\frac{L_{Ald}}{L_{Sun}} = \frac{\cancel{4\pi\sigma}\ (r^2 T^4)_{Ald}}{\cancel{4\pi\sigma}\ (r^2 T^4)_{Sun}}$$

$$\frac{520 \cancel{L}_{Sun}}{\cancel{L}_{Sun}} = \left(\frac{r_{Ald}}{r_{Sun}}\right)^2 \left(\frac{T_{Ald}}{T_{Sun}}\right)^4$$

$$520 = \left(\frac{r_{Ald}}{r_{Sun}}\right)^2 \left(\frac{3.92 \times 10^{3}}{5.80 \times 10^{3}}\right)^4$$

$$\frac{r_{Ald}}{r_{Sun}} = 49.9 = 50$$

Method 2 to calculate ratio of radii:-

The value of constant (2.9×10^{-3}) in Wein's displacement law is not provided at data page. If this is not provided in question than use ratio method.

$$[(\lambda_{max})(T)]_{Sun} = [(\lambda_{max})(T)]_{Ald}$$

$$(500 \times 10^{-9})\ T_{Sun} = (740 \times 10^{-9})\ T_{Ald}$$

$$\frac{T_{Ald}}{T_{Sun}} = \frac{500}{740} = \frac{50}{74} = 0.676$$

Now use Stefan-Boltzmann's law

$$\frac{L_{Ald}}{L_{sun}} = \frac{(4\pi\sigma r^2 T^4)_{Ald}}{(4\pi\sigma r^2 T^4)_{sun}}$$

$$\frac{520 \cancel{L_{sun}}}{\cancel{L_{sun}}} = \left(\frac{\cancel{4\pi\sigma}}{\cancel{4\pi\sigma}}\right)\left(\frac{r^2_{Ald}}{r^2_{sun}}\right)\left(\frac{T_{Ald}}{T_{sun}}\right)^4$$

$$520 = \left(\frac{r_{Ald}}{r_{sun}}\right)^2 (0.676)^4$$

$$\frac{r_{Ald}}{r_{sun}} = 2.49 \times 10^3$$

$$= 49.9$$

$$= 50$$

25.3 Hubble's law and the Big Bang theory

Candidates should be able to:

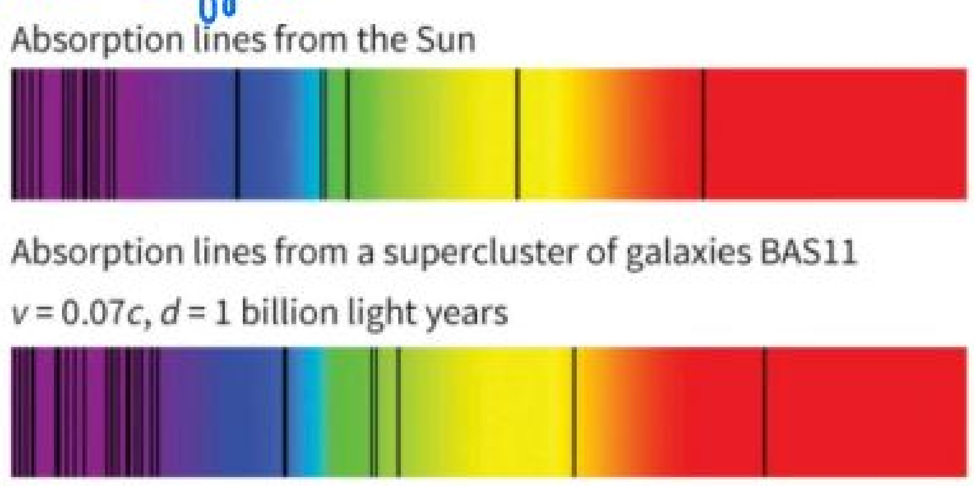
1 understand that the lines in the emission spectra from distant objects show an increase in wavelength from their known values

2 use $\Delta\lambda / \lambda \approx \Delta f / f \approx v / c$ for the redshift of electromagnetic radiation from a source moving relative to an observer

3 explain why redshift leads to the idea that the Universe is expanding

4 recall and use Hubble's law $v \approx H_0 d$ and explain how this leads to the Big Bang theory (candidates will only be required to use SI units)

1- Astronomers observe the light from distant galaxies using powerful telescopes and came to this conclusion that all observed wavelengths of all spectral lines are longer than the ones observed in the laboratory. This shows that they all are moving away from us by Doppler's effect.



