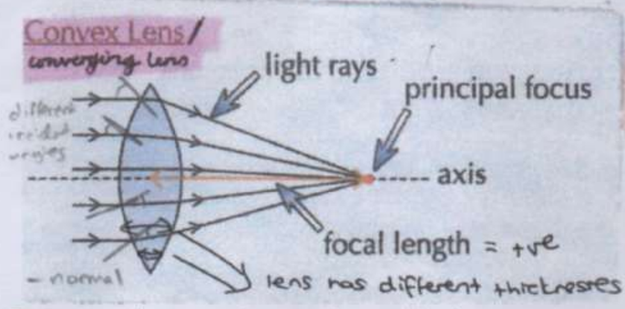
The principal focus is on each side of the lens (convex or concave)

Light and lenses

axis: line passing through middle of lens
principal focus (convex lens): where rays hitting the lens, parallel to axis, all meet
principal focus (concave lens): where rays hitting the lens, parallel to the axis, appear to come from.
focal length: distance from centre of lens to principle focus.

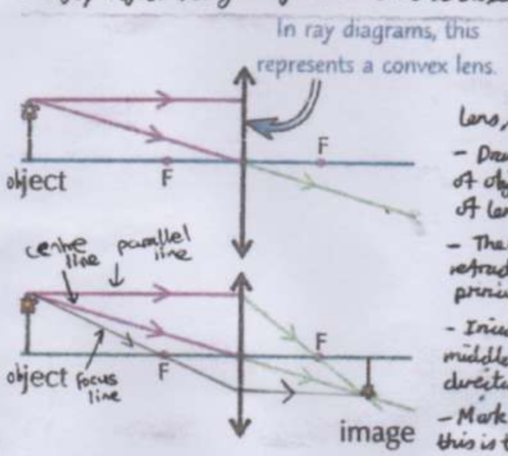
Convex Lens / converging lens



magnification = image height / object height

height (mm or cm)

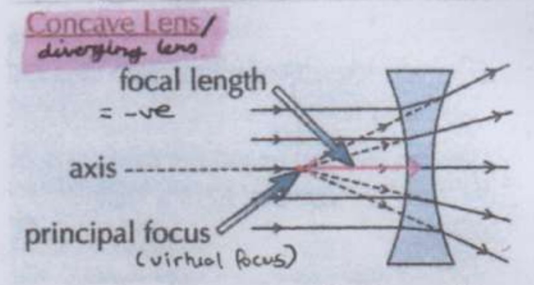
- Image produce can be real or virtual
- convex lens are used in magnifying glasses (creates magnified virtual image) object being magnified must be closer than the focal length



Steps to draw:
- Pick point on top of object
- Draw line from object to lens, parallel to axis
- Draw another ray from top of object going through middle of lens.
- The ray parallel to the axis is refracted and passes through the principal focus (F)
- Incident ray passing through middle of lens carries on in same direction.
- Mark where the rays meet - this is the top of the image.
- Repeat process for a point on bottom of image.

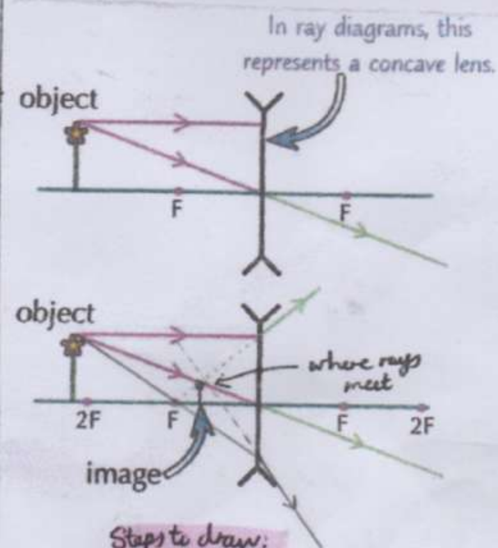
There can be focal points on both sides of the lens

Concave Lens / diverging lens



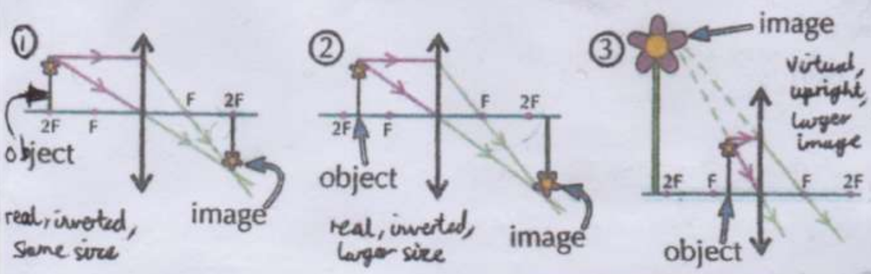
- Focal length for virtual focus is negative
- when rays are extended back they meet at a point called the virtual focus

- Image produced is always virtual, upright, smaller and on same side as the object - no matter where object is.

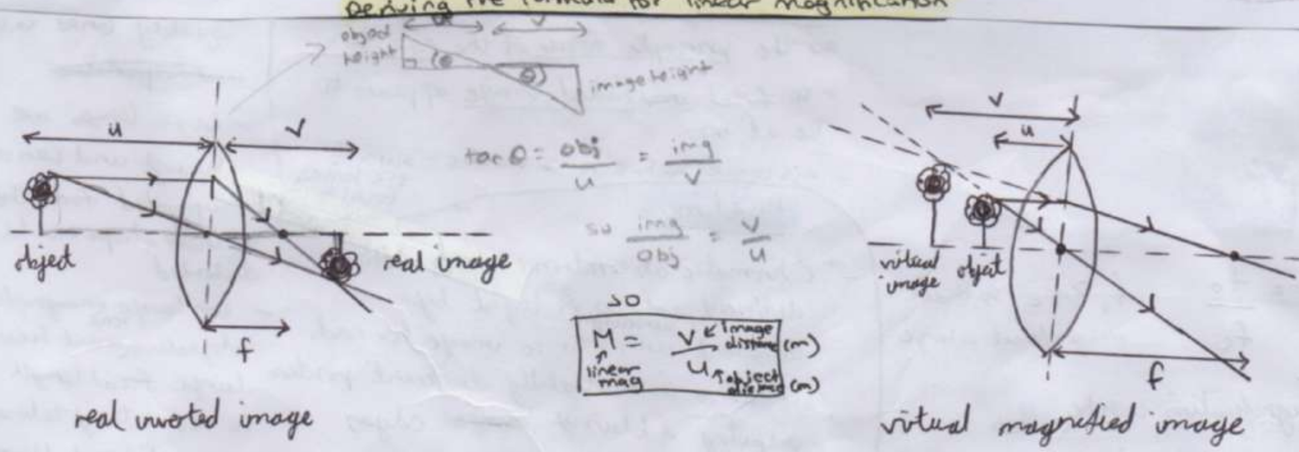


There can be focal points on both sides of the lens

Steps to draw:
- Pick point on top of object
- Draw line from object to lens, parallel to axis
- Draw another ray from top of object going through middle of lens.
- The ray parallel to the axis is refracted so it appears to have come from the principal focus, so draw a dotted line from the principal focus to lens.
- Incident ray passing through middle of lens carries on in same direction.
- Mark where rays meet - this is top of image.



Deriving the formula for linear magnification



$\tan\theta = \frac{obj}{u} = \frac{img}{v}$

so $\frac{img}{obj} = \frac{v}{u}$

so

$$M = \frac{v}{u}$$

M = linear mag; v = image distance (m); u = object distance (m)

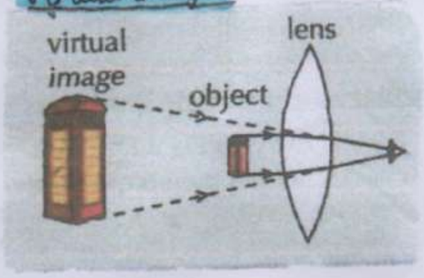
- If object is further than a focal length away from lens, image is real
- If object is closer than a focal length, image is virtual.

v is: +ve if image is real
-ve if image is virtual

$$\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$$

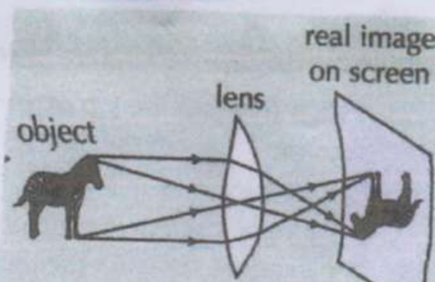
Real and virtual images

Virtual images



- is when rays are diverging so light from the object appears to be coming from a different place.
- Examples: your face in mirror, magnified object.

