① Luminosity =>

Total Power of EM radiation emitted by an object (e.g. stars). $\text{Power} = \frac{\text{Energy}}{\text{Time}}$ WATT

② Radiant Flux Intensity "F"

apparent / observed brightness Wm^{-2}

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

distance b/w star & observer.

Star Proxima Centauri → 2.8×10^{23} W → L

$F \rightarrow 1.09 \times 10^{-11}\ Wm^{-2}$. How far is the star away from us?

$$F = \frac{L}{4\pi d^2} \qquad d^2 = \frac{L}{4\pi F} \rightarrow \sqrt{\frac{L}{4\pi f}}$$

$$d = \sqrt{\frac{(2 \cdot 8 \times 10^{23})}{(4\pi)(1 \cdot 09 \times 10^{-11})}} = 4.52 \times 10^{16} m$$

③ Standard Candles

a class of stellar objects which has known luminosity and whose distance can be determined by measuring Radiant Flux Intensity

An example of Stellar radii are the stars whose radius varies periodically; causing temperature of star to change so that the luminosity also varies periodically.

Astronomical objects whose luminosity, L is known and reliably estimated.

A Cepheid variable star is Galaxy G1 is found to have a measured flux intensity of $1.18 \times 10^{-4}\ W\ m^{-2}$. The distance to G1 is known to be $1.50 \times 10^{21}\ m$. A telescope observed a Cepheid with the same period in galaxy G2 with a measured flux intensity of $6.1 \times 10^{-15}\ W\ m^{-2}$.

F_1 d_1 F_2

Calculate the distance to Galaxy G2.

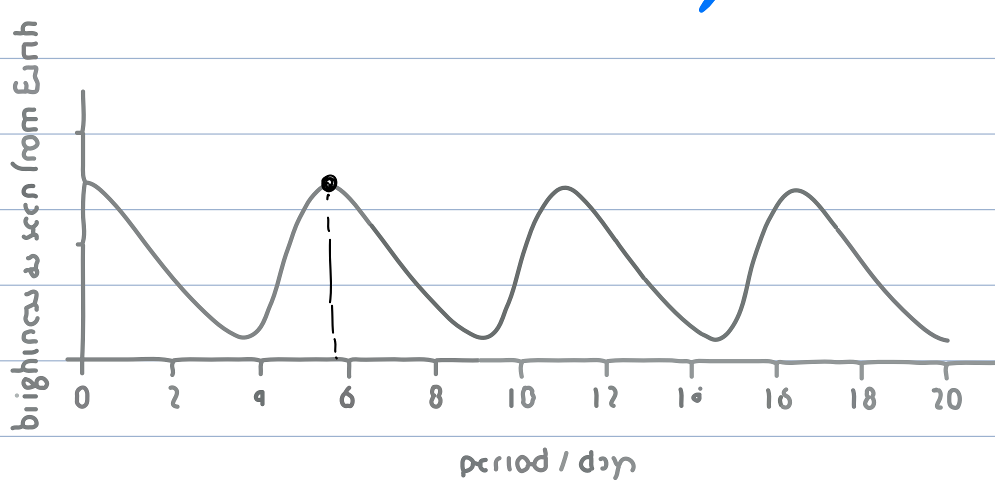
$$F = \frac{L}{4\pi d^2} \quad L \rightarrow \text{constant.} \quad \Rightarrow F \propto \frac{1}{d^2}$$

$$\frac{F_1}{F_2} = \left(\frac{d_2}{d_1}\right)^2 \longrightarrow \frac{1.18 \times 10^{-4}}{6.1 \times 10^{-15}} = \left(\frac{d_2}{1.5 \times 10^{21}}\right)^2$$