The absorption lines in the spectrum of the galaxies are all shifted to longer wavelengths – redshifted. The top spectrum is the spectrum from a 'stationary source', the Sun.

Dopplers effect:-

Statement: The apparent change in the observed frequency / wavelength due to motion of a source and the observer.

Mathematical form:- $f_o = \dfrac{(f_s)(v)}{v \pm v_s}$

f_o - observed frequency
f_s - Frequency of source
v - velocity of wave, v_s - velocity of source.

Result:

1. The observed wavelength of electromagnetic wave is longer for a receding source and shorter for an approaching source.

2. Doppler equation can be used to determine the relative speed of a star/glaxy using a shift in wavelength from a hydrogen emission.

2- Doppler redshift:-

Redshift means that all spectral lines show an increase in wavelength. The fractional increase in the wavelength depends on the recesion speed v of the source/galaxy.

Relationship:-

$$\underbrace{z}_{\text{Redshift}} = \frac{\overbrace{\Delta f}^{\text{change in frequency}}}{\underbrace{f}_{\text{original frequency of e.m. waves from source}}} \approx \frac{\overbrace{v}^{\text{recession velocity of object/source}}}{\underbrace{c}_{\text{speed of e.m waves in vacuum } (3.00\times10^{8}\,m\,s^{-1})}} \approx \frac{\overbrace{\Delta\lambda}^{\text{change in wavelength}}}{\underbrace{\lambda}_{\text{original wavelength of e.m. waves from source}}}$$

Example: Astronomers normally assign a value for the term 'redshift'. For example, a galaxy shows redshift of 7.0% means that:

$$\frac{\Delta\lambda}{\lambda} \approx \frac{\Delta f}{f} \approx \frac{v}{c} \approx 0.070$$

Q.6) In the laboratory, an emission spectral line is observed at a wavelength of 656.4 nm. The same spectral line, in the spectrum from a distant galaxy, has wavelength 663.1 nm.

Calculate the speed *v* of the galaxy.

Step 1: Since the observed wavelength is longer; therefore galaxy is receding. Initially, calculate the change in wavelength of spectral line.

$$\Delta\lambda = (663.1 - 656.4)10^{-9} = 6.70 \times 10^{-9} m$$

Step 2: Use Doppler redshift equation to calculate v.

$$\frac{\Delta\lambda}{\lambda} = \frac{v}{c}$$

$$\frac{6.70 \times 10^{-9}}{656.4 \times 10^{-9}} = \frac{v}{3.00 \times 10^{8}}$$

$$v = 3.06 \times 10^{6} ms^{-1}$$

Q.7) The fractional change in the wavelength of the observed light from a galaxy is 0.15; its redshift is 15 %.

Calculate its recession speed.

$\frac{\Delta\lambda}{\lambda} = 0.15 =$ Redshift

$$\frac{\Delta\lambda}{\lambda} = \frac{v}{c}$$

$$0.15 = \frac{v}{3.00 \times 10^{8}} \Rightarrow v = 4.50 \times 10^{7} ms^{-1}$$

Q.8) The Tadpole galaxy has a recession speed of 9400 km s^{-1}.

