The Solar System and Gravity

The Sun is the centre of the Solar System. It's orbited by eight planets, along with a bunch of other objects.

The Solar System has One Star — The Sun

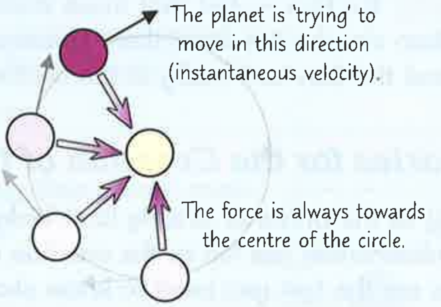
A satellite is an object that orbits a second, more massive object.

The Solar System is all the stuff that orbits our Sun. This includes things like:

1) Planets — these are large objects that orbit a star. The eight planets in our Solar System are, in order (from the Sun outwards): Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus and Neptune.
2) Dwarf planets, like our pal Pluto. These are planet-like objects that aren't big enough to be planets.
3) Moons — these orbit planets with almost circular orbits. They're a type of natural satellite (i.e. they're not man-made).
4) Artificial satellites (ones humans have built) that usually orbit the Earth in fairly circular orbits.
5) Asteroids — lumps of rock and metals that orbit the Sun. They're usually found in the asteroid belt.
6) Comets — lumps of ice and dust that orbit the Sun. Their orbits are usually highly elliptical (a very stretched out circle) — some travel from near to the Sun to the outskirts of our Solar System.

Gravity Provides the Force That Creates Orbits

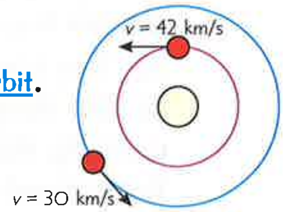
1) The planets move around the Sun in almost circular orbits (same goes for the Earth and the Moon).
2) You saw on p.17 that an object in a circular orbit at a constant speed is constantly accelerating.
3) The force causing this is the centripetal force. It acts towards the centre of the circle.
4) This force would cause the object to just fall towards whatever it was orbiting, but as the object is already moving, it just causes it to change its direction.
5) The object keeps accelerating towards what it's orbiting but the instantaneous velocity (which is at a right angle to the acceleration) keeps it travelling in a circle.
6) The force that makes this happen is provided by the gravitational force (gravity) between the planet and the Sun (or between the planet and its satellites).



The Force due to Gravity Depends on Mass and Distance

1) Back on page 17 you saw that the weight (i.e. the force on an object due to gravity) of any object varies depending on the strength (g) of the gravitational field that it is in.
2) Gravitational field strength depends on the mass of the body creating the field. The larger the mass of the body, the stronger its gravitational field. (The Earth is more massive than the Moon, so an object would weigh more on Earth than it would on the Moon.)
3) Gravitational field strength also varies with distance. The closer you get to a star or planet, the stronger the gravitational force is.
4) The stronger the force, the larger the instantaneous velocity needed to balance it.
5) So the closer to a star or planet you get, the faster you need to go to remain in orbit.
6) For an object in a stable orbit, if the speed of the object changes, the size (radius) of its orbit must do so too. Faster moving objects will move in a stable orbit with a smaller radius than slower moving ones.

The fact that different planets orbit the Sun at different speeds means that the distances between planets vary over time.



Revision's hard work — you've got to plan et...

Make sure you know what orbits what and how to tell a moon from a dwarf planet. Then get your head around all that stuff about orbits — it sounds a bit complicated, but it's really just about balancing forces.

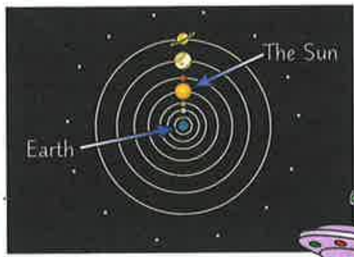
Q1 Describe the orbits of: a) planets b) moons c) comets [3 marks]

Changing Ideas about the Universe

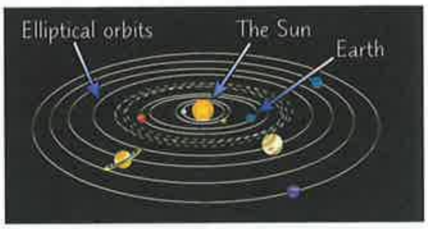
Over time, we've come up with lots of ideas about how the Universe began and how our Solar System looks.

Ancient Greeks Thought the Earth was the Centre of the Solar System

There have been lots of different models of our Solar System:



1) Geocentric model — this theory suggested that the Sun, Moon, planets and stars all orbited the Earth in perfect circles.
   It arose because people on Earth didn't have telescopes and saw the Sun and Moon travelling across the sky in the same way every day and night. It was the accepted model of the Universe from the time of the ancient Greeks until the 1500s.
2) Next up was the heliocentric model (Sun at the centre of the Solar System).
   It said that the Earth and all of the planets orbited the Sun in perfect circles.
3) Galileo found one of the best pieces of evidence for this theory — the moons around Jupiter.
   Whilst looking at Jupiter with a telescope, he noticed some stars in a line near the planet. When he looked again, he saw these 'stars' never moved away from Jupiter and seemed to be carried along with the planet. This showed not everything was in orbit around the Earth — evidence that the geocentric model was wrong.
4) Gradually, evidence for the heliocentric model increased thanks to more technological advances.
5) The current model still says that the planets in our Solar System orbit the Sun — but that these orbits are actually elliptical rather than circular (we treat them as circular to make life easier though) and the Sun isn't really at the centre of the Universe.



