MATTER AND HOW IT IS FORMED

Text: Heinemann Physics 11 4th Edition Chapters 5, 6, 7 Pages 167 – 256

Physics with Synno – Matter – Lesson 1

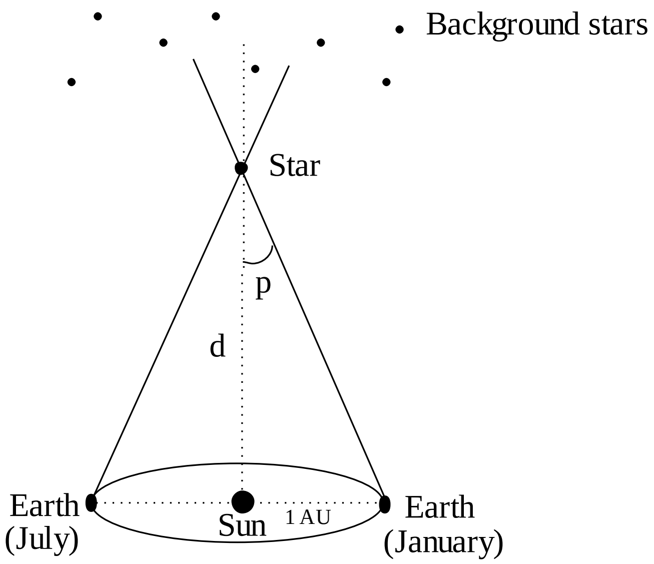
M.1 Measuring Stellar Information

Demo: Hold finger up. Close one eye, close the other

Video: How do we measure the distance to stars?

M.1.1 Parallax

The simplest method of measuring the distance to a star is by using parallax. Parallax is the apparent shifting of a star, against a background of more distant stars, due to the Earth's orbit. The parallax angle *p* is half the apparent shift in angle.



From this diagram we have

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

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

for small angles $\tan p \approx p$

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

where the angle is measured in arcsec. $\left(1\,\text{arcsec} = 0^0 00'01'' = \frac{1}{3600^0}\right)$

d is measured in parsec (pc)

Note: ***To convert degree to arcsec multiply by 3600***

The distances in space are huge. The distance to the Andromeda galaxy is approximately $\mathbf{2.4 \times 10^{22}} m$. ***Instead of metres other units are used.***

Astronomical unit (AU) – the distance from Earth to the Sun. 1.496×10^{11}m
Light Year (ly) – the distance light travels in one year. 9.461×10^{15}m
Parsec (pc) – 3.086×10^{16}m
To convert parsec to Astronomical units (AU) multiply by 206 265
To convert parsec to light-years multiply by 3.2616

Example. Estimate the distance, *d*, to a star if the parallax angle is 0.00006°. Give your answer in parsecs, light-years and astronomical units.

Solution $0.00006° = 0.00006 \times 3600 = 0.216$ arcsec

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

$$d = \frac{1}{0.216}$$

$d = 4.629$ (pc)

$d = 4.629 \times 3.2616 = 13.924$ light-years

$d = 4.629 \times 206265 = 954800$ AU

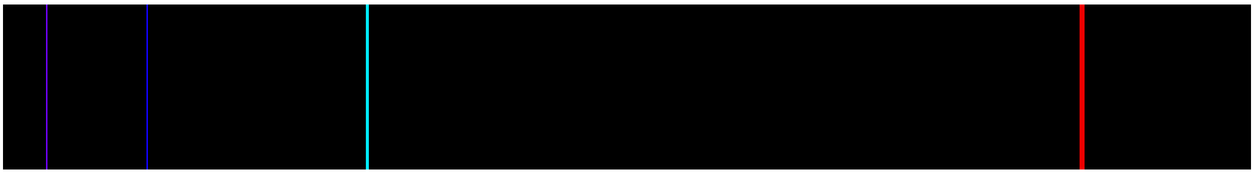
Parallax is useful for stars up to a distance of about 100 ly (≈33 pc) where the parallax angle is 0.03 arcsec. Beyond that distance, parallax angles are too small to measure accurately.