Calculate the fractional change in the wavelength of the observed spectrum.

$$\frac{\Delta\lambda}{\lambda} = \frac{v}{c}$$

$$\frac{\Delta\lambda}{\lambda} = \frac{9400 \times 10^{3}}{3.00 \times 10^{8}} \Rightarrow \frac{\Delta\lambda}{\lambda} = 3.13 \times 10^{-3}$$

3. Conclusion obtained from Redshift:-

The Redshift of spectral lines from distant galaxies shows that all galaxies are receding from us. Therefore size of Universe is increasing.

4- Hubble's Law:-

Statement:- The recession speed (v) of a galaxy is directly proportional to its distance d from observer/Earth.

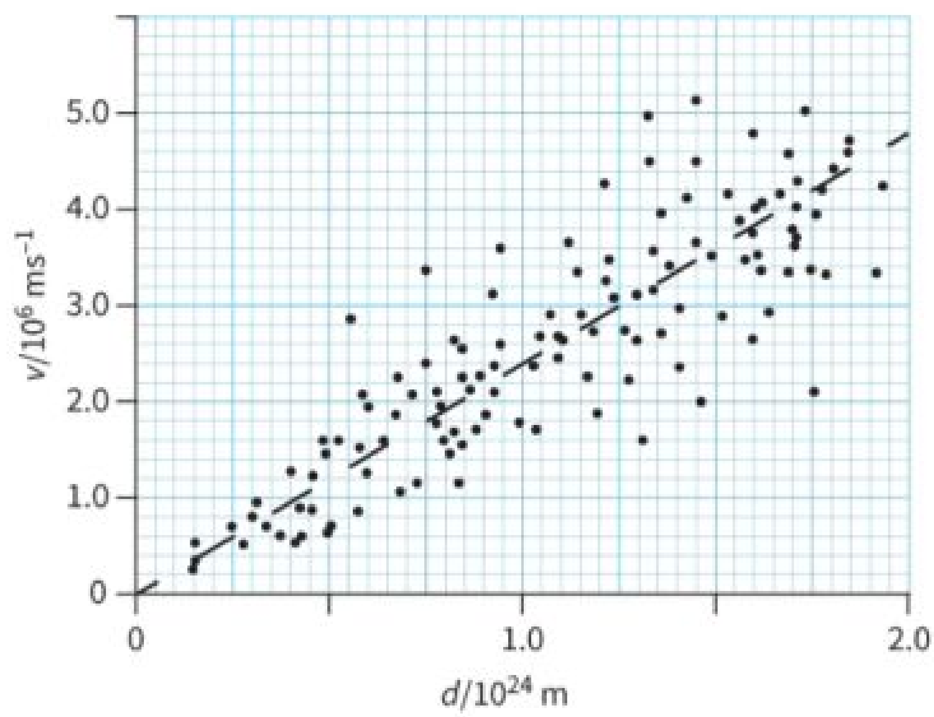
Mathematical form:-

$$v \propto d$$

$$v = H_0 d$$

Here H_0 is Hubble's constant and its value in S.I. is $2.22 \times 10^{-18} s^{-1}$

Graph:

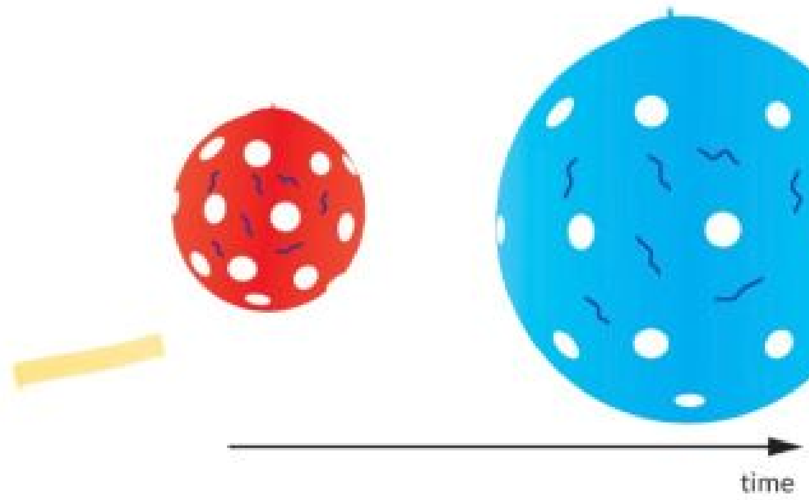


Gradient = Hubble constant

Hubble's law shows that recession speed of galaxy ∝ distance from us. The gradient of the best-fit line is equal to H_0 in s^{-1}. The scatter of the data shows considerable uncertainties in the observation.