$$d_2 = 2.1 \times 10^{26}\ m$$

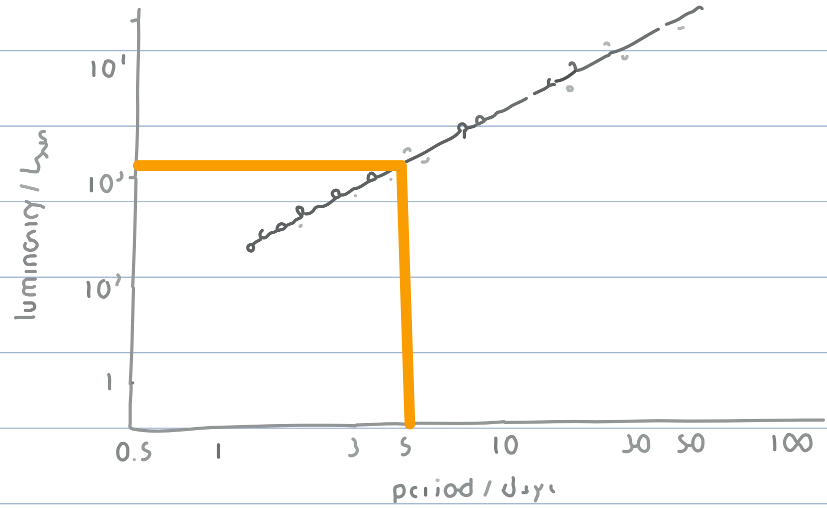
Exercise 2 (pg601, Collins)

Figure below shows the light curve of a Type 1 Cepheid variable star. It is found to have a measured flux intensity on Earth of $500\ nW\ m^{-2}$. $\rightarrow F$



(a) Determine the period $= 5.5$ days.

(b) Figure below is a period-luminosity diagram for Type 1 Cepheid variable stars



Use your answers in (a) to estimate the luminosity of the Cepheid and hence calculate the distance of the Cepheid from the Earth.
(Luminosity of Sun = 3.8×10^{26} $W\ m^{-2}$)

(a) $\dfrac{L}{L_{sun}} = 10^3 \rightarrow L = (3.8 \times 10^{26})(10^3)$
$= 3.8 \times 10^{29}$ W

(b) $F = \dfrac{L}{4\pi d^2} = \dfrac{3.8 \times 10^{29}}{4\pi d^2} = 500 \times 10^{-9}$

$d = 2.5 \times 10^{17}$ m

Example (pg543, Collins)
A Type 1a supernova is observed in another galaxy with a peak radiant flux intensity of 9×10^{-18} $W\ m^{-2}$
(a) If we assume that the peak luminosity of all Type 1a supernovae is about 10^{36} W, estimate the distance of the galaxy from Earth.
(b) How long ago did it explode? Use 1ly = 9.46×10^{15} m.

a) $F = \dfrac{L}{4\pi d^2} \longrightarrow d = \sqrt{\dfrac{L}{4\pi F}} = \sqrt{\dfrac{10^{36}}{4\pi \times 9 \times 10^{-18}}} = 9 \times 10^{25}$ m

b) $\dfrac{9 \times 10^{25}}{9.46 \times 10^{15}} \approx 10^{10}$ ly SUPERNOVA EXPLODED!

Black Body Radiation

A perfect absorber of energy. Stars are black body because they absorb light at any wavelength and do not reflect any back.

→ Emits Electromagnetic radiation over a wide range of wavelengths but there will be one peak wavelength.

WEIN DISPLACEMENT'S LAW

Wavelength of peak emission intensity (λmax) is inversely proportional to the absolute temperature of the object.

$$\lambda max \propto \frac{1}{T} \rightarrow \lambda max = \frac{b}{T}$$

$\lambda \downarrow$ E_{photon} emitted $\uparrow$ when $T \uparrow$

At all temperature, radiation is emitted over a continuous range of wavelengths.

The Peak of the graph moves towards SHORTER λ as temperature increases.

The Higher the surface temperature, the greater the power radiated by the Black body. $E_{photon} \uparrow\uparrow$

STEFAN BOLTZMANN'S LAW

A body when heated will emit electromagnetic radiation over a range of wavelengths with a total intensity that is proportional to the fourth power of its Absolute Temperature.

$$I \propto T^4 \Rightarrow I = \sigma T^4$$

$\sigma \rightarrow$ STEFAN BOLTZMANN CONSTANT.