Real images



- is where light from an object comes together to form an image on a screen

Examples: image formed on retina at back of an eye.

Describing an image

- How big it is compared to the object
- whether it is upright or inverted
- whether it is real or virtual

you can't project a virtual image onto a screen.

Light

Each colour has its own narrow range of wavelengths ranging down at 400nm (violets) up to 700nm (reds).

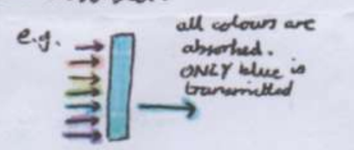
Colour and transparency

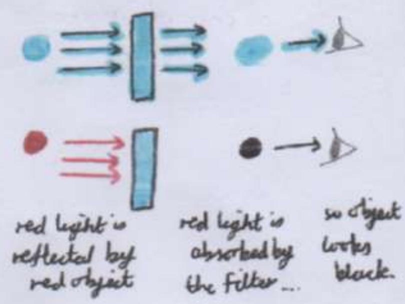
- Different objects absorb, transmit, and reflect different wavelengths of light
- Opaque objects absorb some wavelengths and reflect some of them. The colour we see is the wavelength that is strongly reflected.
- white objects reflect all wavelengths equally
- black objects absorb all wavelengths
- Transparent or translucent objects transmit light. The colour we see is the wavelength that is transmitted and reflected by it.

Filters

- Colour filters, filter out different wavelengths, so only certain colours (wavelengths) are transmitted and the rest are absorbed.

e.g.

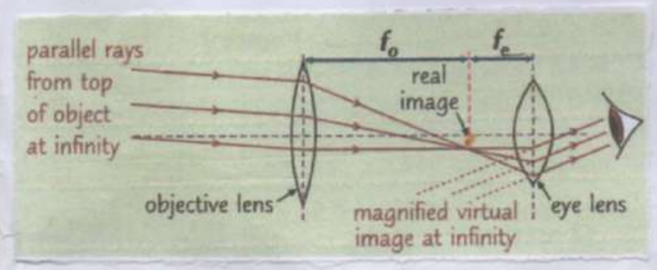




Optical telescopes

Refracting telescopes

- Uses 2 converging lens
- eye lens acts as a magnifying glass to form a magnified virtual image.



- If you assume object is at ∞, then rays from it are parallel, and real image is formed on focal plane
- In normal adjustment, a telescope is set up so the principal focus of objective lens is in the same position as the principle focus of the eye lens
- so final magnified image appears to be at ∞
- Distance between 2 lenses = sum of the lenses focal length

$$M = \frac{\theta_i}{\theta_o} = \frac{f_o}{f_e}$$

$f_o > f_e$ so that magnification is large

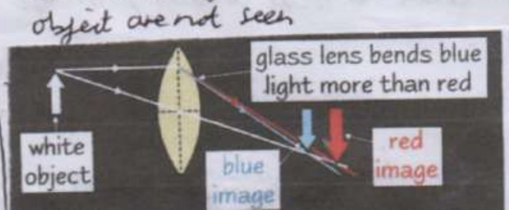
- angular magnification, M can be written in terms of angles (angular magnification) or in terms of focal length.

θ_i = angle subtended by image at the eye

θ_o = angle subtended by object at unaided eye

Problems

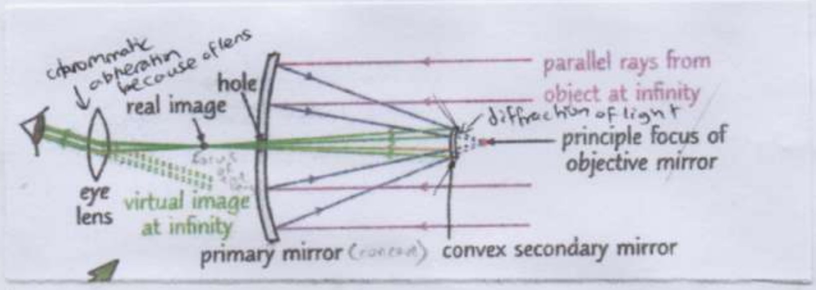
- Chromatic aberration: glass refracts different colours/wavelength of light by different amounts so image for each colour is in a slightly different position outputting a blurry ~~image~~ edges
- Bubbles and impurities in the glass can absorb light, so very faint object are not seen



- building large good quality lens is difficult ~~and expensive~~
- large lenses are heavy and can only be supported from the edge so their shape can be distorted
- for large magnification objective lens must have large focal length and so refracting telescopes are very long, large buildings needed to house these large telescopes

Reflecting telescopes

- A parabolic concave mirror (primary mirror) converges parallel rays from an object forming a real image
- ⊝ An eye lens magnifies the image
- The principal focus (where image is formed) is infront of the mirror
- An arrangement needs to be devised so observer does not block out light, so a cassegrain arrangment which uses a convex secondary mirror is used to solve this problem



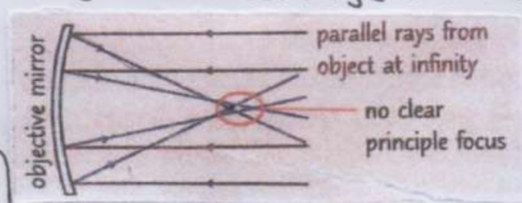
Advantages

- better resolving power as mirrors can be larger
- more light gets through but lens absorbs more light

- Large mirrors (collects more light) of good quality are much ~~cheaper to build than large lenses~~
- ⊝ The mirrors are supported from underneath so they don't distort as much as lenses.
- No chromatic abberation as mirror are used so no refraction. Only some chromatic aberation in eye lens

Disadvantages

- Spherical aberation - mirror is not perfectly parabolic so the parallel light rays don't converge onto the same point



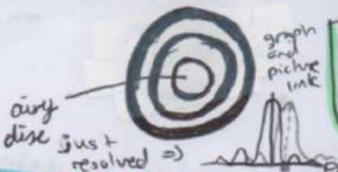
Resolving power (a measure of how much detail can be seen)

- Resolving power is dependent on minimum angular resolution (the smallest angular separation an instrument can distinguish 2 points

min angular resolution

Note! - The smaller the min angular resolution the better the resolving power

- Resolution is limited by diffraction. A beam of light passing through a circular aperture will form a diffraction pattern. For 2 light sources to be distinguished, the centre of the Airy disc for 1 source must be a least as far away as the minimum of the other source



Rayleigh criterion of a telescope: $\theta \approx \frac{\lambda}{D}$ Resolving power $\theta = 1.22\frac{\lambda}{D}$

θ = min angular resolution (rads)
λ = wavelength of light (m)
D = diameter of aperture (m)

- To see finer detail increase diameter

For telescopes D is diameter of objective lens or objective mirror

CCD (charge coupled device)

- They are very sensitive image detectors. They are made of silicon chips divided into a grid of millions of identical pixels
- When a photon hits a pixel, an electron is released, altering the charge on each pixel. The charged can be measured and used to create a digital signal
- The signal describes where the light hits, the brightness and intensity, as the charge on each pixel depends on how many photons hit it. A digital image is created
- CCD's are used in digital cameras, barcode scanners, giant astronomical telescopes

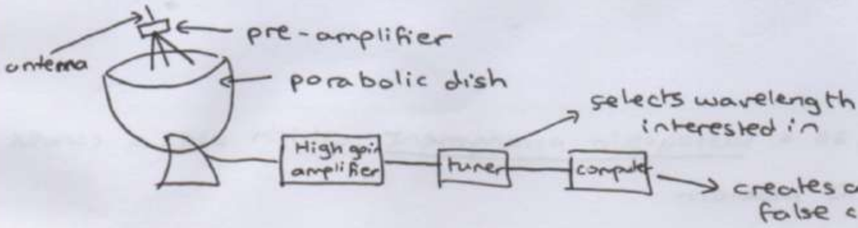
Comparing CCD's and Human eyes as image detectors

