Physics Knowledge Organiser

P16 - Space

Our solar system

Our solar system consists of:

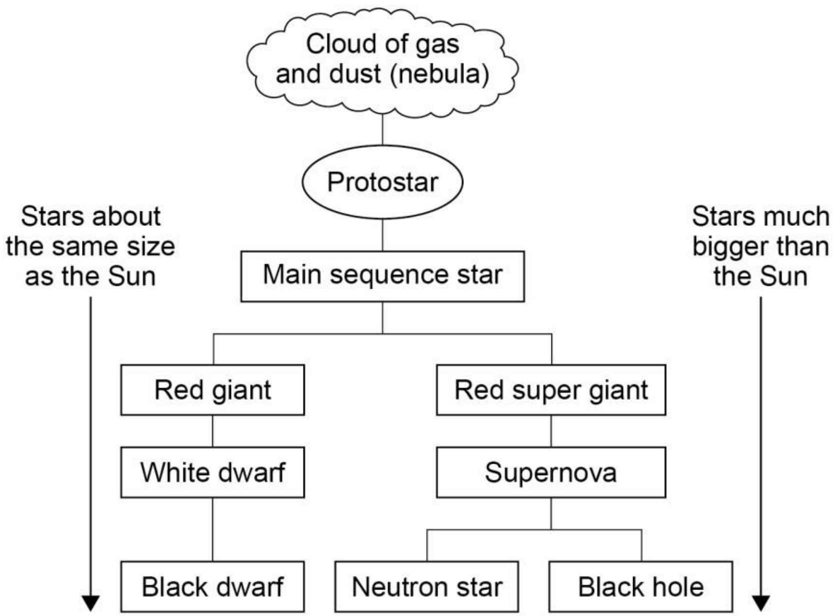
- One star: the Sun;
- Eight planets, which orbit the Sun;
- Dwarf planets, such as Pluto, which also orbit the Sun;
- Natural satellites: the moons that orbit some of the planets (including our moon);
- Other objects like asteroids and comets.

Our solar system is a very small part of the Milky Way galaxy. Galaxies consist of millions of stars, held together by their gravitational attraction to one another.

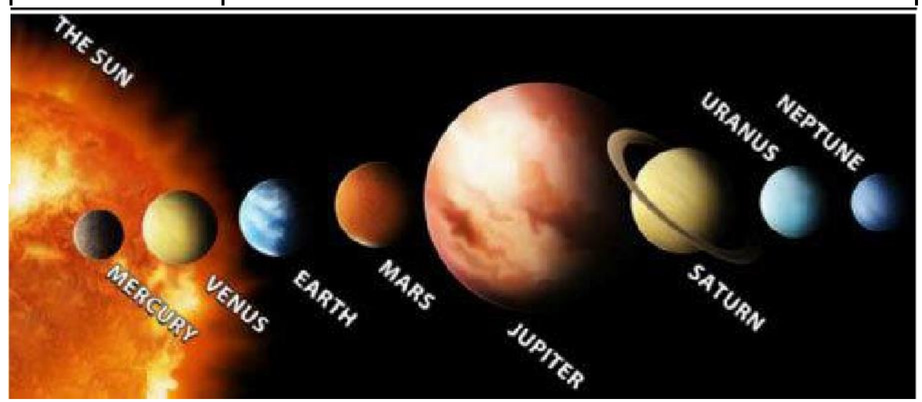
Stars and their life cycle

Stars form when a huge cloud of gas and dust (a **nebula**) comes together thanks to the **gravitational** attraction between the particles from which it is made. The diagram outlines the stages a star goes through during its life cycle. Note that the stages of the life cycle depend on the **initial mass** of the star.

Lower mass stars (like the Sun) end more discreetly than others with much larger masses.