$5.67 \times 10^{-8}\ Wm^{-2}K^{-4}$

S.A of Sphere $= 4\pi R^2$

$I = \dfrac{\text{Luminosity}}{\text{Area}} = \dfrac{\text{Radiant Flux}}{\text{Intensity}} = F$

$\sigma T^4 = \dfrac{L}{4\pi r^2} \longrightarrow L = 4\pi\sigma r^2 T^4$

stellar radii

Absolute temp of star (Wein's Displacement)

$\sigma = 5.67 \times 10^{-8}\ Wm^{-2}K^{-4}$

Examples (pg548, Collins)

1) The sun has a surface temperature of 5780K and the wavelength of light for which the maximum rate of emission occurs is 480 nm. The radiation from another star in our galaxy is found to have its maximum intensity at a wavelength of 250 nm. Estimate its surface temperature.

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

$\dfrac{\lambda_{sun}}{\lambda_{star}} = \dfrac{T_{star}}{T_{sun}}$

$\dfrac{480}{250} = \dfrac{T_{star}}{5780} \rightarrow 11000\ K$

2) The star Sirius A has a surface temperature of about 10 000 K and its luminosity is about 9.9×10^{27} W. Estimate the radius of Sirius A.

$I = \dfrac{L}{A}$

$\sigma T^4 = \dfrac{L}{4\pi r^2}$

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

$$r = \sqrt{\frac{(9.9 \times 10^{27})}{(4\pi)(5\cdot 67 \times 10^{-8})(10000)^4}}$$

$r = 1.1787 \times 10^9\ m$

$\approx 1.2 \times 10^9\ m$

3) A black body emitting radiation at 2000 K has its maximum intensity at a wavelength of 1450nm. The star Betelgeuse has been measured to have a wavelength of 850nm at peak intensity and has luminosity of 3.1×10^{31} W. Estimate its radius

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

$$\frac{\lambda_1}{\lambda_2} = \frac{T_2}{T_1}$$

$$\frac{1450}{850} = \frac{T_2}{2000} \rightarrow 3410\,K$$

STEFAN BOLTZMANN!

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

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

$$\sqrt{\frac{(3.1\times10^{31})}{(4\pi)(5.67\times10^{-8})(3410)^4}} = 5.67\times10^{11}\,m$$

EM RADIATION

① RADIANT FLUX INTENSITY

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

① estimate distance from stars to observers.

② STANDARD CANDLES

Luminosity L

③ λ_{max} of Light from Stars $\rightarrow$ $\lambda \propto \frac{1}{T}$

WEIN's Displacement.

$$\lambda = \frac{b}{T}$$

STEFAN BOLTZMANN

$$F \propto T^4$$

$$\boxed{L} = 4\pi\sigma r^2 T^4$$

② stellar radii calculation

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 $2.6\,\text{nW m}^{-2}$.

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

Standard Candle .... [1]

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

$$F = \frac{L}{A} \longrightarrow 2.6 \times 10^{-9} = \frac{4.8 \times 10^{21}}{4\pi d^2} = 3\cdot 83 \times 10^{18}$$

Earth

distance = 3.8×10^{18} 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.

Wein's Displacement Law

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

$$\frac{\lambda\,sun}{\lambda\,star} = \frac{T_{star}}{T_{sun}}$$

$$\frac{500}{430} = \frac{T_{star}}{5800}$$

$T_{star} = 6740\,K \approx 6700\,K$ shown. [2]