M.1.2 Spectroscopy

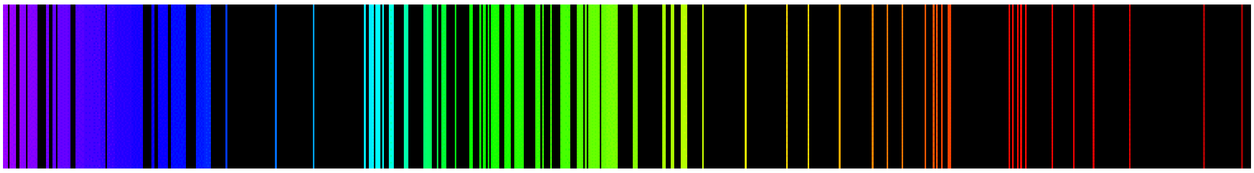
Video: Emission & Absorption spectra

Web: http://jersey.uoregon.edu/vlab/elements/Elements.html
http://chemistry.beloit.edu/BlueLight/pages/elements.html

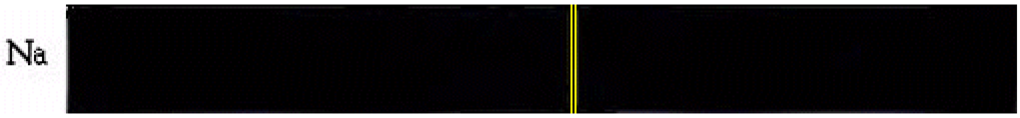
Gases may be excited so that they emit light. This is simply done by applying a high voltage to a discharge tube. When the light is analysed through the slit of a spectroscope we notice that there is not a continuous spectrum but a series of lines, called a line spectrum. When a high voltage is applied to a gas the energy can excite electrons to higher energy levels. When the electron drops back to its original energy level that energy is released in the form of light. Since there are only certain discrete energy levels for the electrons only certain wavelengths of light will be emitted. Thus each element will have its own line spectrum.



Hydrogen



Iron



Sodium

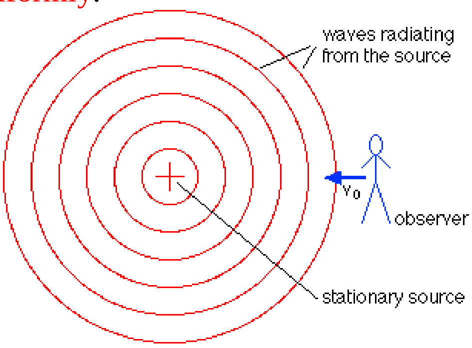
Stars also emit light when their atoms or molecules lose energy. Thus investigating the spectrum of light from a star can tell us about the chemical composition of that star. The line spectrum of the star is compared to those of known elements and those elements with line corresponding to the stars spectrum must be contained in the star.
The line spectrum and the continuous spectrum emitted by a black body are known as emission spectra.
The line spectra of a star tells us about the chemical composition of the star.
Observing the spectra of a star reveals other interesting information about the star.

M.2 The Expanding Universe

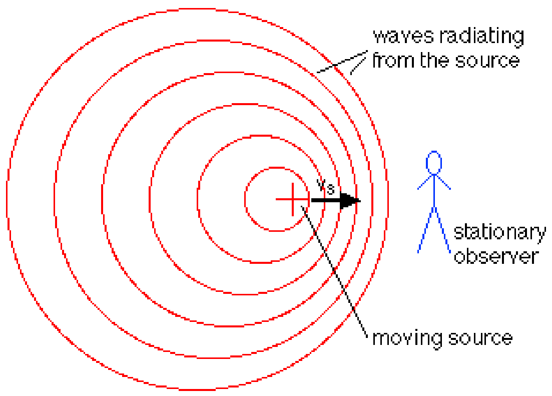
M.2.1 The Doppler Effect

Video: Doppler Effect
Car Horn Doppler effect
The Doppler Effect what does motion do to waves

