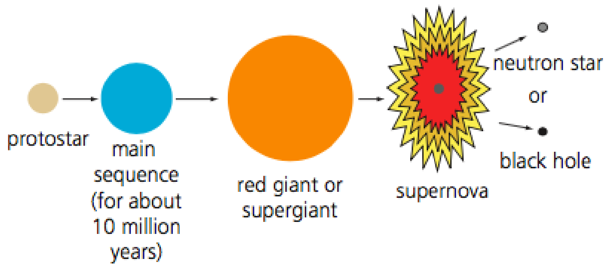
Evolution of Massive Stars

Explain the reasons for the transition between a main sequence star and a red [super] giant
Describe when supernovae may occur.
Apply knowledge to explain why Neutron stars and pulsars are formed.

Giant and Supergiant Stars



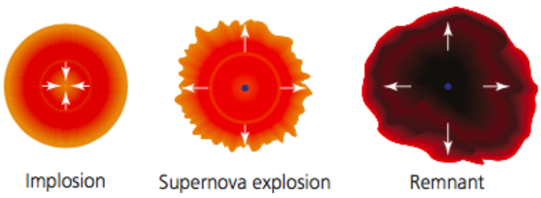
The evolution of stars with a mass higher than about $1.4M_{Sun}$ is different from that described previously. This is because these stars fuse hydrogen to helium but do so primarily via the CNO cycle. Stars between $1.4M_{Sun}$ and $3M_{Sun}$ also evolve into red giants, but they end their life as **supernovae**, leaving behind a **neutron star**. Stars with a main-sequence mass in excess of 3*M*Sun evolve into red **supergiants**, and when these explode as supernovae they leave behind a **black hole.**

A red supergiant is formed when the high-mass star runs out of hydrogen in its core. The core contracts and the star expands in size, burning hydrogen in its outer layers, increasing its luminosity and becoming much redder. The interior temperature gets much higher than in red giants, so elements heavier than hydrogen and helium can be fused, producing elements as heavy as iron, in a series of layers around their core.

Blue supergiants also exist, which are much hotter than red supergiants but smaller. They form when a star of more than 10 solar masses exhausts the nuclear fuel in its core and starts burning its outer layers. Like red supergiants, they have very short lifetimes of only a few million years.

Supernovae

A **supernova** is a star that suddenly and very rapidly increases in absolute magnitude because of an explosion that ejects most of its mass. Supernovae are classified into two types:



- Type I supernova. This is a star that accretes (draws in) matter from another star in a **binary system** until it becomes compressed and runaway nuclear reactions are set off, blasting its matter into space.
- Type II supernova. This is a single star – a red giant or supergiant – that runs out of nuclear fuel and collapses rapidly under its own gravity, ejecting its outer layers with enormous energy.

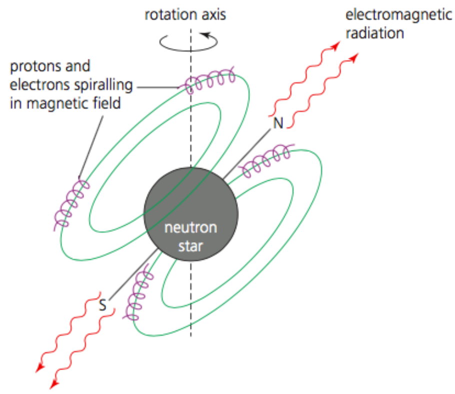
In a Red Giant, or Red Super-Giant, when the nuclear fuel is exhausted, the gravitational compression is so strong that the star collapses on itself extremely rapidly creating a gigantic explosion, and rapidly increasing the absolute magnitude. The outer parts of the star are blown into space. What is left is called a supernova remnant, at the centre of which is an exotic object called a **neutron star**.

Neutron Stars and Pulsars

What is left after a supernova is an extremely dense object called a **neutron star**. The gravitational contraction has become so great that the electrons in the atoms are forced into protons, forming neutrons. A neutron star is thus composed almost entirely of neutrons, surrounded by an iron outer crust. The escape velocity from the surface of an object of mass M and radius R is given by:

$$V_{esc} = \sqrt{\frac{2GM}{R}}$$

where G is the gravitational constant G = 6.67×10^{-11} N m^2 kg^{-2} .



Neutron stars may behave as a **pulsar**. A pulsar is a rotating neutron star with a very strong magnetic field. The surface of a neutron star has numerous protons and electrons where the gravitational field is not strong enough for them to be pushed into each other to form neutrons. They are accelerated towards the magnetic poles of the neutron star, and in doing so emit electromagnetic radiation over a wide range of wavelengths in a narrow beam in opposite directions. The neutron star can rotate up to 600 times per second, giving a pulsed beam rather like a lighthouse.