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

STEFAN BOLTZMANN

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

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

$$\sqrt{\frac{(4.8\times10^{29})}{(4\pi)(5.67\times10^{-8})(6700)^4}}$$

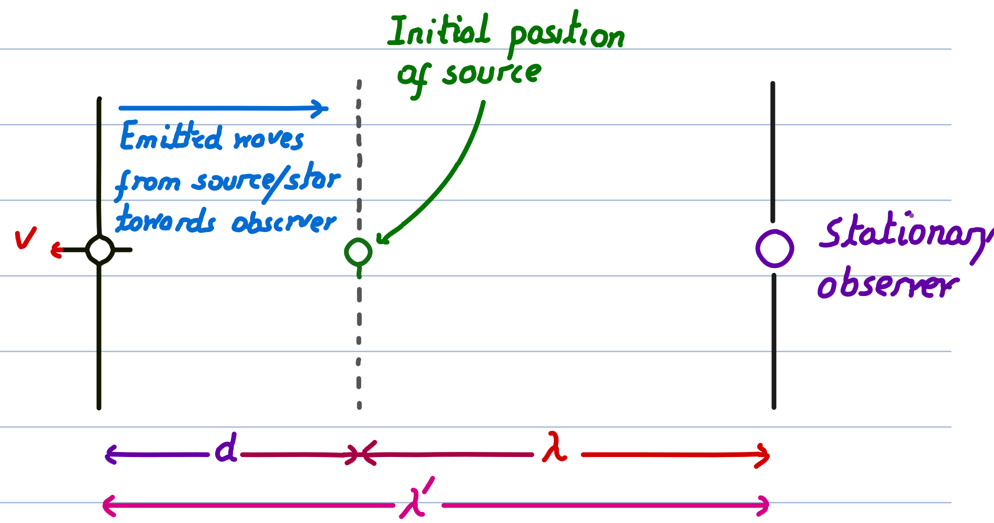
radius = 1.8×10^{10} m [2]

[Total: 7]

DOPPLERS EFFECT

Doppler shift.

- Red shift: Freq decrease, Source moving away
- Blue shift: Freq increase, Source moving towards



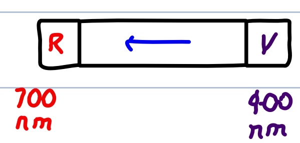
$$\boxed{\frac{\Delta\lambda}{\lambda} = \frac{v}{c}}$$

$$\boxed{\frac{v}{c} = \frac{\Delta\lambda}{\lambda} = \frac{\Delta f}{f}}$$ ✓

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

- v: Speed of radiation source
- c: speed of light in vacuum
- $\Delta\lambda$: change in apparent wavelength
- λ: Actual wavelength
- f: Actual freq.

When source moves away from a stationary observer, freq. of recieved/detected by observer is less than the actual freq OR wavelength of recieved signal is greater than actual wavelength,



Red shift → Increase in wavelength; Decrease in freq.

Examples (pg551, Collins) $\nearrow$ star (observed)

1) A particular spectral line in the spectrum of a star is found to have wavelength of 600·80nm compared to 600.00 nm as measured in the laboratory.

λ ref.

What is the velocity of the star? Is it moving towards us or away from the Earth?

λ becomes longer, so "red shift" $\rightarrow$ moving away / receeding

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

$$\frac{(600 \cdot 80 - 600 \cdot 00)}{(600.00)} = \frac{v_{star}}{3 \times 10^8}$$

$V_{star} = 4.0 \times 10^{5}\ ms^{-1}$

receeding.

λ ref.

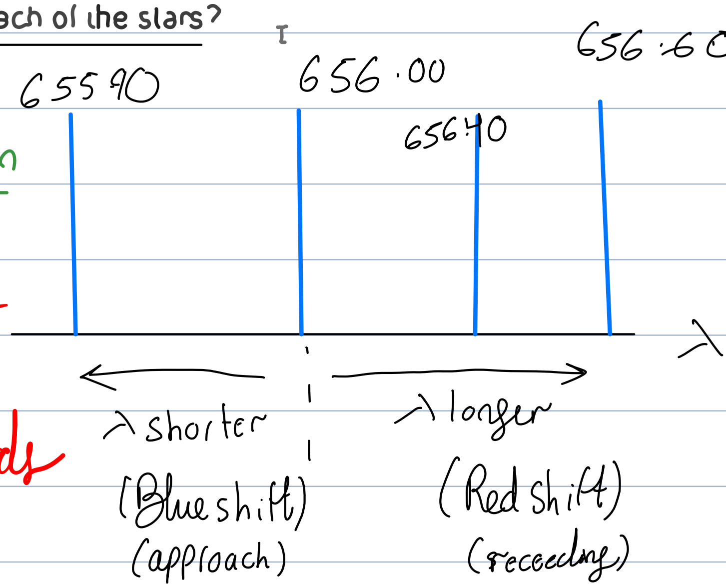
2) The H alpha emission line in the hydrogen spectrum is 656.0 nm when measured in the laboratory. Star A is observed to have that line at 656.60 nm star B at 655.90nm and star C at 656.40 nm.