- **Quantom efficiency** - proportion of incident photons detected on CCD is 80%. Eye is 1%
- **Detectable light spectrum** - CCD detects IR, UV, visible. Eye detects only visible light
- **Resolution** - CCD spatial resolution = 10µm. Eye spatial resolution = 100µm spatial resolution is how far apart different parts of an object needs to be in order for them to be distinguishable
- **Convinence** - Human eye does not need extra equipment. CCD needs to be set up. CCD's can produce digital images that can be stored, copied and shared globally

Non optical telescopes

Radiotelescopes

- A radiotelescope has a porabolic dish
- It works in the same way as the objective mirror of and optical reflecting telescope
- An antenna is used as a detector at the focal point instead of an eye or camera



- radio telescope are manoverable allowing the source of waves to be tracked

- For a radiotelescope to have the same resolving power as an optical telescope, its dish would need to be a million times bigger (large diameter). The resolving power of the telescope is worse than the unaided eye
- To solve this there is a large network of telescopes around the world that are linked together (equivalent to 1 huge dish). Therefore resolutions thousands of times better than optical eletescopes can be achieved

Advantages

- Instead of a polished mirror, wire mesh can be used as radiowaves don't notice the gaps, so construction is cheaper/easier
- The shape of the dish has a precision of $\lambda/20$ to avoid spherical abberation. So the dish does not have to be anywhere near as perfect as a mirror.

Disadvantages

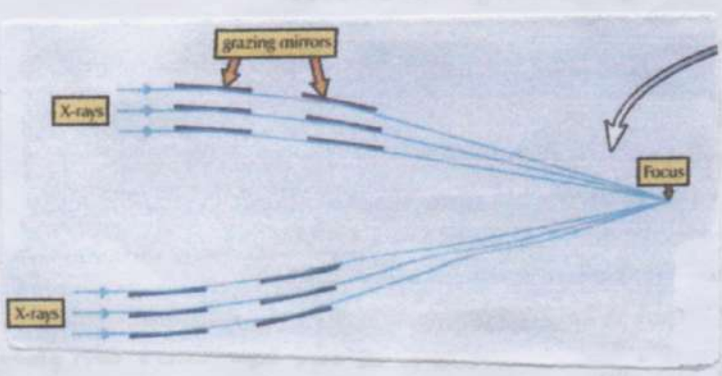
- unlike optial telescopes, radio telescopes have to scan across the whole radio source to build up an image

IR and UV telescopes - similar structure to optical telescopes

- They use parabolic mirrors to focus radiation onto a detector
- Both IR and UV telescopes use CCD's or special photographic paper as radiation detectors
- IR has longer wavelength so telescopes don't need to be shaped perfectly (they produce their own IR so they heat up, therefore they need to be cooled.
- UV has smaller wavelength so need to be made more precisely

X-ray telescopes

- X-rays don't reflect of surfaces the same way other EM radiation. It is usually absorbed or passes straight through



- X rays reflect when they graze a mirrors surface
- A series of nested mirrors gradually alter the direction and bring them to focus on the detector This is a grazing telescope
- Newer X-ray telescopes use highly sensitive X-ray CCD cameras
- X-rays can be detected using Gieger counters or fine wire mesh

Resolving power is limited by :

- Rayleigh criterion - depends on the λ and diameter of dish/objective mirror
- Quality of detector - resolution of detector (this can be the no' of pixels on a CCD or how fine the wire mesh is to detect X-rays)
- How much detail the telescope can show is called resolution

Collecting power

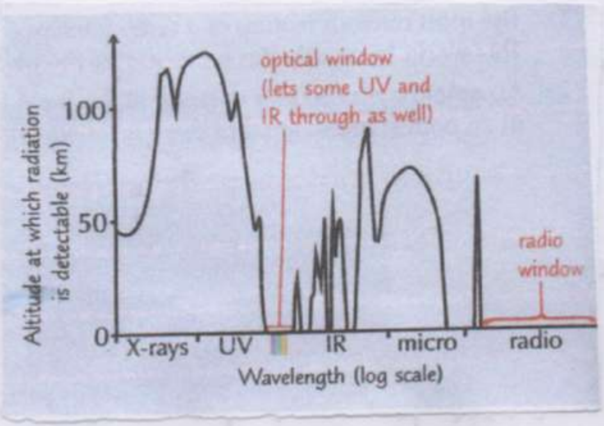
- **Collecting power $\propto$ Diameter^2**

energy per unit area = $\frac{\text{power}}{\pi r^2}$

- Bigger dish = more energy collected = more intense image so can observe fainter objects
- For radio, optical, UV, IR telescopes, this is the area of the objective mirror/dish
- For X-ray telescopes it is the area of opening through which X-rays can enter the telescope
- X-ray telescopes have a much smaller collecting power than other types of telescopes

- Advantages of larger diameter telescopes :
  - greater collecting power so images are brighter
  - ~~grea~~ better resolving power so images are clearer

Atmosphere blocks certain EM λ



- Optical and radio telescopes can be used on the earths surface because light and radio wavelengths are not blocked by the earths atmosphere

- IR is absorbed by water vapour. IR telescopes are usually used in high and dry places like in Mauna Kea volcano in Hawaii

- UV and X-rays are absorbed high up the atmosphere, so these telescopes are strapped to high altitude weather balls or aeroplanes

- the best way to observe all these wavelengths is to get the telescope into space and set it to orbit around the earth.

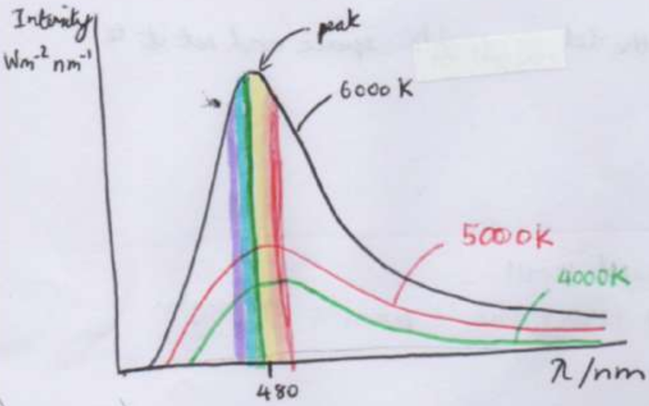
Why telescopes are put into space

- The absoption of EM waves by the atmosphere
- the light pollution and other interferance at ground level
- The effect the atmosphere has on the path of light as it passes through

Black body radiation

- stars emit and absorb a large range of wavelengths
- a perfect black body absorbs all EM radiation incident on it. So no EM radiation λ will be transmitted or reflected.
- so it is a perfect emitter of all λ of radiation
- stars can be approximated as a black-body radiator because they emit a large variety of λ

Black body curve



- This peak is in the visible part of the spectrum so the sun appears bright.
- This is a curve for a given temperature (surface temperature of the star because the surface is where the star emits and absorbs radiation.
- stars with different surface temps will have different black-body distributions
- As temp ↓ peak λ ↑
- If humans are modelling as black bodies, because the temp is very low, the peak wavelength emitted is going to be much longer.
- If 2 stars have the same black body temp, the star with the brighter absolute magnitude has the larger diameter

Wiens law

- cooler stars appear red and hotter stars appear blue
- Wiens displacement law: for a black body distribution, the peak wavelength is inversely proportional to the bodies absolute temperature
- $\lambda_{max} \propto \frac{1}{T}$ — (K); λ_{max} → (m)

converting between θ and K ⇒ $T(K) = \theta(°C) + 273.15$

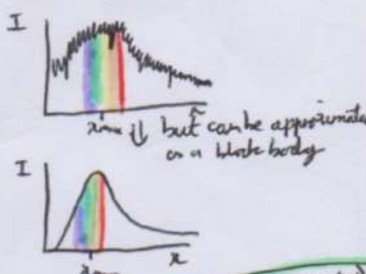
- Wiens constant: $\lambda_{max} T = C$ (← wiens constant)