Key Terms	Definitions
Star	A huge (compared to Earth) sphere of superhot gas (plasma) undergoing nuclear fusion reactions.
Planet	A spherical object much smaller than a star, made of rocky or gaseous material (or a combination), which orbits a star.
Dwarf planet	Small planets that have not cleared their orbit of other material. Like planets, they orbit a star.
Satellites	Object that orbit a planet. Natural satellites are not launched by humans – so moons are natural satellites. Ones that we launch are called artificial satellites.
Orbit	To follow a path around another object due to the gravitational attraction between the objects, while being physically separated. Orbits can be circular, or elliptical (oval shaped).
Galaxy	A giant cluster of stars held together by their gravitational attraction to one another. Our galaxy is called the Milky Way.
Nebula	A cloud of gas and dust in space.
Nuclear fusion	A nuclear (not chemical) reaction in which the nuclei of atoms are joined together to make larger nuclei, releasing energy. For example, hydrogen nuclei are fused to helium nuclei in the Sun and other stars. Thus, fusion processes cause the formation of new elements. This can only happen at immense pressures and temperatures, when gases have ionised to become plasma. Nuclear fusion allows **nucleosynthesis** - making new nuclei.



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Stages of star life cycles

You've seen the basic life cycle. Now for some detail.

- A **protostar** is a dense region in a nebula, which is still gathering mass by pulling in material from the nebula by its gravitational pull. So, at this stage, the star is still forming and has **not** yet started nuclear fusion reactions.
- **Main sequence** star: the Sun is a main sequence star. During this stage of a star's life cycle, the star is stable in size because the forces acting towards the centre and the outward forces caused by the nuclear fusion processes are in **equilibrium**. With an object as big as a star, the gravitational force acting on any particular particle is intense, so the star might be expected to collapse. However, there is an outward force leading to expansion, caused by the fusion processes occurring in the star. Essentially, this outward force is due to gas pressure (ok, plasma pressure) in the star. Pressure in gases increases if their temperature increases, making the star expand; in turn, this decreases the pressure and therefore cuts the rate of nuclear fusion. Therefore, main sequence stars are nicely self-regulating systems (using negative feedback).
- **Red giant** and **red super giant** stages: as the diagram showed, this is where the life cycle diverges according to the mass of the star. Stars finish their main sequence when the hydrogen in the core runs out (it has all been fused to helium). This reduces the outward pressure, so the star begins to collapse inwards due to gravity. In turn, this allows some of the hydrogen *outside* the core (the layer of a star we actually see) to begin going through nuclear fusion, and at a much more rapid rate than during the main sequence. This higher rate of nuclear fusion produces a larger outward pressure, so the outer layer of the star expands by a great deal, perhaps as far as the orbit of Venus in the case of the Sun! (Hence the 'giant' in the name.)
- The red giant or red super giant stage ends as the fuel runs out. This causes a drop in outward pressure, so gravity wins out and causes the collapse of the star. This is really rapid, though, and causes a shock wave outwards. In stars like the Sun, this is violent but not crazy – the outer layers of the star are ejected relatively slowly out. However, in larger stars this outwards shock wave is extremely violent, resulting in a **supernova**. A supernova is such a colossal explosion that a red supergiant entering its supernova stage can outshine its whole galaxy! This spreads the new elements made in the star by nuclear fusion (or **nucleosynthesis**) out across the universe. This is actually the reason why large elements (anything larger than iron) are found on Earth – the atoms were spread out after their formation in supernovae.
- The core of the Sun, and similar sized stars, will become a **white dwarf**. When it has totally cooled off, it will be a **black dwarf** – just the cold remnants of its core. The core of larger stars will be left as **neutron stars**, which are insanely dense objects: as illustrative values, a neutron star may be only 20 km in diameter but have a mass *twice* that of the Sun! Should the star have started as a *really* massive star, the core will collapse to make a **black hole**, which is even more dense than a neutron star and a place where conditions are so extreme that physicists are struggling to express the rules that govern the behaviour of matter in black holes.