λ star

a) Which star is moving the fastest relative to Earth?

b) What is the direction of motion of each of the stars?

Star	$\Delta\lambda$	Motion
A	656.60-656.00 = +0.60nm	Away
B	−0.10nm	Towards
C	+0.40nm	Away



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

a) Star A has largest $\Delta\lambda$, so fastest speed (recession)

$\Delta\lambda \propto V$

3) Neutral, atomic hydrogen gas in the spiral arms of the Milky Way emits a spectral line of wavelength 21 cm, which is in the microwave part of the electromagnetic spectrum. The spectral line when detected by radio telescope in a certain orientation is observed to be shifted by 0.1 mm less than 21 cm ⇝ blue shift → towards.

$\Delta\lambda$

How fast is this part of the galaxy is moving relative to us along the line of sight? Is it moving towards us or away from Earth?

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

$$V = 1.4 \times 10^{5}\ ms^{-1}$$

$$\frac{0.1 \times 10^{-3}}{21 \times 10^{-2}} = \frac{V}{3 \times 10^{8}}$$

$\Delta\lambda$ negative

$\lambda\downarrow$ blueshift!

EM radiation ⇝ moving towards earth.

d) The frequency of a calcium line in the absorption spectrum of the star Alpha Centauri is observed to have a frequency of 7.560×10^{14} Hz The same line when observed in the spectrum of the Sun is measured at 7.559×10^{14} Hz

Obs.

Calculate the speed at which Alpha Centauri is moving away from our solar system.

$$\frac{\Delta f}{f} = \frac{V}{c}$$

⇝ observed.

$$V = 4.0 \times 10^{4}\ ms^{-1}$$

$$\frac{(7.560 \times 10^{14} - 7.559 \times \cancel{10^{14}})}{7.559 \times \cancel{10^{14}}} = \frac{V}{3 \times 10^{8}}$$

HUBBLE'S LAW

observations of distant galaxies show that a vast majority of cases, the absorption spectra from distant galaxies are found to be red shifted

This indicates all galaxies are moving away from us.

HUBBLE DIAGRAM :- A plot of recession velocity against distance.

in ms^{-1}

$$V = H_0 \times d$$

m

recession velocity — Doppler red shift.

Hubble's constant $H_0 = 2.2 \times 10^{-18}$

distance of galaxy. {standard candle}

SOURCES OF ERRORS.

→ galaxies may have rotational motion

→ motion of galaxies are not always along the line of sight b/w observer & source (stars)

BIG BANG :- Galaxies receeding from Earth. $V \propto d$ (Hubble's law)

further away → greater recession.

in past; Galaxy; at one point.

The Universe begin from a point of infinite density called Singularity.

AGE OF UNIVERSE:-

$V = H_0 d$; speed of light $c = \frac{d}{t}$ $\quad d = ct$

$\cancel{c} = H_0(\cancel{c}t)$

$t = \frac{1}{H_0} = \frac{1}{2.2 \times 10^{-18}} = \frac{4.55 \times 10^{17}\,s}{60 \times 60 \times 24 \times 365} = 14 \times 10^{9}$ years.

14 billion years?