$C = 2.90 \times 10^{-3}$

$$\lambda_{max} = \frac{C}{T}$$

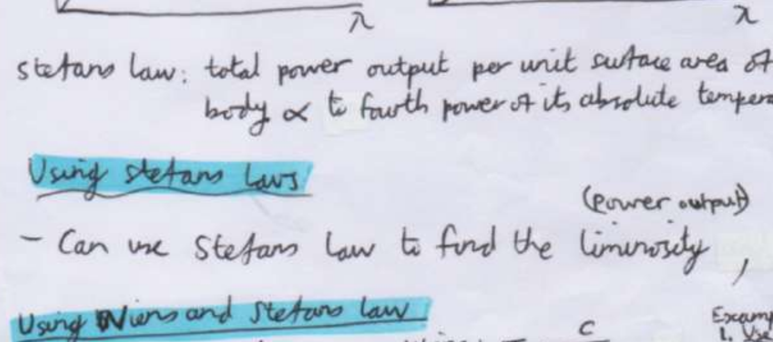
C ← wiens constant (mK); T ← absolute temp (K); λ_{max} ← peak wavelength (m)

when actually observed a stellar spectrum is created



Stefans law

- This law only applies to blackbodies



$$\frac{d_1}{d_2} = \frac{T_2^2}{T_1^2}\sqrt{\frac{P_1}{P_2}}$$

to find ratio of diameters (d)

$$\text{Luminosity} = \frac{\text{total energy output (J)}}{\text{time (s)}}$$

Luminosity (Watts) ← total energy emitted per second

$$I = \frac{P}{4\pi d^2}$$

I ← Intensity (Wm^{-2}); P ← power (W); d ← distance from star (m)

$$P \text{ or } L = A\sigma T^4$$

σ ← stefans constant $= 5.67 \times 10^{-8}$; T ← absolute temp (K) of surface; A ← surface area (m^2), for a sphere $A = 4\pi r^2$; P or L ← luminosity (W)

stefans law: total power output per unit surface area of a black body $\propto$ to fourth power of its absolute temperature

Using stefans laws

- Can use Stefans law to find the luminosity (power output), surface temperature of a star, and the radius.

Using Wiens and Stefans law

Stefans: $T^4 = \frac{L}{4\pi r^2 \sigma}$

Wiens: $T = \frac{C}{\lambda_{max}}$

$T^4 = \frac{C^4}{\lambda_{max}^4}$

$$\frac{L}{4\pi^2 \sigma r^2} = \frac{C^4}{\lambda_{max}^4} \Rightarrow r^2 = \frac{L\lambda_{max}^4}{4\pi C^4}$$

($L\lambda_{max}^4$ ← observables; $4\pi C^4$ ← constant)

Example: find radius of a distant star given values for the sun and λ_{star}

1. Use Wiens law

$\lambda_{star} = \frac{C}{T_{star}}$ $\quad \lambda_{sun} = \frac{C}{T_{sun}}$

$\lambda_{star} T_{star} = C \quad \lambda_{sun} T_{sun} = C$

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

$\Rightarrow T_{star} = \frac{\lambda_{sun} T_{sun}}{\lambda_{star}}$

2. Use Stefans law to find r

$$L = 4\pi r^2 \sigma T_{star}^4 \Rightarrow r = \sqrt{\frac{L}{4\pi T_{star}^4 \sigma}}$$

Stellar distance

closest star: α Centauri
closest galaxy: Andromeda galaxy

Intro

$$\text{luminosity} = \frac{\text{total energy output}}{\text{time}}$$

luminosity (W); total energy output (J); time (s)

- Intensity of radiation is power per unit area incident on a surface at right angles to the radiation

$$\text{Intensity} = \frac{\text{Power}}{\text{Area}}$$

Intensity (Wm^{-2}); Power (W); Area (m^2)

- at earth we cannot measure energy output of a distant star because the radiation spreads out a lot between the distances of the stellar bodies.

Inverse square law

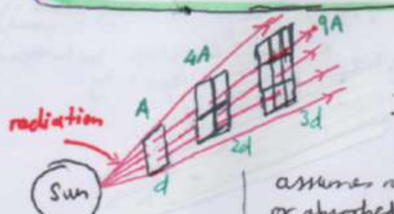
For a spherical surface, the light emitted has a surface intensity:

Intensity at surface of star

$$I = \frac{L}{4\pi r^2}$$

intensity (Wm^{-2}); L = luminosity (W); $4\pi r^2$ = surface area of sphere (m^2)

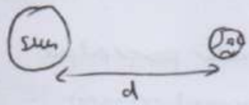
- The light from the surface of the star will continually spread out radially.
- This means that the area the radiation is incident on increases.
- So intensity is inversely proportional to surface area.
- power output of star remains, given by luminosity



$I \propto \frac{1}{A}$

$I \propto \frac{1}{d^2}$

assumes no light is scattered or absorbed between source and observer and source is treated as a point



Intensity of star on e.g. earth

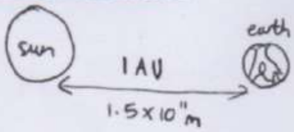
$$I = \frac{L}{4\pi d^2}$$

intensity (Wm^{-2}); L = luminosity (W); d = distance between earth and star (m)

Astronomical distances

3 new units:
- AU
- ly
- parsec

Astronomical unit



$1 AU = 1.5 \times 10^{11} m$

The light-year

- distance light travels in a vacuum in 1 year
- Is mainly used for expressing the diameter of our galaxies and distances between galaxies

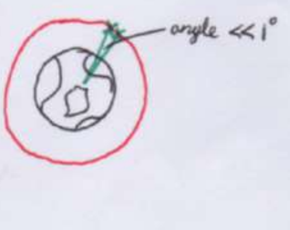
$1 ly = 1 year \times c$

$= 60 \times 60 \times 24 \times 365 \times 3.0 \times 10^8$

$1 ly = 9.46 \times 10^{15} m$

Arcminutes and Arcseconds

- very small scale of Angles used in astro because the angle subtended by 2 close stars in the night sky is very much less than 1°



1° = 60 arcminutes

1 arcminute = 60 arcseconds

$1 arcsec = \frac{1}{60} arcmin$

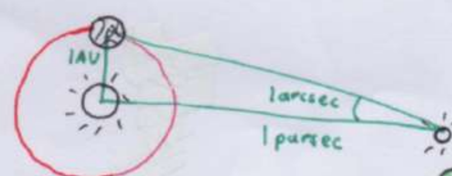
$= \frac{1}{60} \times \frac{1}{60}$

$1 arcsec = \left(\frac{1}{3600}\right)^\circ = 0.000277^\circ \approx 0.00028^\circ$

$1 arcminute = \left(\frac{1}{60}\right)^\circ = 0.01667^\circ$

Parsec

- Is the distance at which a radius of 1 AU subtends an angle of 1 arcsecond.



$1 pc = \frac{1 AU}{\tan(1 arcsec)}$

$= \frac{1.5 \times 10^{11}}{\tan\left(\frac{1}{3600}\right)^\circ}$

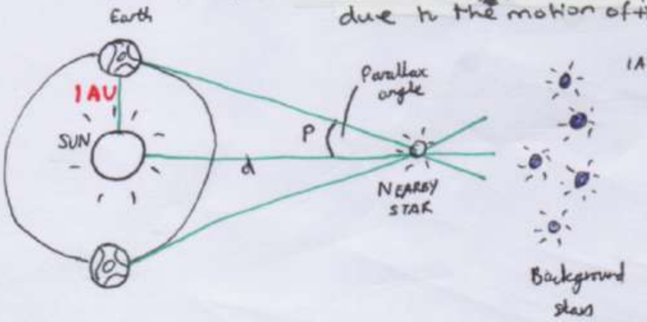
$1 pc = 3.08 \times 10^{16} m$

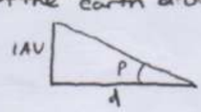
$1 pc = 3.26 ly = 2.06 \times 10^5 AU$

Parallax

Parallax – Is an observational effect where the apparent position of a nearby object changes with respect to a fixed background

- can use parallax to calculate distance to stars that relatively close to the Earth e.g. < 100pc away
- stellar parallax effect – this is the 'wobble' of nearby stars with reference to distant background stars due to the motion of the earth around the sun





$\tan p = \frac{1 AU}{d}$

- can use this to find d (distance between earth and nearby star)