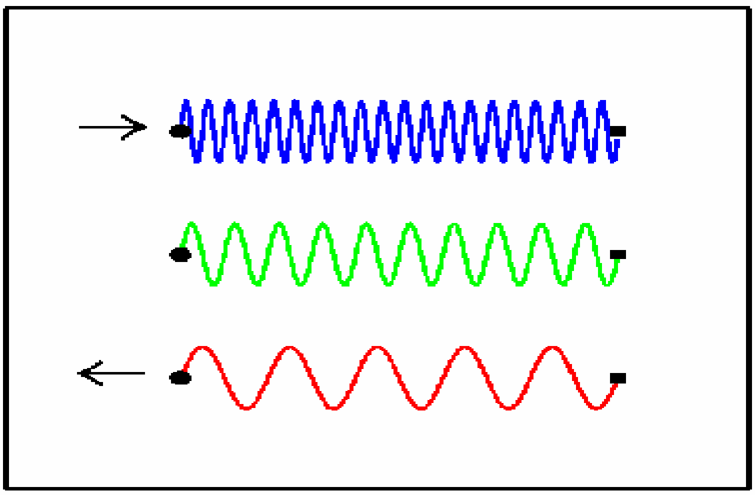
The Doppler effect describes the shift in the frequency of a wave sound when the wave source and/or the receiver is moving. Consider first the case of a stationary source, and an observer (you, for example) moving toward the source. As shown in the diagram, the waves are emitted by the source uniformly.



If the observer is stationary, the frequency received by the observer is the frequency emitted by the source. If the observer moves toward the source at a speed v_o, more waves are intercepted per second and the frequency received by the observer goes up. Effectively, the observer's motion shifts the speed at which the waves are received.
If the observer is stationary but the source moves toward the observer at a speed v_s, the observer still intercepts more waves per second and the frequency goes up.



The same principle applies for light as well as for sound. In detail the amount of shift depends a little differently on the speed, since we have to do the calculation in the context of special relativity. But in general it's just the same: if you're approaching a light source you see shorter wavelengths (a blue-shift), while if you're moving away you see longer wavelengths (a red-shift).

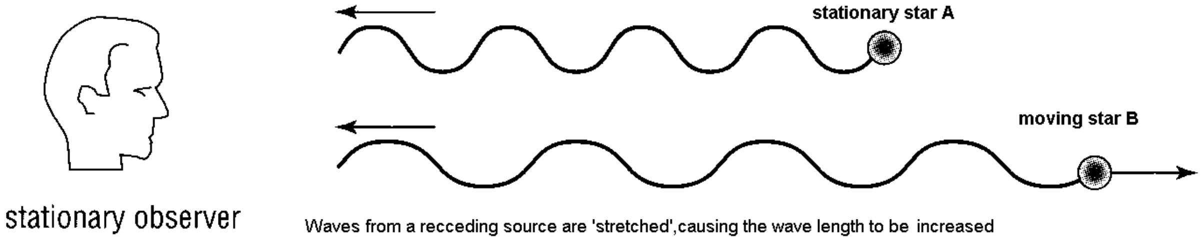


Distant galaxies are moving away from us extremely fast. So fast in fact that it is relatively easy to measure the shift in their spectral lines. This is evidence that the Universe is expanding, which is one of the most important pieces of evidence in support of the Big Bang picture.

M.2.2 Redshift

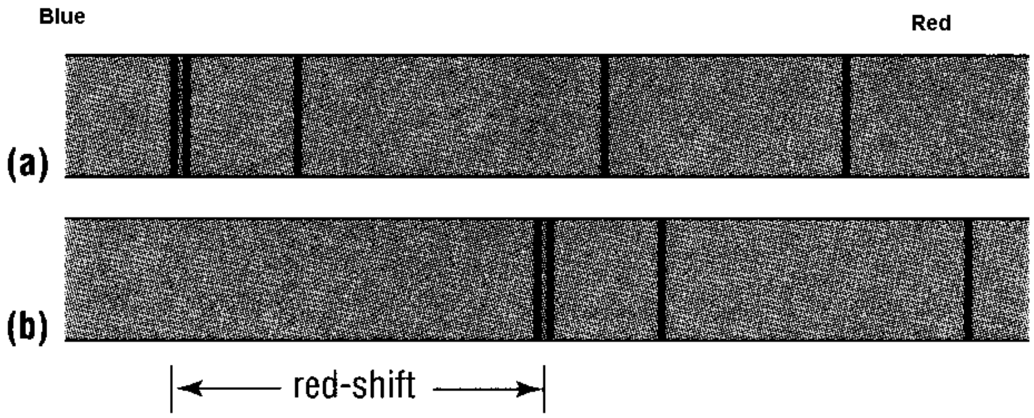
Video: Red Shift and Doppler Effect

If distant galaxies are moving away from us the effect is to increase the wavelength of the light emitted by the star.