1) The recession velocity of the galaxy NGC 4889 has been determined to be $v = 6.4 \times 10^{6}\,ms^{-1}$. Estimate its distance in m. Take $H_0 = 2.2 \times 10^{-18}\,s^{-1}$ (pg553, Collins)

$V = H_0 d$

$\frac{6.4 \times 10^{6}}{2.2 \times 10^{-18}} = d = 2.9 \times 10^{24}$

red shift

2) The wavelength of a spectral line in the spectrum of light from a distant galaxy was measured at 398.6 nm. The same line measured in the laboratory has a wavelength of 393.3 nm. Calculate
a) the speed of recession of the galaxy $\quad$ ~~sour~~ c c
b) the distance to the galaxy. (pg347, Oxford Uni Press)

$\frac{\Delta\lambda}{\lambda} = \frac{V}{c} \rightarrow \frac{(398.6 - 393.3)}{393.3} = \frac{V}{3 \times 10^{8}}$

$V = 4.0 \times 10^{6}\,ms^{-1}$

$V = H_0 d$

$\frac{V}{H_0} = d$

$\frac{4.0 \times 10^{6}}{2.2 \times 10^{-18}} = 1.8 \times 10^{27}\,m = d.$

3) a) The emission lines of hydrogen in the spectra of almost all galaxies show a red shift. Explain the meaning of the term redshift.

$\lambda \uparrow$

The increase in the wavelength of EM radiation due to relative motion between the stellar object and observer.

b) The emission lines of Hydrogen Spectrum has a wavelength of 21.1 cm Measurement of the redshift of this line in the spectrum of M84 show it is redshifted by 0.0633 cm. Calculate the velocity of galaxy M84.

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

$$\frac{0.0633}{21} = \frac{V}{3\times10^8}$$

$$V = \frac{0.0633}{21.1} \times 3.0\times10^8$$

$$V = 9\times10^5 \text{ ms}$$

c) Given that this galaxy is 60 million light years distant calculate value for the Hubble constant in s^{-1} (use $1ly = 9.46\times10^{15} m$)

$$V = H_0 \times d$$

$$d = 60\times10^6 \text{ ly}$$

$$9.0\times10^5 = H_0 \left[(60\times10^6)(9.46\times10^{15})\right]$$

$$H_0 = 1.6\times10^{-19}$$

d) suppose at some distant time in the future, astronomers observed that most galaxies were showing a blue shift in their spectra What could you deduce about the expansion of the Universe?

Big Bang Theory (RED SHIFT) :- Universe originated from a dense single point and has been expanding ever since.

BLUE SHIFT Shows a decrease in observed λ, all galaxies are moving towards each other.

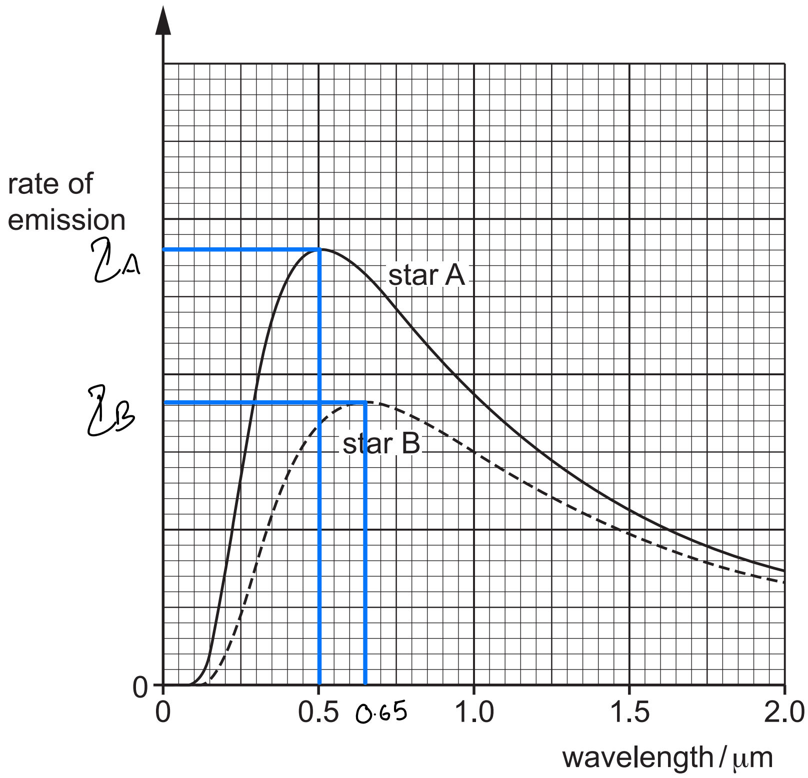
Hence the universe stops expanding and is now contracting.