Small angle approximations

$\tan\theta \approx \theta$

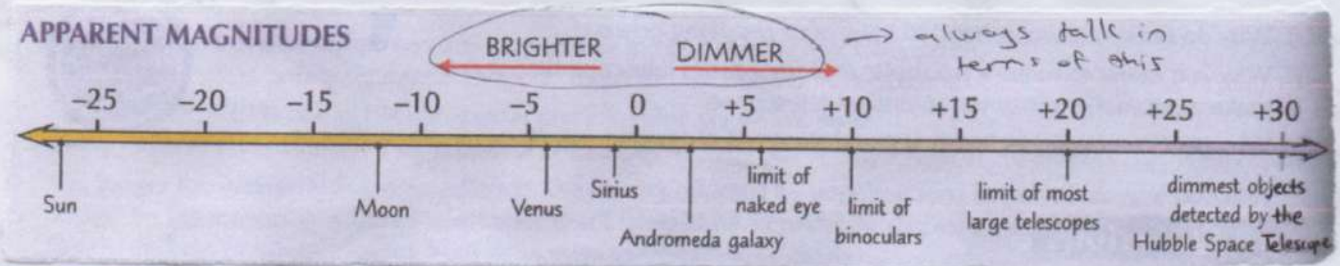
$\therefore p = \frac{1 AU}{d}$

$$d = \frac{1}{p}$$

d = distance from a source (parsecs); p = parallax angle (arcsec)

Apparent magnitude, m

- Is how bright things appear from earth. This will depend on luminosity and distance from earth
- A magnitude 1 star has an intensity 100 times greater than a magnitude 6 star. $-15-(-10)$



$$\frac{I_2}{I_1} \approx 2.51^{m_1 - m_2}$$

I_1 = intensity of star 1
I_2 = intensity of star 2
m_1 = apparent magnitude of star 1
m_2 = apparent magnitude of star 2

- Brightness is a subjective scale of measurement.
- Difference of magnitude 1 on scale is equal to an intensity ratio of 2.51 (therefore log scale is used)
- There is a negative relationship between apparent magnitude and density

Absolute magnitude, M

Indicates the star has greater power output

- only depends on luminosity of the star
- The absolute magnitude is the brightness (apparent magnitude) of the star if it was 10 parsecs away from earth

$$m - M = 5\log\left(\frac{d}{10}\right)$$

d is distance in parsecs (d = distance from earth)

- Some stars appear brighter because:
  - It could be closer
  - It could be emmiting more power at visible wavelengths
- If ~~the stars~~ m = M the star must be 10pc away

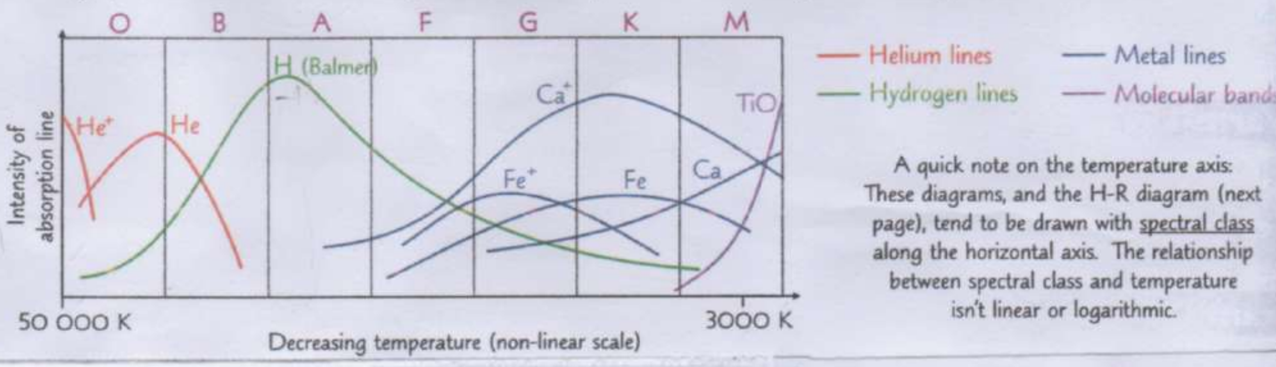
Stellar classification

Description of the main classes:

Spectral class	Intrinsic colour	Temperature / K	Prominent absorption lines
O	blue	25 000 – 50 000	He^{+}, He, H
B	blue	11 000 – 25 000	He, H
A	blue-white	7 500 – 11 000	H (strongest) ionized metals
F	white	6 000 – 7 500	ionized metals
G	yellow-white	5 000 – 6 000	ionized & neutral metals
K	orange	3 500 – 5 000	neutral metals
M	red	< 3 500	neutral atoms, TiO

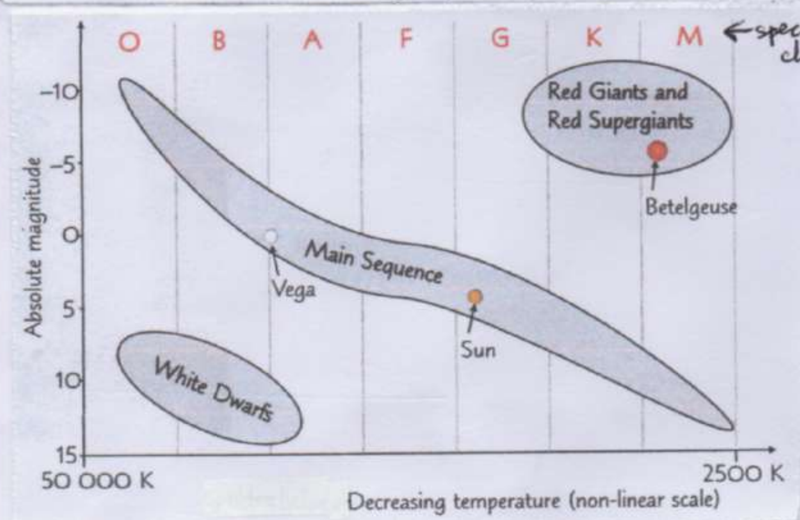
Temperature related to absorption spectra limited to Hydrogen Balmer absorption lines: requirement for atoms in an $n = 2$ state.

2) The graph shows how the **intensity** of the visible spectral lines changes with **temperature**:



A quick note on the temperature axis: These diagrams, and the H-R diagram (next page), tend to be drawn with spectral class along the horizontal axis. The relationship between spectral class and temperature isn't linear or logarithmic.

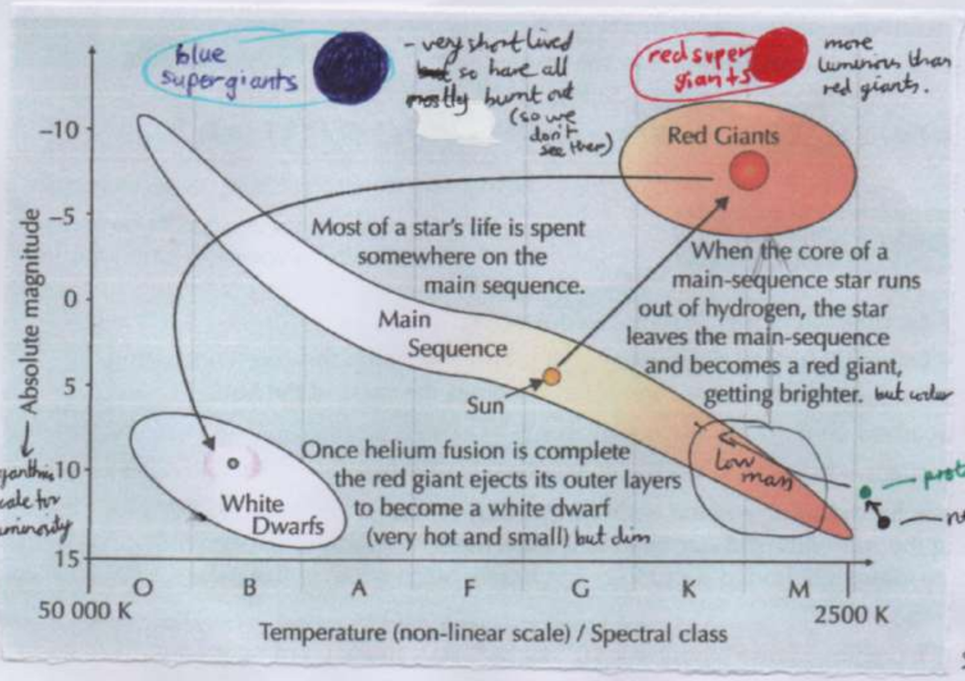
- The balmer lines represent the jump of electrons from the n=2 level to above levels
- The electrons start on n=2 as the star has high temp



