Physics Factsheet

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Stellar Processes and Life Cycle of Stars

Different GCSE Specifications include this topic to differing extents for GCSE. This Factsheet will either provide a useful revision of ideas covered at GCSE or fill in a gap in your knowledge and understanding as a good foundation for your A-level studies.

A Star is Born

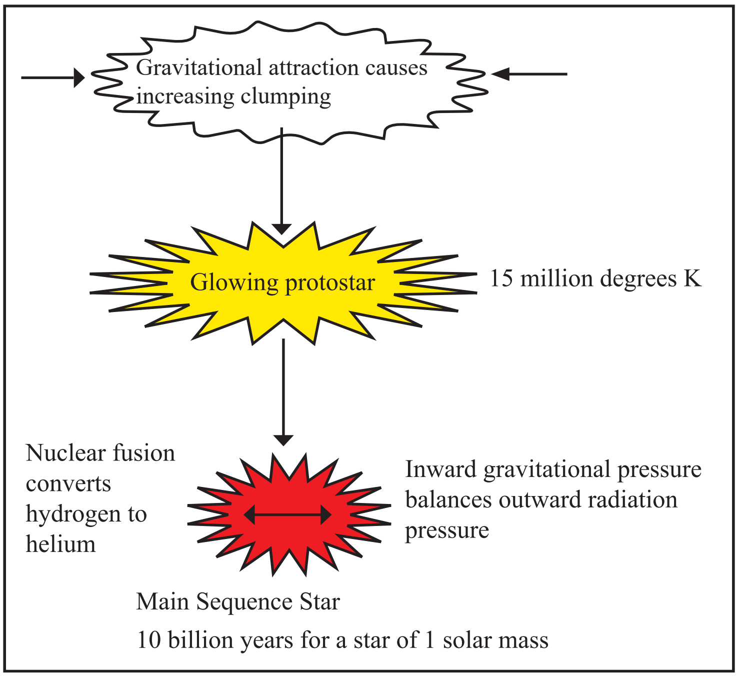
Nebulae – large clouds of dust and gas – are stellar nurseries.

Figure 1 Nebula

If the dust and gas were perfectly and uniformly distributed, then no changes would occur, but if there is a small disturbance, then some particles will come closer together and therefore gravitational attraction will increase. This process is self-perpetuating as more and more particles are attracted, forming "clumps" of matter. This causes the temperature to rise as the clump becomes denser, and the clump is now a glowing "protostar". The temperature in a protostar can reach 15million degrees K at its centre, if there is enough material in it. At this temperature, nuclear fusion can begin. The star releases energy and the inward pressure of the condensing matter is balanced by the outward radiation pressure, so that the star is stable. It is now a "Main Sequence" star. How long it remains as a main sequence star and what happens to it after that, depends on the mass of the star. A star about the mass of our Sun remains on the main sequence for about 10 billion years, until the hydrogen for the nuclear reaction runs out.

1. **It is gravitational attraction which starts the process.**
2. **Nuclear fusion of hydrogen to helium provides the energy.**
3. **The balance of inward gravitational pressure and outward radiation pressure allows the star to remain stable (main sequence) until the nuclear fusion process stops.**

Figure 2 Star formation



The Main Sequence

The Nuclear Process

Stars of about 1 solar mass (that is, the mass of our Sun) undergo fusion by the proton-proton chain reaction. You do not need to know the full details of the process, but essentially it begins with hydrogen nuclei (protons) and ends up as helium ions (2 protons, 2 neutrons). Several other particles are emitted and since the mass of the final products is slightly less than the sum of the original particles, a great deal of energy is released ($E = \Delta mc^2$, where E is the energy, Δm is the loss of mass and c is the speed of light).

Test your understanding:

1. *What force causes the clumping of matter in space?*
2. *What process begins when the protostar reaches a high enough temperature?*
3. *What opposing forces allow a star to remain a "main sequence star"?*