$\lambda_{max} \propto \frac{1}{T}$ max intensity, Absolute (Surface) Temp

10 (a) State Wien's displacement law.

Wavelength of maximum intensity of an electro-magnetic radiation is inversely proportional to the thermodynamic surface temperature. [1]

(b) Fig. 10.1 shows the wavelength distributions of electromagnetic radiation emitted by two stars A and B.



$\downarrow E = \frac{hc}{\lambda \uparrow}$

Fig. 10.1

The surface temperature of star A is known to be 5800 K.

(i) Determine the surface temperature of star B.

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

$\frac{(\lambda_{max})_A}{(\lambda_{max})_B} = \frac{T_B}{T_A}$

$\frac{0.5\,\mu m}{0.65\,\mu m} = \frac{T_B}{5800} = 4461\,K$

surface temperature = 4500 K [2]

(2sf)

(ii) Star B appears less bright than star A when viewed from the Earth.

Use Fig. 10.1 to suggest, with a reason, how else the physical appearance of star B compares with that of star A.

STAR B has a greater wavelength where rate of emission is maximum. Hence STAR B appears to be more RED.

[2]

(c) The lines in Fig. 10.1 have been corrected for redshift.

(i) State what is meant by redshift.

Observed apparent wavelength is greater than reference value due to the movement of stars away from the observer.

[2]

(ii) Explain how cosmologists are able to determine that light from a distant star has undergone redshift.

By studying and comparing line spectrum of Electromagnetic radiation from the distant star with the Line spectrum already known when observing a stationery object.

[2]

[Total: 9]

Luminosity $L = \frac{E}{t}$

Luminosity of sun
$L_\odot = 3.8 \times 10^{26}\,W$ (1 standard candle)

Radiant Flux Intensity $F = \frac{L}{A}$

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

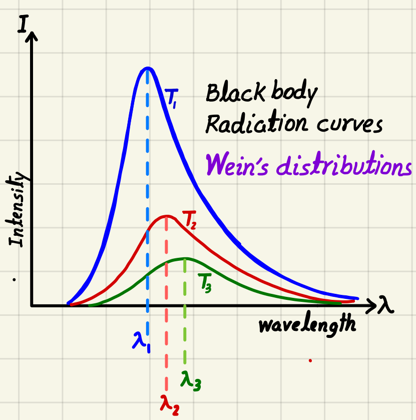
Wein's Displacement law

$$\lambda_{max} = \text{Const.}\ \frac{1}{T}$$

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

where const. is 2.9×10^{-3} mK
Wein's constant

$\lambda_{max} \longrightarrow$ Wavelength of emitted radiation at maximum intensity



$T_1 > T_2 > T_3$

$\lambda_1 < \lambda_2 < \lambda_3$

Stafen Boltzman's Law

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

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

where
$A = 4\pi r^2$
surface area of sphere

Stafen Boltzman's
constant $5.67 \times 10^{-8}\ Wm^{-2}K^{-4}$

Doppler's shift

$$\frac{V}{c} = \frac{\Delta\lambda}{\lambda} = \frac{\Delta f}{f}$$

$V \longrightarrow$ speed of wave source
$c \longrightarrow$ speed of waves

Hubble's Law

$$V \propto d$$

$$V = H_0 d$$

where H_0 represents
Hubble's constant.
$H_0 = 2.2 \times 10^{-18}\, s^{-1}$