← spectral class

- Our sun has surface temp of 5800K and so is a G-type star, absolute magnitude of 5
- stellar densities don't vary too much so a greater mass will be contained in a larger volume (to keep ρ constant)
- As temp decreases, mass decreases and radius decreases and luminosity decreases.
- more luminous stars radiate more energy through nuclear fusion at a faster rate. Hydrogen is used up quicker.
- This means hotter stars have a shorter lifetime

Hertzsprung - Russell diagram (HR diagram)

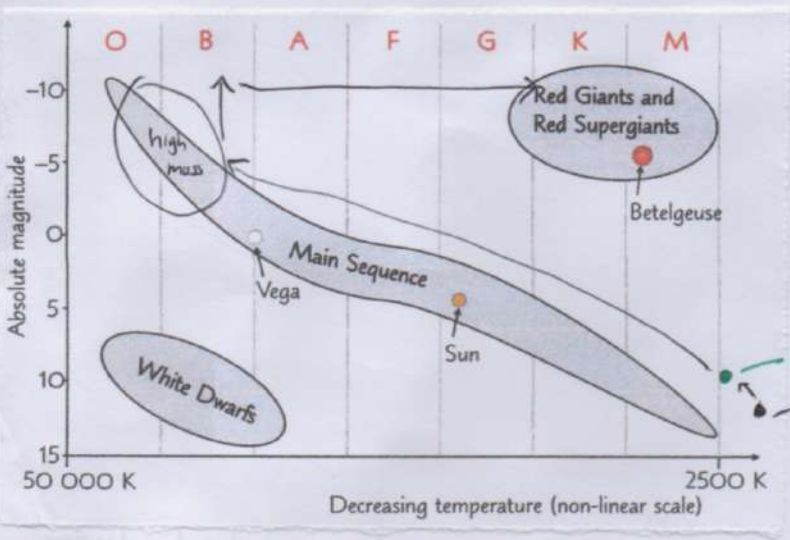


- Scales can be adjusted to be logarithmic like shown on y axis as absolute magnitude. This is the logarithmic values for luminosity
- hotter main sequence stars are more luminous and vice versa.
- Fewer stars clustered in other regions because the lifetime of these phases are shorter than the main sequence phase.

Evolutionary path of high/low mass stars

Low mass star evolution on HR diagram

- nebula has low temp and luminosity
- protostar has higher temp and luminosity
- because it is a low mass, it will form a cooler, less luminous main sequence stars, due to slower fusions.
- temp will fall and luminosity will increase when it becomes a red giant
- temp will start to increase as the cool layers are blown away forming white dwarfs.



High mass star evolution on HR diagram

- They have high mass so these are located as shown.
- when they increase in size luminosity increase while temp initially remains high. They then cool very rapidly and become red supergiants

Galactic bodies

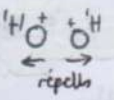
- Universe has billions of galaxies and hundreds of billions of stars
- Pluto is not considered a planet because there are other objects in its orbital path around the sun, so it doesn't clear its orbital path around the sun
- Asteroids are rocky with circular orbits
- Comets are icy with eccentric orbits (their orbits reach into the distant horizon of our solar system before whirling back closer to the sun.)
- Planetary satellites are objects that orbit a planet. Can be a moon (natural satellite) or even manmade satellite.

Star formation

Nubulae: dust and gas particles attract due to their charges. Electrostatic forces cause the particle to attract and coagulate. As mass gets larger, its larger gravitational force attracts more particles. This happens over millions of year forming gigantic clouds of gas (nubulae). They are very dense so they block light from surrounding stars.

Protosar: nubula gains mass and so more particles are attracted, so density increases. As the particles come together Ep is converted to thermal energy causing the temperature to increase rapidly. The cloud is uneven in density. The part with greater density attract more mass and so heat up more. This process form very hot dense sphere called the core in the dense region of the cloud forming a protostar

Nuclear fusion: To form a star the protostar must radiate energy. This is done through nuclear fusion in core. Temperature and pressure KE↑ to high levels, that electrostatic repulsion of +ive hydrogen nuclei are overcome and so they fuse to form a helium nucleus. This releases lot of energy which radiates outwards, making the star bright.



Main sequence: the radiation radiates outwards and so there is a pressure acting outwards from the core which is called radiation pressure. Collisions between nuclei in core also produces outwards pressure called gas pressure. When these 2 outwards pressures equal the gravitational forces (that compresses the star) the star is stable. Larger stars are on the main sequence stage for a shorter time because they burn their hydrogen more quickly (faster rate of fusion). All these forces act radially so the star has a spherical shape.

Star evolution (for low mass stars)

Red Giants: hydrogen in the core runs out so the core shrinks because of inward gravitational forces. This heats the outer shell (layer after the core) allowing hydrogen burning to occur again. Now radiation pressure causes the outer layers of the star to expand and becomes cooler. The star becomes a red giant. Shell becomes more helium rich

Planetary nebula: the carbon oxygen core is not hot enough for any more fusion so fusion stops occuring, so the core continues to contract. The shell becomes more unstable and so the star pulsates and ejects its outer layer into space as a planetary nebula

White dwarfs: what is left is a dense hot core called a white dwarf. No fusion takes place in a white dwarf. The white dwarf doesn't colapse anymore due to electrons degeneracy pressure that acts oppositely to gravatational collapse.

black dwarf: white dwarf cools until it loses all it energy. Takes very long and hasn't been observed

Star evolution (for high mass stars)

- high mass stars will have hotter cores and so these stars produce heavier elements because of high temperatures

Super red giants:

- due to the core contracting because of high gravitational forces, the core becomes hot enough for the He nuclei to fuse releasing huge amounts of energy causing greater expansion of the outer layers. The core becomes increasingly carbon and oxygen rich. This is due to core helium burning.

- After He runs out in the core it begins to contract, building up temperature on the shell so the helium in the shell begins to burn. This expands the outer layers even more forming a red super giant. This is shell helium burning.

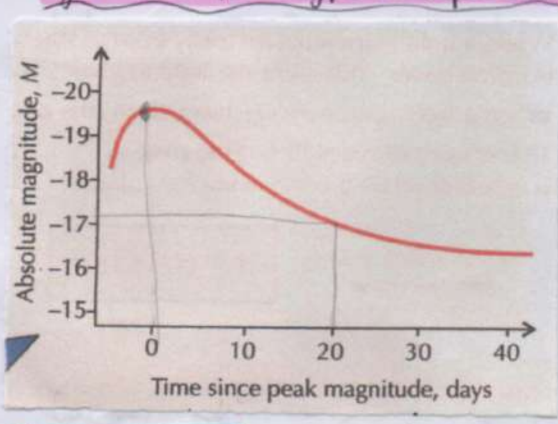
- After this, if the mass of the star is massive, there will be more nuclear burning in the core to form much heavier elements due to very high temperature. There will be many layers of nuclear burning in a red super giant.

- This process happens until an iron core forms (for very massive stars). Iron is stable and won't fuse.