Classification of Stars

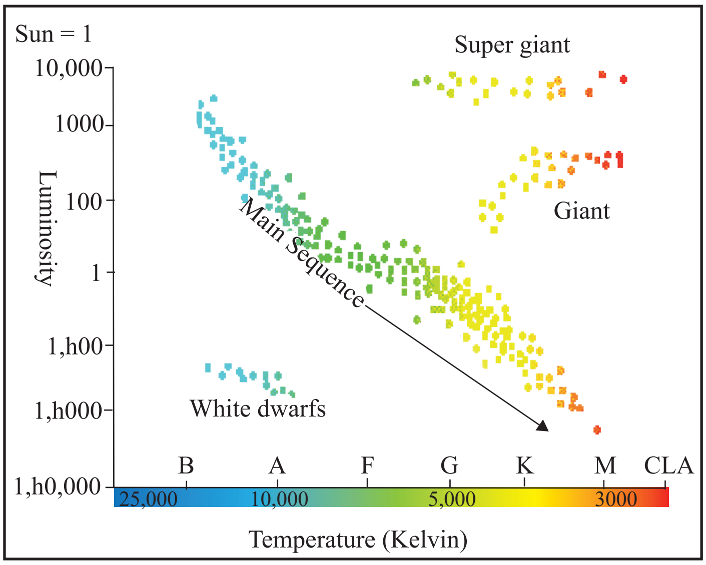
Stars are classified in several ways, including by colour (which is related to the temperature), and luminosity (which is total energy emitted per second).

The Hertzsprung-Russell Diagram

You will probably not have covered the Hertzsprung–Russell diagram in your GCSE course, but it will form part of your A Level studies. This is an introduction to the concepts.

Figure 3 is a convenient way of displaying features of stars.

Figure 3 The Hertzsprung-Russell Diagram



In one version of the Hertzsprung–Russell, luminosity is plotted against temperature, but note that the temperature scale goes from high to low, not low to high as usual. The luminosity is plotted in terms of the luminosity of the sun (designated 1).

Luminosity is the total energy emitted by the star per second and is dependent on 2 factors: the temperature and the surface area.

The Hertzsprung–Russell diagram plots luminosity against temperature for stars.

The scatter-graph in the Hertzsprung–Russell diagram shows a dominant diagonal line from top left to bottom right. These are all stars on the main sequence.

Time on the Main Sequence

A star of about 1 solar mass will spend about 10 billion years on the main sequence. Stars of higher mass have more material, but the reaction is faster because of a higher temperature, therefore more massive stars spend less time on the main sequence.

Other Groups of Stars on the Diagram

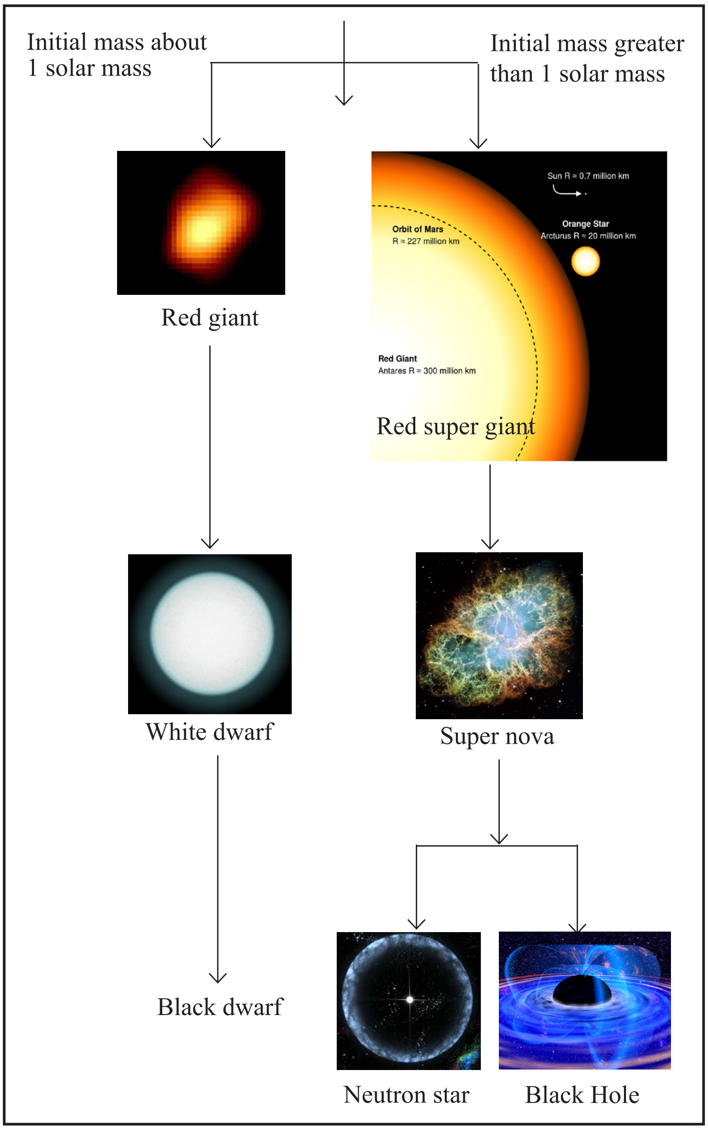
90% of stars are on the main sequence, but what happens when the nuclear fusion process ends? It depends on the initial mass of the star.