Our current view of the Solar System.

Theories for the Creation of the Universe Have Also Changed Over Time

As big as the Universe already is, it looks like it's getting even bigger (it's expanding).
This observation has led to the creation of numerous models that try to explain the creation of the Universe.
These are the two you need to know about:

Steady State — Matter is Always Being Created

1) The 'Steady State' theory says that the Universe has always existed as it is now, and it always will do. It's based on the idea that the Universe appears pretty much the same everywhere.
2) As the Universe expands, new matter is constantly being created.
3) This means that the density (p.93) of the Universe is always roughly the same.
4) In this theory there is no beginning or end to the Universe.

The Big Bang — the Universe Started with an Explosion

1) Initially, all the matter in the Universe occupied a very small space.
2) This tiny space was very dense (p.93) and so was very hot.
3) Then it 'exploded' — space started expanding, and the expansion is still going on.
4) This theory gives a finite age for the Universe (around 13.8 billion years).

Currently, the Big Bang is the accepted theory of how the Universe began.
This is based on evidence shown on the next page.

Forget the Sun, I'm pretty sure everything revolves around me...

Make sure you can describe each theory above and how it compares to our current ideas about the Universe.

Q1 Explain the difference between the geocentric and heliocentric models of the Solar System. [1 mark]

Q2 Give two differences between the Steady State and Big Bang theories. [2 marks]

Red-shift and CMB Radiation

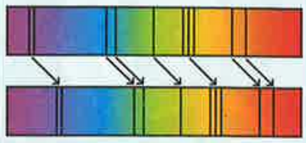
The Big Bang model is the most convincing explanation we've got for how the Universe started.

Red-shift Suggests the Universe is Expanding

Most galaxies seem to be moving away from each other.
There's good evidence for this:

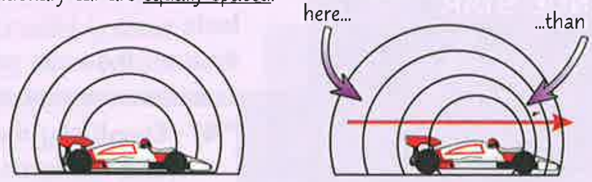
1) Different elements absorb different frequencies (or wavelengths) of light.
2) Each element produces a specific pattern of dark lines at the frequencies that it absorbs in the visible part of the EM spectrum (p.43).
3) When we look at light from distant galaxies we see the same patterns but at slightly lower frequencies than they should be.
4) There's an observed increase in the wavelength of light coming from the galaxies and the patterns have been shifted towards the red end of the spectrum. This is called red-shift.

An absorption spectrum showing dark lines measured on Earth.



The same absorption spectrum measured from light from a distant galaxy. The dark lines in this spectrum are red-shifted.

Red-shift is the same effect as the vrrr-oom from a racing car or the sound of an ambulance as they drive past you. The noise sounds lower-pitched when it's travelling away from you because it drops in frequency (the Doppler effect).



5) Measurements of the red-shift suggest that all the distant galaxies are moving away from us very quickly — and it's the same result whichever direction you look in.
6) More distant galaxies have greater red-shifts than nearer ones — they show a bigger observed increase in wavelength.
7) This means that more distant galaxies are moving away faster than nearer ones. This provides evidence that the whole Universe is expanding.

There's Microwave Radiation from All Directions

1) Scientists have detected low frequency electromagnetic radiation coming from all parts of the Universe.
2) This radiation is mainly in the microwave part of the EM spectrum. It's known as the cosmic microwave background radiation (CMB radiation).

CMB radiation is Strong Evidence for the Big Bang

1) Red-shift can be explained by both the Steady State and Big Bang theories.
2) In both models, objects are moving away from the observer as the Universe expands, so red-shift would be observed for either model.
3) However, CMB radiation only supports the Big Bang model as it shows the Universe had a beginning.
4) This is why the Big Bang theory is currently our accepted model for the start of the Universe.

According to the Big Bang model, the CMB radiation is the leftover energy of the initial explosion.

My brain's shifted towards the tired end of the spectrum...