Supernova:

- Is a very bright high energy explosion that occurs after nuclear burning stops in a red supergiant
- Iron don't fuse so immense gravitational force causes the layers of the star to collapse to its centre and causes an explosion. The layers bounces of the core and the material is expelled out into space.
- burst of gamma rays can be emitted for very large stars
- energy released in the explosion is 10^{44} J (roughly the total energy output of the sun in its life)
- elements heavier than iron are formed in a supernova explosion
- defining property of a supernova is that it increase absolute magnitude rapidly

Light curve for Type Ia supernova



- called type Ia because they always happen in the same way with a star of the same mass.
- so it can be used as a standard candle to determine distances
- They are so bright distances up to 1000 Mpc can be measured.
- Type Ia supernova is a result of an exploding white dwarf star which is part of a binary system
- The white dwarf increases in mass as it attracts material from its companion reaching a size that allows fusion. In some cases this causes the star to explode
- the neutron degeneracy pressure keeps the neutron star stable (prevent collapse into a singularity)

Neutron star:

- a dense hot core is left behind after the supernova and it keep contracting because the gravitational force is greater than electron degeneracy. This happens when the core is 1.4 times the mass of the sun.
- electrons are squashed into atomic nuclei combining with protons to form neutrons and neutrinos
- are made of neutrons and have density of $4 \times 10^{17}\ kg\,m^{-3}$
- some neutron stars emit radio waves
- they rotate very fast. Rotating neutron stars are called pulsars
- becomes a neutron star if its core mass is 2 times the mass of the sun.

Black holes:

- for extremely large stars (where the core mass left after the explosion is more than 3 times the mass of the sun) the core will collapse into an infinitely dense point called a singularity (this is because the neutron degeneracy pressure is not high enough to prevent gravitational collapse)
- Schwarzschild radius is the distance at which the escape velocity is speed of light
  - → radius of the event horizon
- has extremely strong gravitational fields

$$\frac{1}{2} \cancel{m} v^2 = \frac{GM\cancel{m}}{r}$$

$$r = \frac{2GM}{v^2} \Rightarrow R_s = \frac{2GM}{c^2}$$

(R_s in m; M = mass of black hole (kg); c = speed of light)

Supermassive black holes – from stars with large core masses.

- are thought to be at centre of galaxies because they have enough gravitational force to have billions of stars orbit it
- they have a mass of several million times the mass of the sun.

Doppler effect – the change in wavelength of a wave reaching an observer due to the motion of the wave source

- applies to wave sources that are moving
- change in wavelength and frequency is called the Doppler effect. This is because the waves bunch together infront of the source and stretch out behind it. This depends on the velocity of the source
- When light sources move away they become red (red shift) (wavelength is longer)
- when light sources move towards us they become blue (blue shift) (wavelength is shorter)

$z = \frac{v}{c}$ if $v << c$
(z = red or blue shift; v = radial (orbital) velocity; c = speed of light; v is much less than c)

$z = \frac{\Delta f}{f} = -\frac{\Delta \lambda}{\lambda}$
(z = red or blue shift; f = emitted frequency; λ = emitted wavelength (original))

$\Delta \lambda = \lambda_{emitted} - \lambda_{observed}$

$\Delta f = f_{emitted} - f_{observed}$

v = -ve = moving towards (blue shift)
z = -ve

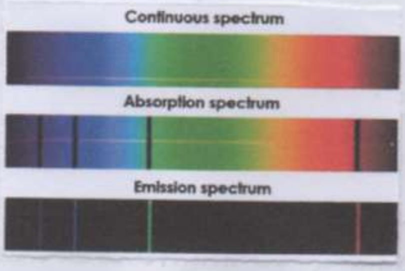
v = +ve = moving away (red shift)
z = +ve

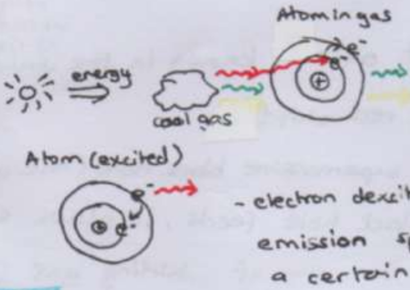
- z is treated as positive for red shift

Spectral line shifts

How spectra lines work

- each individual element has different absorption/emission spectra





electron absorbs red light and becomes excited (red is black in absorption spectrum as it was absorbed)

- electron dexcites and release a photon (red). This is indicated in the emission spectrum with the red colour. The photon will have a certain energy which will correspond to a wavelength.

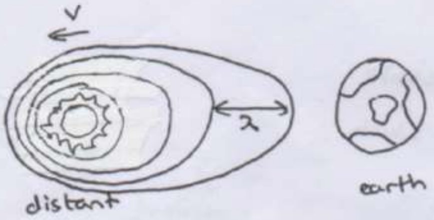
Absorption spectrum of the sun

To know what elements are in the atmosphere of the sun look at absorption spectra

- Atoms in the gas will absorb the energy, exciting the electrons (this will result in a certain line spectra)
- Absorption lines will differ from which element absorbs the energy
- The line spectra of the sun can be compared to other elements line spectra to see what elements are present on the sun

Red shift of galaxies

- The spectra of distant galaxies all show red shift (on the spectral line the wavelengths of the elements are longer than expected)
- In the case of our universe it is undergoing cosmological red shift (where space itself is expanding, stretching the light waves along with. The same formula hold as long as v is much less than c ⇒ $v << c$



↑ same applies for galaxies

- The stars motion will distort the wavefronts of light it emits so at Earth we observe longer wavelength (red shift) (vice versa for blue shift)

Conventional directions

z = +ve = move away from earth = red shift

z = -ve = move towards earth = blue shift

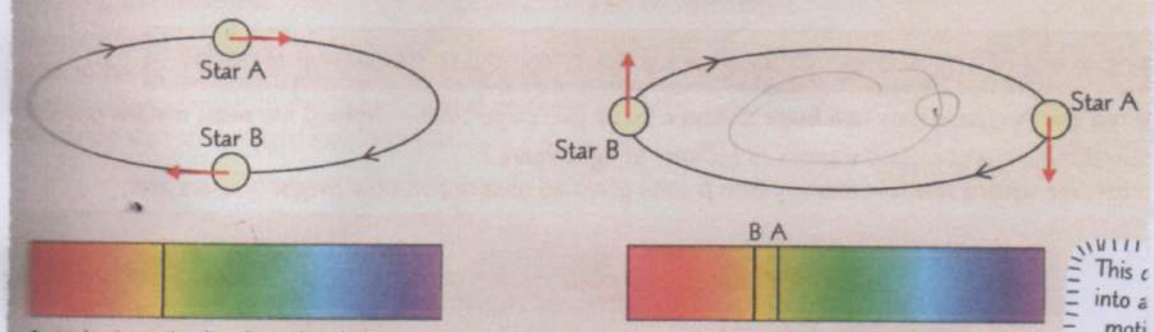
Spectroscopic binary stars

- Most of the stars we observe are 2 stars orbiting each other
- Many of them are too far away to be resolved with telescopes but their spectra lines show a binary star system

For simplicity, think about only one absorption line from the spectrum:

a) Both stars are moving at right angles to our line of sight, so there's no Doppler shift.

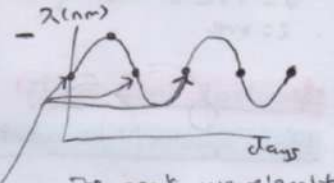
b) Both stars are moving along our line of sight. *Star A shows maximum blueshift.* Star B shows maximum redshift.



A single absorption line from the whole system

Separate lines from each star (one redshifted and one blueshifted)

- As the stars orbit each other, the separation between the lines goes from zero [a)] up to maximum separation [at b)] and back to zero in half a period



- The peak wavelength occurs when the star is receding from our view at its max velocity

eclipse - when star is moving at right angles to our line of sight

- circumference of orbit = orbital speed × orbital period

Qusars (bright radio sources)

- They are the most brightest and distant object known in the universe
- Therefore their spectra shows a huge red shift
- A quasar is thought to be an active supermassive black hole (one which takes in matter) at the centre of a distant galaxy.
- The black hole is surrounded by a huge mass of whirling gas falling into it which produces the bright light. Magnetic fields produce jets of radiation streaming out of the poles forming a quasar
- The black hole must consume mass of about 10 suns per year to produce the energy observed
- use equation $I = \frac{P}{4\pi d^2} \Rightarrow I 4\pi d^2 = P \Rightarrow P \propto Id^2$ to find distances / power outputs

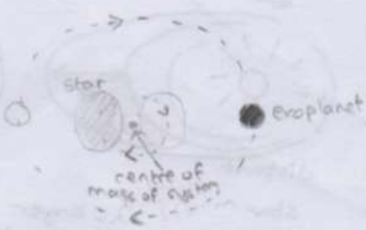
Exoplanets (extra solar planets)