Test your understanding:

4. *What is plotted on a Hertzsprung–Russell diagram?*
5. *What is meant by the luminosity of a star?*
6. *What factors does luminosity depend on?*
7. *Explain why a larger mass star spends less time on the main sequence.*

What happens to a star when the fusion process stops depends on the initial mass of the star.

Figure 4 The Fate of Stars



For A-level, you will need to understand the processes the star that undergoes in more detail, but here is an outline, which should provide a framework for you, on which to build your further understanding.

Star of Solar Mass (the Mass of our Sun)

When the fusion reaction stops, the core collapses and gets hotter, and the shell expands. The surface area is much larger, therefore the luminosity increases, even though the temperature decreases, so the star´s position on the H–R diagram moves to that of a Red Giant. The outer layers drift off into space and the star is left smaller and so less luminous, as in the white dwarf position.

Star of Greater Mass

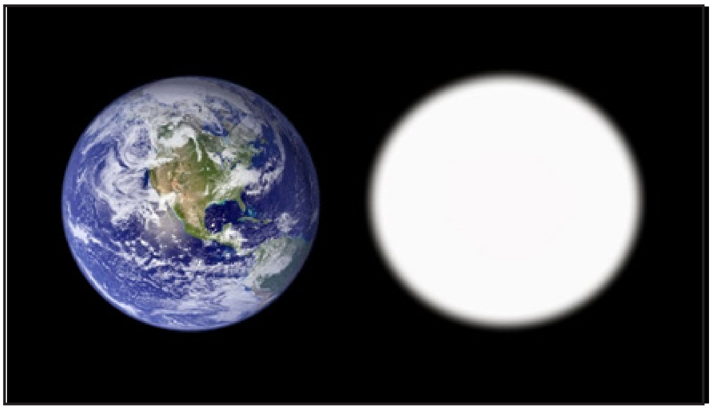
Initially, the same process occurs as in a star of solar mass (the core collapses and the shell expands), but since the star was more massive in the first place, it becomes a Red Super Giant. Now, instead of the outer layers just drifting off, the change is so rapid that the star explodes as a Super Nova. The core compacts even more until the electrons are drawn into the protons to form neutrons, and produces a Neutron star. If the star is dense enough it can become a Black Hole.

Test your understanding:

8. *What first happens to a star of about 1 solar mass when the fusion process stops?*
9. *What is the usual fate of a solar mass star?*
10. *Why does a Red Super Giant become a Super Nova?*

Characteristics of These Objects

Figure 5 White dwarf



A white dwarf typically has the mass of the Sun, but the size of the Earth.

Supernova

A supernova is not an object, but a process – the outer layers explode. A Super Nova redistributes the material, so that the stellar processes can begin all over again.

Figure 6 Supernova

Neutron Star

A Neutron star is typically about 20km in diameter, but has a mass of about 1.4 times that of the Sun; so dense that a teaspoonful of the material on Earth would weigh a billion tons!

Black Hole

The gravitation pull of a Black Hole is so strong that nothing can escape, not even light.

Figure 7 Black hole

Test your understanding:

11. Prepare a Power Point presentation, with accompanying script, to deliver to other students on the topic: "Formation of Stars and Stellar Processes".

12. Do your own research and produce an A4 sheet on "Black Holes" or "Neutron Stars".

Conclusion

Scientists´ understanding of the Universe and the processes taking place in it has increased rapidly in the last few years, mainly due to improved detection techniques and satellites and probes. It is bound to become an even more important area of study in the future.

Answers to "Test your understanding"

1. Gravitational attraction causes the clumping of material in space.
2. Nuclear fusion via the proton-proton reaction commences when the temperature is high enough.
3. In a main sequence star, radiation pressure balances the gravitational pressure.
4. On a Hertzsprung–Russelll diagram, luminosity is plotted against temperature.
5. Luminosity is the total energy per second given out by a star.
6. Luminosity depends on temperature and surface area.
7. A higher mass star spends less time on the main sequence because, although it has more material to begin with, the nuclear process is at a higher rate.
8. It becomes a Red Giant.
9. It ends up as a White Dwarf.
10. A Red Super Giant has much more material, so when the nuclear process stops, the outer core is removed explosively.
11. Look for:
    (a) Accuracy of the ideas.
    (b) Clarity of the presentation.
    (c) The student´s own interpretation of diagrams, etc. This is showing understanding, not just "cut and paste".
12. As for 11, but also look for the inclusion of new material.

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