Evidence for the Big Bang:

All galaxies in the Universe are receding (moving away) from each other. Visualise the change in the separation of dots as galaxies on the surface of an expanding balloon with time.



The galaxies are modelled as dots on the surface of a balloon. Expansion of the balloon makes all the dots move **away** from each other.

As per Hubble's Law, distant galaxies appear to be moving faster ($V \propto d \Rightarrow V = H.d$). Hubble's law provides the evidence for birth of universe due to its expansion. The initial shape of balloon lead to the conclusion that Universe must have had beginning — the Big Bang.

Q.9) The speed of the receding galaxy at a distance of 9.5×10^{25} m is $2.1 \times 10^{7} m s^{-1}$. Estimate the time when our galaxy and this receiding were at the same place (time of the Big Bang) if we assume that speed of receding galaxy remain constant.

$$\text{Speed} = \frac{\text{Distance}}{\text{time}}$$

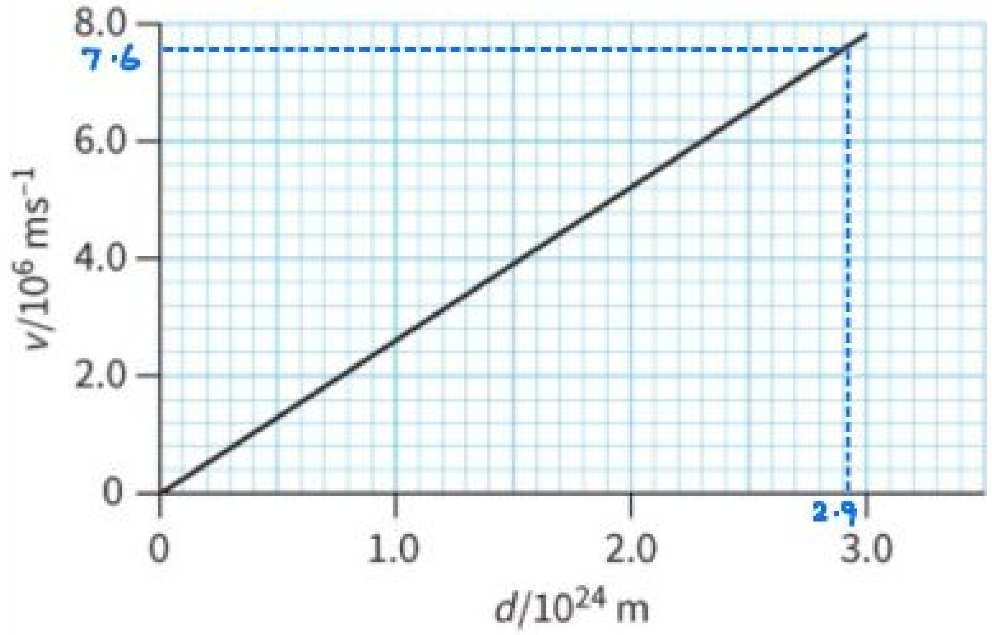
$$2.1 \times 10^{7} = \frac{9.5 \times 10^{25}}{\text{time}}$$

$$\text{time} = 4.52 \times 10^{18} \text{ s}$$

So, the age of Universe is roughly $\left(\frac{4.52 \times 10^{18}}{365 \times 24 \times 60 \times 60}\right)$

$$= 1.43 \times 10^{11} \text{ years} = 14 \text{ billion years}$$

Q.10) The recession speed v against distance d graph for some galaxies is shown.



