A2 Level Physics

Chapter 12 – Space

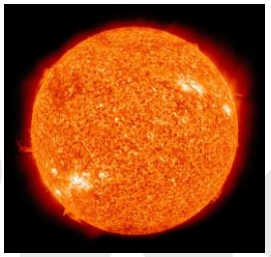
12.1.1 Stars and Hertzsprung-Russell diagram

Notes

The Universe

There are countless galaxies in the universe, each with many stars. It's also packed with interstellar dust and dark matter (neutrinos and black holes), and it's saturated with electromagnetic radiation, mostly in the microwave range.

- A **galaxy** is a cluster of billions of stars that rotate slowly around its centre of gravity. **Our galaxy is the Milky Way**.



- Our **solar system** is found in the Milky Way. The Sun, planets, asteroids, satellites and comets are all part of the solar system.

- **Stars** are massive nuclear fusion reactors that constantly release large amounts of electromagnetic radiation. **The Sun is a star**.

- **Planets** are relatively cold objects moving in slight elliptical orbits. The **Earth is a planet**.

- **Moons** are natural satellites of planets.

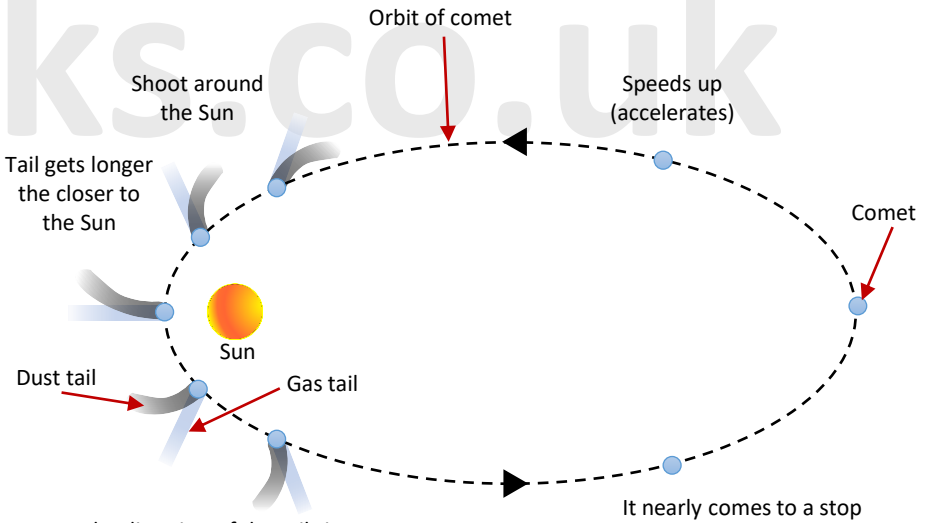
The Universe

Comets:

Consist of ice, rock and a cloud of gas.

The comet's faint tail emerges only when it is close to the Sun, and it always points away from the Sun.

The solar wind, an emission of ions from the Sun's surface, causes the comet's gases to spread out, become ionised and therefore glow creating the tail.



The direction of the tails is always away from the Sun. The gas (ion) tail points straight away from the Sun. The dust tail curls in the direction of the orbital path.

Formation of a Star

Summary:

Stars, such as our Sun, go through several stages in their existence and move around the H-R diagram as they do so.

- A star is formed from a cloud of gas and dust (a nebula).
- Gravitational collapse occurs and dust cloud collapses.
- Due to gravitational collapse, the temperature of the dust cloud rises. The KE of the atoms in the cloud increases, causing the cloud to heat up.
- Fusion occurs (when temperature is $\approx 10^7 K$).
- Protons/hydrogen nuclei combine to make helium nuclei and energy.
- Stable size star is produced when radiation pressure is equal to gravitational pressure.

Stars with a mass smaller than our Sun:

- When the star's hydrogen runs out, the outer layer expands while the core shrinks.
- Red giant formed and eventually the core becomes a white dwarf.
- The white dwarf is extremely dense, has a high surface temperature, and has a low luminosity, with no fusion reactions.
- Fermi pressure prevents the white dwarf from collapsing.
- Although a red giant is colder than a white dwarf, it has a large surface area and hence emits a lot of energy. As a result, the star shines brightest when it is at its coldest.

Formation of a Star

Stars with a mass greater than our Sun:

- When hydrogen/helium runs out the outer layers of the star expands, forming a super red giant is formed.
- The core of the star collapse rapidly, and a supernova is formed.
- Depending on the initial mass of the star the remnant either a neutron star or a blackhole is formed.

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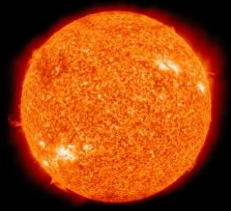
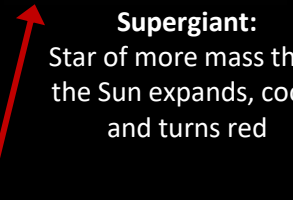
Formation of a Star

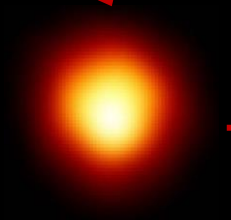
Nebula:
Dense region in the nebula begins to shrink, warms up and becomes a protostar.



