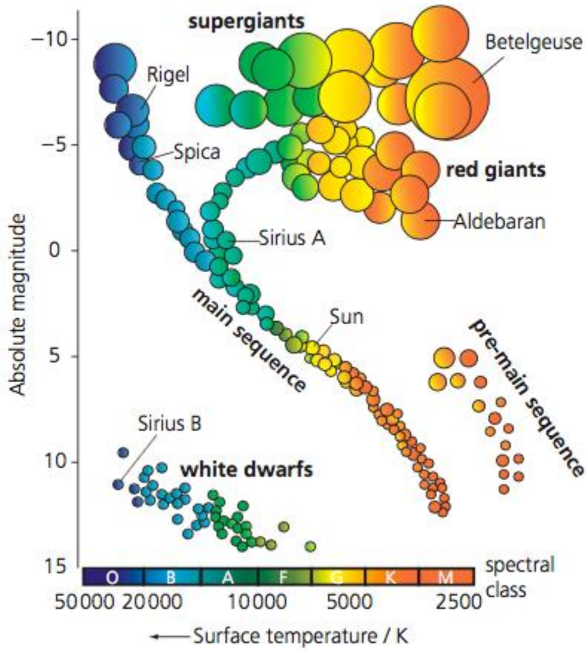
Life cycle of stars and the Hertzsprung-Russel Diagram

Describe and explain an HR diagram.
Use an HR diagram to explain the evolutionary path of a Star of given mass.
Understand the life-time of a star of differing spectral classes

Hertzsprung-Russel Diagram

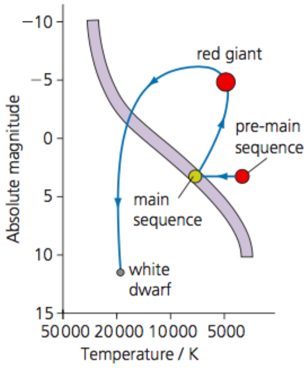


A graph of absolute magnitude versus spectral class of a star is known as a **Hertzsprung–Russell diagram** (or **HR diagram**).
An **HR diagram** is essentially a plot of the luminosity of stars against their surface temperature. The stars on the HR diagram are divided into four principal groupings:

1) **Main sequence (the long diagonal band)**. At the top of the main sequence are the hot and luminous blue stars, and at the bottom are the cool and dim reddish stars.
2) **Red giants** are similar in mass to our Sun but have an expanded outer shell and hence large size and surface area. They are cooler and hence redder but highly luminous. Nuclear fusion of helium occurs in their cores.
3) **Supergiants** have masses typically 10–100 times that of the Sun and are therefore substantially larger and more luminous even than the red giants. In their cores the temperatures are hot enough for nuclear fusion reactions to produce carbon and heavier elements.
4) **White dwarfs** are old stars that have a high surface temperature but are not very luminous, because they no longer generate energy by nuclear fusion, and because they are small (planet sized). They are extremely dense. Eventually, they cool to the point of emitting no heat or light and become **black dwarfs**, which appears to be the end state of all low-mass stars.

From the **HR diagram**, we can see different stages of stellar evolution – how stars are born, grow old and die.

Evolution of a Sun-like star on the Hertzsprung–Russell diagram

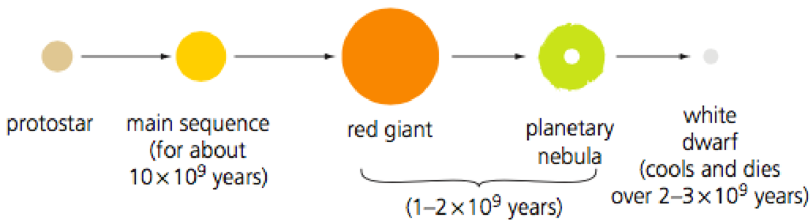


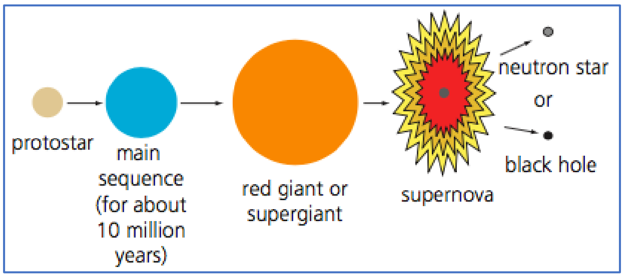
A star will move through different stages in the HR diagram as it moves though different stages in its own life cycle. Eventually, when the red giant star has exhausted (following the path of protostar → pre-main sequence star → main sequence star → red giant) all of its nuclear fuel, its outer layers are ejected (thrown off), forming a **planetary nebula** (diagram bottom left), and its core collapses into a dense **white dwarf**. Since nuclear burning has ceased, there is no more outward pressure to halt the crushing force of gravity, and the core of a white dwarf is compressed to a size roughly the same as that of the Earth.

The lifetimes of stars

The lifetime of a star is determined by its mass. Stars spend roughly 90% of their lives converting hydrogen into helium on the main sequence, and the mass of a star determines the rate of hydrogen burning. In more massive stars fusion reactions proceed at a faster rate than in lower mass stars due to the higher temperature and pressures in their cores. The Sun, a G type star, has a main-sequence lifetime of about 10^{10} years. It is currently about 5×10^9 years old. Stars higher along the main sequence than the Sun (spectral classes O to F) must be younger than the Sun or they would have used up all the hydrogen in their cores and would have moved off the main sequence.

Mass / M_{Sun}	Spectral class	Main-sequence lifetime / 10^6 year
25	O	3
15	B	15
3	A	500
1.5	F	3000
1.0	G	10 000
0.75	K	15 000
0.50	M	> 200 000


protostar
main sequence
(for about
10 × 10^9 years)
red giant
planetary
nebula
white
dwarf
(cools and dies
over 2–3 × 10^9 years)
(1–2 × 10^9 years)


protostar
main
sequence
(for about
10 million
years)
red giant or
supergiant
supernova
neutron star
or
black hole