Key Terms	Definitions
Protostar	An early star – basically a big dense part of a nebula that is gathering mass but hasn't started nuclear fusion yet.
Main sequence	The stable stage of a star's life cycle, where inward and outward forces are in equilibrium.
Plasma	The 'fourth state of matter' – a superhot gas, where electrons are stripped from nuclei, leaving a sea of positive nuclei and negative electrons.
Red giant	The stage after the main sequence for stars with a similar mass to the Sun.
Red supergiant	The stage after the main sequence for stars much more massive than the Sun.
White dwarf	The collapsed core of a star like the Sun. Very dense (about 200 000 times more dense than Earth), but not as dense as neutron stars or black holes.
Black dwarf	When a white dwarf has fully cooled down, it no longer emits any radiation so it is a black dwarf. So in the universe, there aren't any black dwarves because it isn't old enough for white dwarves to have cooled off yet!
Supernova	The enormous explosion resulting from the collapse and resulting shock wave of a star much more massive than the Sun.
Neutron star	The collapsed core of a star after a supernova (but not of a star large enough to form a black hole).
Black hole	The collapsed core of really massive stars – about five or more times the mass of the Sun.

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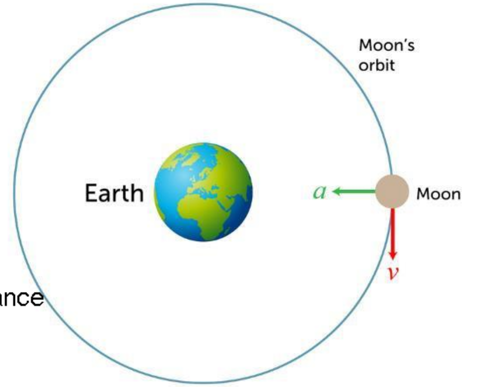
Orbits

Gravity is the force that allows orbits to be maintained. Since an object in motion is moving in a circle, its direction and therefore velocity is constantly changing, even as its speed stays constant. The orbiting object is accelerating towards the object it orbits, as the diagram shows. The velocity at any moment you pick (called the **instantaneous velocity**) is at a tangent to the orbital path.

For an orbit to remain stable, the radius of the orbital path must change if the speed changes. This means, for example, Mercury travels much faster on its orbital path around the Sun than Earth, since the radius of its orbital path is much smaller than ours.

Key Terms	Definitions
Instantaneous velocity	Velocity at a single moment (remember it is vector quantity, with both direction and magnitude).
Red shift	The observed increase in wavelength of light emitted by objects moving away (receding) from an observer.
Big Bang theory	The theory, which is by far the dominant scientific theory for the origin of the universe, that states that the whole universe was once tiny and very hot and dense.
Recessional velocity	How fast something (like a galaxy) is moving away from an observer.
Dark matter	Aka dark mass. A mysterious type of matter that is known to exist (from observations of other galaxies), but no-one knows what it is made of.
Dark energy	The name given to the mysterious energy driving the acceleration in the expansion of the universe.

Red Shift



Red Shift

When we examine the light (electromagnetic radiation) from distant galaxies in space, the wavelength is *increased* compared to what is 'should be'. This stretching of waves that are emitted from a wave source moving away from an observer is called the Doppler effect in general, and **red shift** when we're talking about electromagnetic radiation. Working backwards logically, we know that distant galaxies are *receding* (moving away from us). This shows that the universe (i.e. space itself) is expanding. In turn, this provides great evidence for the Big Bang theory, since when you turn the clock back, the galaxies must have been much closer together in the past, all the way back until the whole universe (space and all the matter in it) was a single hot, dense point.

In 1998 some breakthrough studies of supernovae in distant galaxies showed that the rate of recession of galaxies is greater the further away they are, findings that have been confirmed in numerous studies since. The findings showed that the more distant the galaxy is, the greater the red shift of its light, showing that they are moving away faster than nearer galaxies. The graph shows this – each dot is a galaxy which has been observed and its red shift used to calculate its recessional velocity (how fast it is moving away from us, the observers).

There are still many unsolved questions about all this, though. No-one knows what is causing the acceleration of the universe's expansion (so it often gets the opaque name 'dark energy').

Another giant mystery is 'dark matter' – astronomers know there is a giant 'halo' of matter around objects in space like galaxies, but have no idea what it is made of, hence the name.