Main sequence star:
Star shines as nuclear reactions inside produce light and heat



Supergiant:
Star of more mass than the Sun expands, cools and turns red

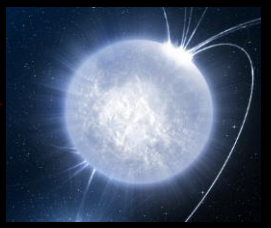


Red giant:
Star of less mass than the Sun expands and glows red as it cools

Supernova:
Supergiant explodes blasting away outer layers

Planetary nebula:
Outer layers of gas blown off, hot core will be exposed as white dwarf

White dwarf:
Star cools



Neutron star:
Core collapse and becomes very dense

Black hole:
Core collapse completely and vanishes

Black dwarf:
Star stops glowing

Formation of a Star

Neutron Stars

A neutron star is almost entirely made up of neutrons, which are packed as densely as the nucleons in an atom's nucleus.

Neutron stars are incredibly dense. They're very small and have a high rotational speed.

As they rotate, they release two beams of radio waves. These rays occasionally sweep over the Earth and can be seen as radio pulses, similar to lighthouse flashes. These pulsing neutron stars are called pulsars.

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Formation of a Star

Black Hole

Black holes are smaller than neutron stars, yet they can hold more matter. This means that their gravitational pull is enormous, so intense that even objects travelling at the speed of light are unable to escape.

Astronomers now believe that every galaxy has a supermassive black hole at its centre. They release tremendous radiation as they consume nearby stars, making galaxies' centres very bright.

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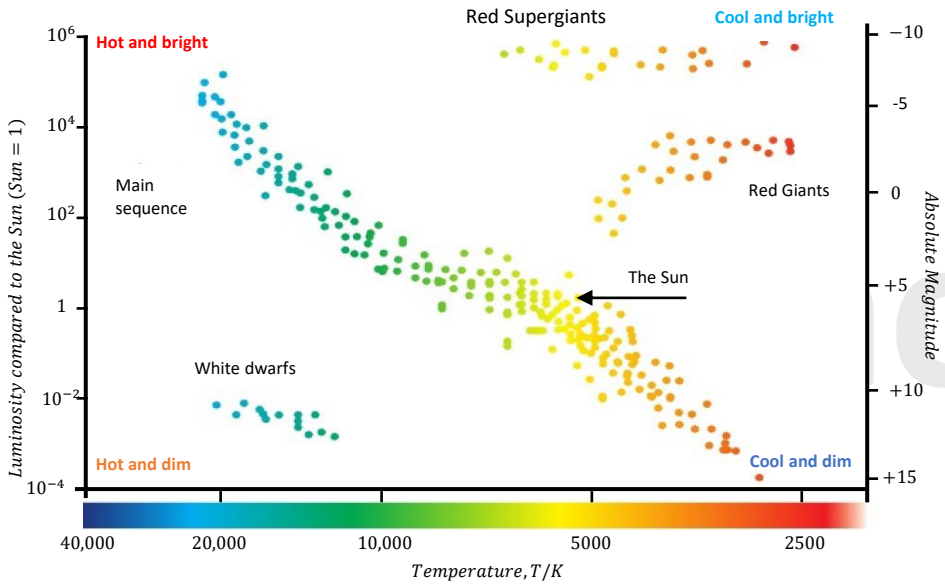
The Hertzsprung-Russell (H-R) Diagram

There is a general correlation between luminosity and star temperature, if you plot a graph of the two. However, keep in mind that the temperature measurement assumes the star behaves like a black body (an idealised physical body capable of absorbing all incident EM radiation regardless of frequency or angle of incidence and emitting all wavelengths of EM radiation). Also, the luminosity measurement is often inaccurate.



This diagram proved to be crucial in the study of star evolution. The main sequence is a diagonal line that runs across the H-R diagram and contains most of the stars we see. These are stable stars that will spend the most of their lives in this state. Their correlation represents the connection between the brightness and high temperature. It's worth noting that the plot is usually drawn with the hotter temps on the left.

The Hertzsprung-Russell (H-R) Diagram

Other stages of a star's evolution can be seen in other parts of the diagram, although they have a much shorter lifespan than the stable period. As a result, certain areas of the H-R diagram have considerably fewer stars. For example, while blue supergiants burn for only a few million years, most of these have already done so, and we don't see many of them and so the H-R diagram's top left quadrant is lightly populated.

The three separate zones on the H-R diagram, where stars fall, correspond to three main types of stars:

- The long, diagonal band is called the main sequence. Main sequence stars are fusing hydrogen into helium and are in their long-lived stable phase. The Sun is a main sequence star.
- Stars that have a high luminosity and a relatively low surface temperature must have a huge surface area. These stars are known as red giants and are found on the H-R diagram's top-right corner. Red giants are stars that have evolved off the main sequence and are undergoing fusion processes other than hydrogen to helium.
- The Sun will become a red giant in billions of years. It will grow to around 20% the size of Earth's current orbit and shine 3000 times brighter than it does now.
- Stars that have a low luminosity, but a high temperature must be very small. These stars are known as White Dwarfs, and they are roughly the same size as the Earth. They are found in the H-R diagram's bottom left corner. White dwarfs are stars that have reached the end of their lives and are progressively cooling down since all of their fusion processes have ended.

Tip: Make sure you know the axis scales by heart, as you may be required to draw an H-R diagram in your exam.

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Please see ’12.1.2 Stars and Hertzsprung-Russell diagram worked examples’ pack for exam style questions.

For more revision notes, tutorials and worked examples please visit www.tutorpacks.co.uk.

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