Waves from a recceding source are 'stretched',causing the wave length to be increased

It has been found, for many stars and galaxies, that the spectral lines do not occur at their 'correct' frequencies. The pattern of lines is correct, but they are displaced, usually towards the red (longer-wavelength) end of the spectrum. We say that the spectrum shows a red-shift.



The line spectrum of a receding star shows a red-shift relative to that of a stationary star: (a) stationary star and (b) receding star

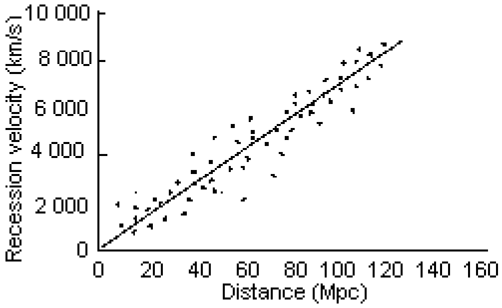
The red-sift of the spectral lines can be used to determine the velocity of a moving star, galaxy or other astronomical object.

A star whose spectral lines show a 10% increase in their wavelengths are moving at 10% of the speed of light, away from the observer.

M.2.3 Hubble's Law

Video: Brian Cox Explains the Hubble Law
Stephen Hawking - The Expanding Universe

Red-shifts can help us to measure the speeds of stars and galaxies. In the 1920's American astronomer Edwin Hubble discovered a relationship between the velocity of recession of a galaxy and its distance from us. He plotted a graph of velocity of recession against distance.



Hubble's law relates the velocity of recession of distant galaxies to their distance.

He showed that the further away a galaxy is, the higher its velocity. It was known that stars and galaxies were moving around. Hubble showed that this motion was not random; in general, the galaxies are all moving apart.

The graph can be represented as an equation relating velocity v and distance d:

$$v = H_o\, d$$

where H_o is the Hubble constant $70\, km\, s^{-1}\, Mpc^{-1}$
v is measured in km s^{-1}
d is measured in Mpc

Thus if we measure the red-shift of a galaxy, we can determine its velocity of recession, and from Hubble's law we can then determine its distance.
Hubble's constant is calculated from the gradient of the line on the graph. The value of Hubble's constant is a hotly debated topic. Since it relies on measurement techniques that have their own uncertainties.

Example. A distant galaxy is found to have a red-shift of 15%.
(a) calculate its velocity of recession

15% red-shift → 15% speed of light = $0.15 \times 3 \times 10^8 = 4.5 \times 10^7$ m/s

(b) deduce a value for its distance.

$v = H_o\, d \qquad 4.5 \times 10^7 = 70\, d$
$d = 6.4 \times 10^5\, Mpc \quad (1.98 \times 10^{25} km - a\ long\ way)$

M.1.4 Hubble and The Expanding Universe

Hubble concluded that space itself was expanding. If space expands, it carries the stars and galaxies with it.

If we believe that space is expanding, it follows that, in the past, its volume was much smaller and everything much closer together. In fact it, appears that, at some time in the past, everything in the Universe was compressed into a tiny space, perhaps even a point.
Another way of looking at it is, if distant galaxies are moving away from us with greater speed the further away from us they get (i.e. they are accelerating). This suggests that a great explosion could have occurred at some time in the past.
Hubble's law can help us estimate the age of the Universe.

From mechanics we know

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

rearranging we get

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

Hubble's law says

$$v = H_0 d$$

rearranging we get

$$\frac{d}{v} = \frac{1}{H_0}$$

Thus the value of $\frac{1}{H_0}$ gives an estimate of the age of the universe.

Example

What is the age of the Universe if the Hubble constant is taken as 70 km s^{-1} Mpc^{-1}?

The age of the Universe is the reciprocal of the constant:

$$T = \frac{1}{H_0} = \frac{1}{70}\ Mpc\ km^{-1}\ s$$

convert Mpc to km. 1 pc = 3.086×10^{16} m. = 3.086×10^{13} km

This means that 1 Mpc = 3.1×10^{19} km

$$T = \frac{3.1 \times 10^{19}}{70}\ s$$

$$T = 4.4 \times 10^{17}$$

$$T = 1.4 \times 10^{10}$$ That is 14 billion years.

Problem Set # 1: Text Page 177 All Questions