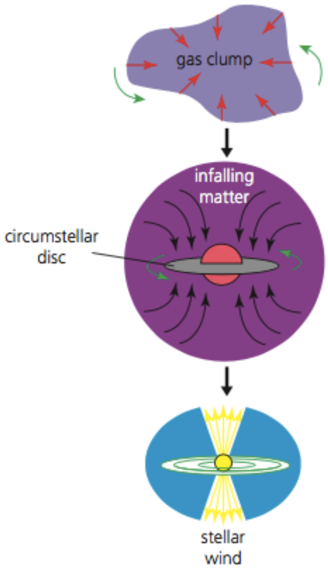
Stellar Evolution

Describe how molecular clouds form protostars.
Explain how nuclear fusion maintains an equilibrium state of main sequence stars.
Understand the 2 nuclear reaction pathways of a stars energy source

Star Birth

Stars are born in the 'space' between stars called the **interstellar medium**, which contains **molecular clouds** (see right) that are mostly made up of cold hydrogen gas in the form of atoms. About 1% of this material is 'dust' in the form of silicates and graphite material.



Protostars are formed when the irregular clumps rotate, and the action of gravity and the conservation of angular momentum spins them inwards to form a denser spherical centre. As such, the density and temperature increase. This is surrounded by a rotating at disc of material called the **circumstellar disc**, where planets may form. and

After a time the temperature of the star so that the mutual **electrostatic repulsion** between hydrogen nuclei can be overcome and **nuclear fusion** reactions begin in its core. A strong outward **stellar wind** is produced, which opposes the infall of material. It starts to shine in the visible part of the electromagnetic spectrum, and is now known as a **pre-main-sequence star**.

Main Sequence Stars and Nuclear Fusion

An equilibrium state is reached because of a balance between the star's own gravitational force due to mass of its outer layers pushing inwards and the internal gas pressure caused by hydrogen burning pushing outwards.
The star now has a fixed mass, and its energy comes only from **nuclear fusion**, not from **gravitational contraction**. It is now a **main-sequence star**. Its mass will determine its future evolution.
The fusion of hydrogen nuclei with a release of nuclear binding energy, known as **hydrogen burning**, is the primary source of energy generation in main-sequence stars.

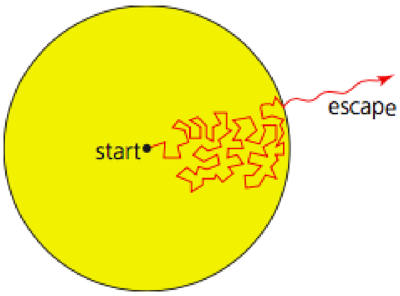


Figure 3 *Radiative diffusion in a star. Photons from the core follow a random path as they travel to the surface, taking thousands of years to do so.*

There are two principal nuclear reaction pathways in which hydrogen burning occurs in a star, determined by the core temperature of the star. These are the **proton–proton chain** (or **p–p chain**) and the **carbon–nitrogen–oxygen cycle** (or **CNO cycle**). In each of these reactions, four protons combine by nuclear fusion to form a single helium nucleus with a small loss of mass, which, by the mass–energy relation $\Delta E = \Delta mc^2$ is released as energy.

Energy from the fusion reactions is transported from the core to the outermost layers by convection and radiative (photon) diffusion.

Nuclear Reaction Pathways

proton–proton chain converts hydrogen into helium in three steps:

$${}^{1}_{1}H + {}^{1}_{1}H \rightarrow {}^{2}_{1}H + {}^{0}_{1}e + \nu_e$$

$${}^{1}_{1}H + {}^{2}_{1}H \rightarrow {}^{3}_{2}He + \gamma$$

$${}^{3}_{2}He + {}^{3}_{2}He \rightarrow {}^{4}_{2}He + {}^{1}_{1}H + {}^{1}_{1}H$$

The CNO cycle has 6 steps:

$${}^{12}_{6}C + {}^{1}_{1}H \rightarrow {}^{13}_{7}N + \gamma$$

$${}^{13}_{7}N \rightarrow {}^{13}_{6}C + {}^{0}_{1}e + \nu_e$$

$${}^{13}_{6}C + {}^{1}_{1}H \rightarrow {}^{14}_{7}N + \gamma$$

$${}^{14}_{7}N + {}^{1}_{1}H \rightarrow {}^{15}_{8}O + \gamma$$

$${}^{15}_{8}O \rightarrow {}^{15}_{7}N + {}^{0}_{1}e + \nu_e$$

$${}^{15}_{7}N + {}^{1}_{1}H \rightarrow {}^{12}_{6}C + {}^{4}_{2}He$$

KEY IDEAS

- Interstellar molecular clouds of hydrogen gas and dust form clumps that collapse under their own gravity to form protostars.
- As the density and temperature of a protostar increase, it begins to shine, first in the infrared. Then nuclear fusion reactions start in its core and it becomes a pre-main-sequence star.
- When fusion reactions are established, a stable equilibrium state is reached and the star shines visibly as a main-sequence star for most of its life.
- The fusion of hydrogen into helium is the primary source of energy in a main-sequence star.
- The energy from the core is transferred by convection and radiative diffusion to the star's outer layers and escapes into space as photons.