(a) Determine the Hubble constant from this graph. Explain your answer.

$$V \propto d \Rightarrow V = (H_0)(d) \Rightarrow H_0 = \frac{V}{d}$$

H_0 = Gradient of graph

$$H_0 = \frac{7.6 \times 10^6}{2.9 \times 10^{24}} = 2.07 \times 10^{-18}\ s^{-1}$$

(b) The Big Bang occured some 14 billion years ago. (1 year $\approx 3.15 \times 10^7$ s)

Estimate the farthest distance we can observe.

Specimen paper for June 2022 exam

12 **(a)** A star has a luminosity that is known to be 4.8×10^{29} W. A scientist observing this star finds that the radiant flux intensity of light received on Earth from the star is $2.6\,\text{nW}\,\text{m}^{-2}$.

(i) Name the term used to describe an astronomical object that has known luminosity.

.... [1]

(ii) Determine the distance of the star from Earth.

distance = ... m [2]

(b) The Sun has a surface temperature of 5800 K. The wavelength λ_{max} of light for which the maximum rate of emission occurs from the Sun is 500 nm.

The scientist observing the star in **(a)** finds that the wavelength for which the maximum rate of emission occurs from the star is 430 nm.

(i) Show that the surface temperature of the star in **(a)** is approximately 6700 K. Explain your reasoning.

[2]

(ii) Use the information in **(a)** and **(b)(i)** to determine the radius of the star.

radius = ... m [2]

[Total: 7]

Marking key :

12(a)(i)	standard candle
12(a)(ii)	$F = L / 4\pi d^2$
	$2.6 \times 10^{-9} = 4.8 \times 10^{29} / 4\pi d^2$ distance = 3.8×10^{18} m
12(b)(i)	(Wien's displacement law states) $\lambda_{max} \propto 1 / T$
	so $T = (5800 \times 500) / 430 = 6700$ K (6740 K)
12(b)(ii)	$L = 4\pi\sigma r^2 T^4$ $4.8 \times 10^{29} = 4\pi \times 5.67 \times 10^{-8} \times 6700^4 \times r^2$
	radius = 1.8×10^{10} m

Data and Formulae to be given in CAIE paper from this chapter:-

Stefan–Boltzmann constant	$\sigma = 5.67 \times 10^{-8}$ W m^{-2} K^{-4}
Stefan–Boltzmann law	$L = 4\pi\sigma r^2 T^4$
Doppler redshift	$\dfrac{\Delta\lambda}{\lambda} \approx \dfrac{\Delta f}{f} \approx \dfrac{v}{c}$

EXAM-STYLE QUESTIONS

1 Which statement is correct about radiant flux intensity? **[1]**

A It depends on the area of the measuring device.

B It is measured in W m^{-2}.

C It is the same as luminosity.

D It is the total radiant power emitted from a star.

2 A group of astronomers have determined the radiant flux intensity F from a star and its distance d. The percentage uncertainty in F is 1.2 % and the percentage uncertainty in d is 2.5 %.

What is the percentage uncertainty in the calculated value of the luminosity of the star? **[1]**

A 1.3 %

B 3.0 %

C 3.7 %

D 6.2 %

3 A particular emission spectral line is measured in the laboratory to have a frequency of 7.3×10^{14} Hz.

a Calculate the wavelength of this spectral line in the laboratory. **[1]**

b Calculate the observed wavelength of this same spectral line in the spectrum of a galaxy moving away from the Earth at a speed of:

i 11 Mm s^{-1} **[3]**

ii 7.0 % the speed of light. **[3]**

c The spectrum of all distant galaxies is redshifted. State and explain what you can deduce about the Universe. **[2]**

[Total: 9]

4 **a** State Hubble's law. **[1]**

b The recession speed v against distance d graph for some galaxies is shown.

