Edexcel Physics A-level

Topic 10: Space

Key Points

Distances

Distance measurements in space physics often make use of units that you may be less familiar with. You should understand the following:

- The **astronomical unit** (AU) is the **mean** distance between the Earth and the Sun
  - 1 AU = 1.5×10^{11} m
- A **light year** is the distance through space that a light **photon** travels in a year
  - 1 light year = 9.46×10^{15} m
  - 1 light minute = 1.80×10^{10} m
  - 1 light second = 3.00×10^{8}

Parallax

Parallax is a method used to measure **distances** in space. It involves observations of stars at different times of year as well as applying **trigonometry** to calculate distances:

- A distant star is viewed from **2 opposite points** on the Earth's orbit (6 months apart)
- The apparent **change of position** of the star relative to fixed background stars is measured
- This change in position is called parallax and can be used to calculate the distance to the star

A star is one **parsec** (pc) away from the Earth if the **parallax angle** is **1 arcsecond**.

Hertzsprung-Russell Diagrams

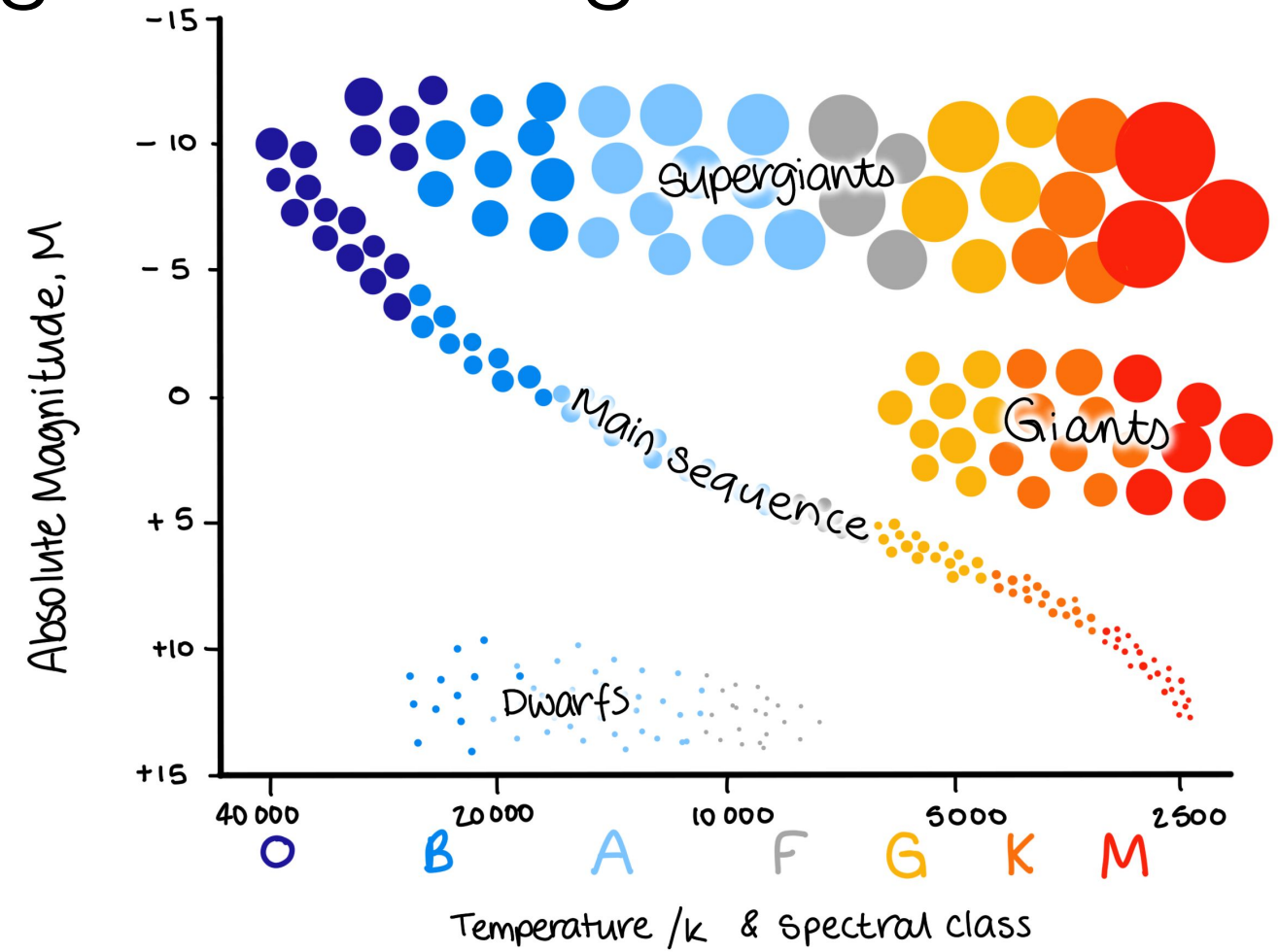
A **Hertzsprung-Russell diagram**, is a visual representation used to help understand the lifecycle of stars. It is a plot of **luminosity** against **temperature**. Stars generally fall into one of **four** different regions on the plot:

1. White Dwarfs
2. Giants
3. Supergiants
4. Main Sequence

The main sequence region is the largest region and forms a diagonal path through the centre of the diagram. **Hotter** stars fall to the left of this path, whilst **cooler** stars are found on the right hand side.

Hertzsprung-Russell Diagrams

You should be familiar with the following Hertzsprung-Russell diagram:



Doppler Effect

The **doppler effect** is the apparent change in **wavelength** of a wave, when the source moves relative to the observer:

- When the source moves **away** from the observer the wavelength will appear to **increase**
- When the source moves **towards** the observer the wavelength will appear to **decrease**

These apparent changes to wavelength consequently also result in a corresponding **change in frequency**. In the case of light, these changes mean that the **colour** of the light will visibly appear to change:

- When a light source moves **away** from the observer, the light will be shifted towards the **red** end of the colour spectrum
- When a light source moves **towards** an observer, the light will be shifted towards the **blue** end of the colour spectrum

The Doppler Equation

The **magnitude** of the wavelength shift that occurs due to the doppler effect, depends on the **relative speed** at which the source and observer are moving away or towards each other. The shift can be calculated using the below equation:

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

Where z = Doppler Shift, $\Delta\lambda$ = the change in wavelength, Δf = the change in frequency and v = the relative speed of the source and observer

You should be aware the when the source and observer are approaching each other, the relative speed should be a **negative** quantity, whereas when they are moving away from each other, the relative speed quantity should be **positive**. This means that positive z values indicate red-shift whereas negative z values indicate blue-shift.

Redshift

The observation of **redshift** in the light emitted by **distant galaxies** has led to **two** key conclusions about the universe:

1. All visible galaxies show redshift, suggesting that all galaxies are **moving away** from each other
2. The more **distant** galaxies demonstrate a **greater** amount of redshift, suggesting they are moving away at a **faster rate**

These redshifts are observed by analysing the **absorption** or **emission spectra** from the light emitted by these galaxies. The positions of the absorption or emission lines are seen to be shifted towards the red end of the spectrum when redshift occurs.

The Big Bang Theory

The **Big Bang Theory** is a theory for the origins of the universe. It states that the universe started as a very **small** and hot region that has **expanded** and cooled over **billions** of years, forming the stars and planets that are present today. There are two main pieces of **evidence** that support this theory over others:

1. Red-Shift
2. Cosmic Microwave Background Radiation (CMBR)

CMBR is radiation present today, that is unexplained for, other than by the Big Bang Theory. This theory explains that high energy **gamma radiation** was released in the big bang, and that this radiation has been stretched over time as the universe has expanded. This 'stretching' has caused the wavelength of the radiation to increase, and the frequency to decrease, hence why it is now of the order of **microwaves**.

Hubble's Law

Hubble's law relates the **distance** of distant galaxies to the **speed** that they are moving away at. It states that:

- The speed at which they are moving away, is **directly proportional** to the distance they are at
- The **constant of proportionality** in this relationship is known as '**Hubble's Constant**' and is denoted by 'H_0'

In equation form, this is:

$$v = H_0 d$$

This can be used alongside observations to produce an approximation for the **age of the universe**. Current data suggests that it has existed for around **14.5 billion years**.

Rate of Expansion

Cosmologists have made observations of the universe over the time and compared them to the data suggested by **Hubble's Law**. This led to the following observations:

- The actual **brightness** of distant galaxies, and the predicted brightness of them do not always agree with each other
  - Distant galaxies aren't as bright as predicted by Hubble's Law
    - This suggests that they are more distant than predicted

These observations led to the conclusion that the universe isn't expanding at a **constant rate**, but that the rate of expansion is in fact **accelerating**. The cause of this acceleration is currently unknown, but one suggestion is the existence of **dark energy**. It is believed that it is this energy that allows the rate of expansion to continually increase. However, this is currently only a **hypothesis**, since dark matter and dark energy can't be easily monitored or observed.