- They are 'planets' that are not in our solar system
- They are hard to find because:
  - They orbit stars much brighter than them. The star therefore drowns out any light from the exoplanet
  - They are too small (the angle subtended is too small for the resolving power of most telescopes)

Detection techniques

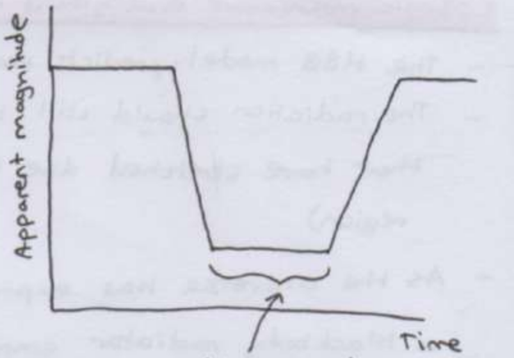
Doppler shift (radial velocity method)

- An exoplanet has a small effect on its stars orbit causing it to wobble
- This wobble cause tiny red and blue shifts in the star's emissions which can be detected on earth (suggesting precense of an Exoplanet)
- From this the min mass can be calculated
- Movement needs to be aligned with the observers line of sight to see a detectable shift



Transit method

- important need for combaration as there may be other reasons for Doppler shifts / periodic apparent magnitude changes



- This method measures the change in apparent magnitude as an exoplanet travels in front of a star
- when the planet crosses the star some of the light is blocked from the Earth's view (lead to a dip)
- From this the radius of the exoplanet can be found
- chances of the planet being perfectly lined up is low, so only can confirm observed exoplanets, not locations of them
- Repeated transits are observed to confirm the existance of exoplanet as sun spots can also cause variations apparent magnitude too

Hubbles Law and constant

- Spectra from galaxies all show red shift. The amount of red shift gives the recessional velocity (how fast the galaxy is moving away)
- $v = H_0 d$
  - v → recessional velocity (kms^{-1})
  - H_0 → Hubble's constant ($kms^{-1}Mpc^{-1}$), SI unit (s^{-1})
  - d → distance (Mpc) from earth
- It is generally accepted that H_0 lies between 65 - 80 $kms^{-1}Mpc^{-1}$
- The model of the expanding universe is that all points within the universe are moving away from each other
- The expanding universe model is supported by the fact that the further away galaxies are, the faster their recessional velocity

Big Bang theory (Hot big bang model)

- The universe is expanding, so it is cooling down. Back in time it must have been smaller and hotter.
- The theory states that the universe started of very hot and dense (infinitely hot, infinitely dense singularity) and has been expanding ever since.

Age of the universe

- If the universe is expanding uniformly the age of the universe is

$$t = \frac{d}{v}$$

$$t = \frac{1}{H_0}$$

(t = age of universe (s), H_0 ← Hubbles constant)

- This is a poor estimate because the universe is expanding at an accelerating rate. The excat value of H_0 is also not known
- Taking into account the radius of the sphere of the universe, it is estimated to be 46-47 billion light years
- The rate of expansion has not been constant. cosmologists are trying to explain this acceleration using dark energy (there is lots of speculation about this)

Cosmological principle

- Homogeneous - every part is the same as every other part (density of the universe is constant) ← same amount of matter in all areas
- Isotropic - everything looks the same in every direction
- on a large scale the universe is homogeneous and isotropic

Cosmic microwave Background radiation (CMBR)

- The HBB model predicts that lots of EM radiation was produced very early in the universe.
- The CMBR is thought to have originated from high energy gamma photons in the early stages, that have stretched due to the expansion of the universe (they are now in the microwave region)
- As the universe has expanded it has cooled to 2.7k. We can treat the universe as a blackbody radiator emmitting at a temperature of 2.7k
- 2.7k corresponds to peak wavelength of 1mm (in the microwave region of spectrum)
  ↳ interpreted as heat left over from Big Bang
- The Big bang theory is the only theory that can explain CMBR
- There are very tiny fluctuations in temperature in the CMBR. The hotter regions represent the the regions of star and galaxy formation

Relative abundance of helium and hydrogen

- The HBB model explain the large abundances of H and He in the universe
- The early universe was hot enough for hydrogen fusion to happen
- By studying how much helium there is compared to hydrogen, we can work out time frame for the fusion
- The hydrogen helium abundance helps to therefore model the expansion rate of the early universe (this is because there was the same amounts of H and He as if the entire universe was the core of 1 big star)
- The amount of He in the universe could not have only been produced by fusion in stars, it must have happened at the begining when there was enough temperature and pressure to to fuse H to make the proportion of He present in todays universe

Dark energy (has never been observed and the origin is unknown)

- Dark energy is thought to excert an overall repulsive effect throughout the universe causing the expansion of space
- The effect of dark energy increases as the universe expands causing it to expand even more

$$\text{Magnification} = \frac{\text{image height}}{\text{object height}}$$

$$M = \frac{\theta_i}{\theta_0} = \frac{f_o}{f_e}$$

θ_i → angle subtended by image at eye (° or rads)
θ_0 → angle subtended by object at unaided eye
f_o → focal length from objective lens (m)
f_e → focal length from eye lens (m)

Raliegh criterion

$$\theta_{min} \approx \frac{\lambda}{D}$$

θ_{min} → min angular resolution (rads)
λ → wavelength of light (m)
D → diameter of aperture (m)

collecting power ∝ diameter^2

$$\text{energy per unit area} = \frac{\text{Power}}{\pi r^2}$$

weins law

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

λ_{max} → peak wavelength (m)
T → absolute temp

Stefans law

$$P \text{ or } L = A \sigma T^4$$

P or L → power / luminosity (w)
A → surface area (m^2)
σ → stefans constant
T → absolute temp of surface (K)

$$\frac{d_1}{d_2} = \frac{T_2^2}{T_1^2}\sqrt{\frac{P_1}{P_2}}$$

Intensity at surface of star

$$I = \frac{L \text{ or } P}{4\pi r^2}$$

I → intensity (Wm^{-2})
L or P → luminosity / power (w)
$4\pi r^2$ → surface area of sphere (m^2)

$$\text{Luminosity / Power (w)} = \frac{\text{total energy output (J)}}{\text{time (s)}}$$

Intensity of star on e.g. earth

$$I = \frac{P \text{ or } L}{4\pi d^2}$$

I → Intensity (w^{-2})
P or L → power / luminosity (w)
d → distance between earth and star (m)

$$\text{Intensity} = \frac{\text{Power}}{\text{Area}}$$

$$1 \text{ arcsec} = \left(\frac{1}{3600}\right)^\circ$$

$$1 \text{ arc minute} = \left(\frac{1}{60}\right)^\circ$$

1 arcminute = 60 arcseconds

1° = 60 arcminutes = 3600 arcseconds

$$d = \frac{1}{p}$$

d → distance from a source (parsecs)
p → parallax angle (arcsec)

$$\frac{I_2}{I_1} \approx 2.51^{m_1 - m_2}$$

I_1 = intensity of star 1
I_2 = intensity of star 2
m_1 = apparent mag of star 1
m_2 = apparent mag of star 2

$$m - M = 5 \log\left(\frac{d}{10}\right)$$

m → apparent mag
M → absolute mag
d → distance from earth (parsecs)

scale of HR diagram 15 to −10

Orange	B	25–50	He^+, He, H
Bats	B	11–50	He, H
Ate	B-W	7.5–11	H (strongest), ionised metals
Fruit	W	6–7.5	ionised metals
Giving	Y-W	5–6	ionised & neutral metals
Korona	O	3.5–5	neutral metals
MOAN	R	<3.5	neutral atoms, TiO

$$R_s = \frac{2GM}{c^2}$$

R_s → schwarzchild radius (m)
M → mass of black hole (kg)
c → speed of light

$$z = \frac{v}{c}$$

z → red/blue shift
v → orbital / recessional velocity (ms^{-1})
c → speed of light (ms^{-1})

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

f → original emitted freq
λ → original emitted wavelength (m)

$$v = H_0 d$$

v → recessional velocity (kms^{-1})
H_0 → Hubbles constant ($kms^{-1}Mpc^{-1}$)
d → distance from earth (Mpc)

$$t = \frac{1}{H_0}$$

t → age of universe (s)
H_0 → Hubbles constant