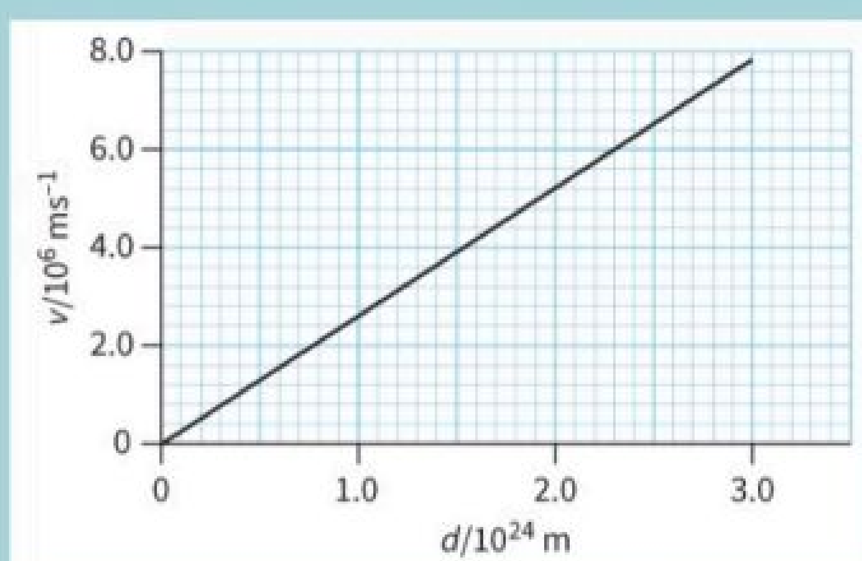


Figure 31.10

Determine the Hubble constant from this graph. Explain your answer. **[3]**

c The Big Bang occurred some 14 billion years ago.

$$1 \text{ year} \approx 3.15 \times 10^7 \text{ s}$$

Estimate the farthest distance we can observe. Explain your answer. **[3]**

[Total: 7]

5 **a** Define the luminosity of a star. **[1]**

b A red giant is a star bigger than our Sun. Explain how the surface of a red giant star can be cooler than the Sun, yet have a luminosity much greater than the Sun. [2]

c An astronomer has determined the surface temperature of a white dwarf star to be 7800 K and its radius as 8.5×10^6 m. Calculate the luminosity of this star. **[3]**

d The surface temperature T of a star depends on the wavelength λ_{max} at the peak intensity of the emitted radiation from the star.

The T against λ_{max} graph for a cluster of stars in our galaxy is shown.

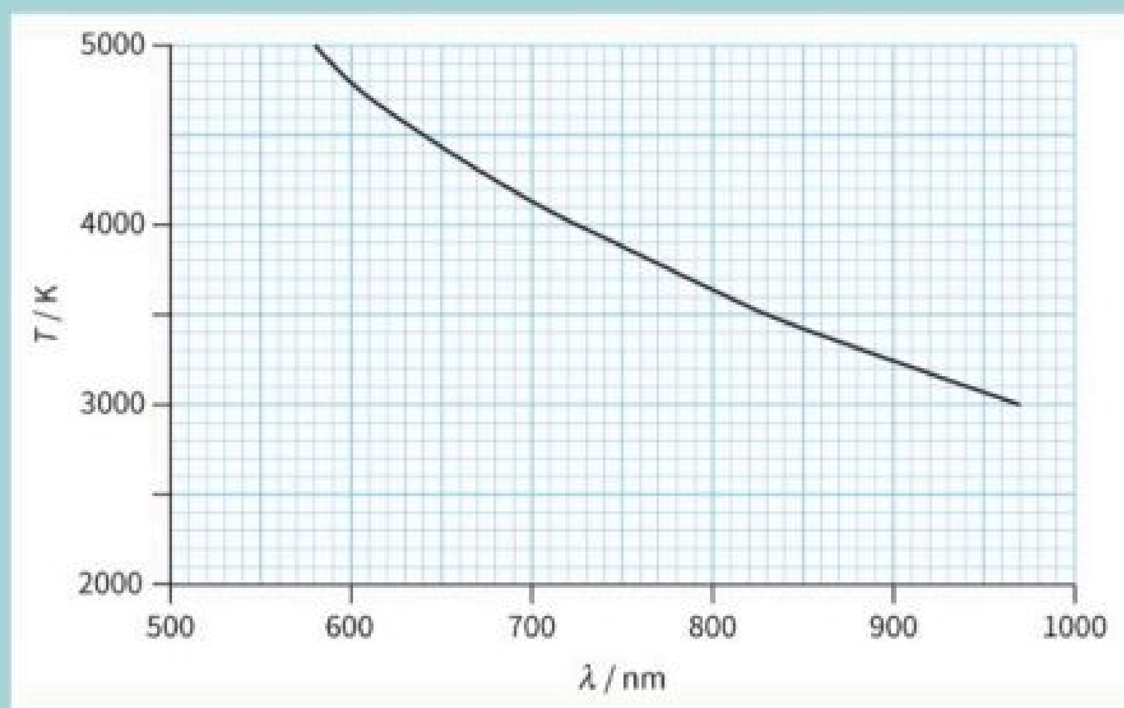


Figure 31.11

i Use the graph to show Wien's displacement law is obeyed. **[2]**

ii Estimate the surface temperature of a star with $\lambda_{max} = 400 \pm 10$ nm. In your answer, include the absolute uncertainty. **[4]**

[Total: 12]

6 Light from a galaxy is passed through a diffraction grating. The diagram shows part of the emission spectrum.

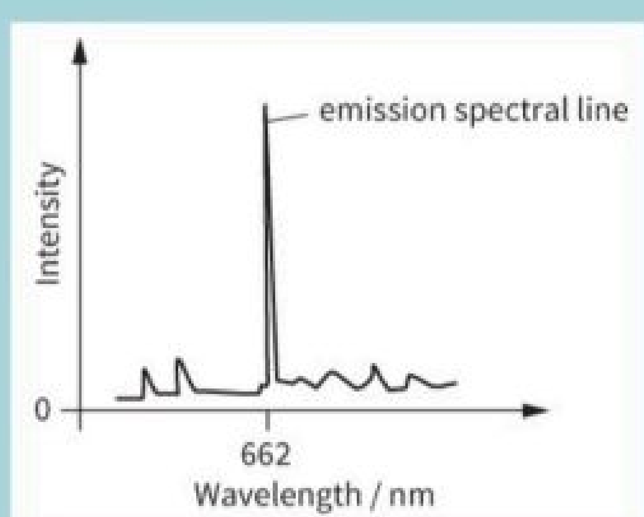


Figure 31.12

The strong emission spectral line has wavelength 662 nm.

a Calculate the energy of a photon of wavelength 662 nm. **[2]**

b Explain how a spectral line is produced by electrons within atoms. **[2]**

c In the laboratory, the same spectral line has wavelength 656 nm.

i Calculate the speed of the galaxy. **[3]**

ii State the direction of travel of the galaxy. **[1]**

d State and explain what the wavelength of the same spectral line would be for a much more distant galaxy. **[2]**

[Total: 10]

7 **a** Define radiant flux intensity. **[1]**

b State the relationship between radiant flux intensity *F* and distance *d* from the centre of a star. **[1]**

c Neptune is the farthest known planet from the Sun in the Solar System. Its distance from the Sun is 30 times greater than the distance of the Earth from the Sun. The radiant flux intensity from the Sun at the Earth is 1400 $W\ m^{-2}$.

A space probe is close to Neptune.

Calculate the maximum radiant power received by an instrument of cross-sectional area 1.0 cm^2 on this space probe. **[3]**

[Total: 5]