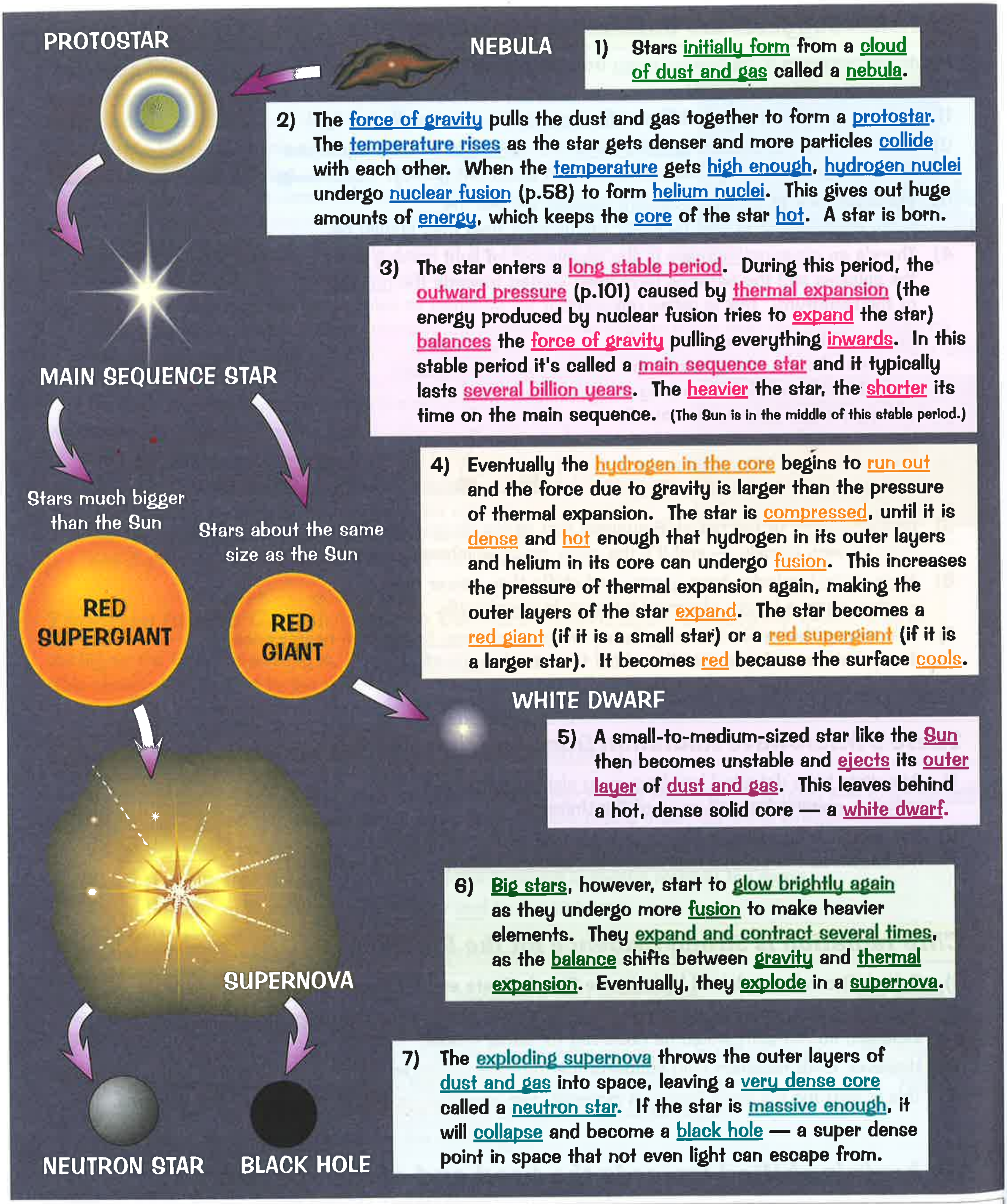
The Big Bang model is the best one we've got to explain how the Universe began, but it may need some tweaking in the future if we find new evidence it can't explain. Scientists, pfft, don't they ever finish anything?

Q1 What is red-shift? [1 mark]

Q2 What theory does CMB radiation support? [1 mark]

The Life Cycle of Stars

Stars go through many traumatic stages in their lives — just like teenagers.



1) Stars initially form from a cloud of dust and gas called a nebula.

2) The force of gravity pulls the dust and gas together to form a protostar. The temperature rises as the star gets denser and more particles collide with each other. When the temperature gets high enough, hydrogen nuclei undergo nuclear fusion (p.58) to form helium nuclei. This gives out huge amounts of energy, which keeps the core of the star hot. A star is born.

3) The star enters a long stable period. During this period, the outward pressure (p.101) caused by thermal expansion (the energy produced by nuclear fusion tries to expand the star) balances the force of gravity pulling everything inwards. In this stable period it's called a main sequence star and it typically lasts several billion years. The heavier the star, the shorter its time on the main sequence. (The Sun is in the middle of this stable period.)

4) Eventually the hydrogen in the core begins to run out and the force due to gravity is larger than the pressure of thermal expansion. The star is compressed, until it is dense and hot enough that hydrogen in its outer layers and helium in its core can undergo fusion. This increases the pressure of thermal expansion again, making the outer layers of the star expand. The star becomes a red giant (if it is a small star) or a red supergiant (if it is a larger star). It becomes red because the surface cools.

5) A small-to-medium-sized star like the Sun then becomes unstable and ejects its outer layer of dust and gas. This leaves behind a hot, dense solid core — a white dwarf.

6) Big stars, however, start to glow brightly again as they undergo more fusion to make heavier elements. They expand and contract several times, as the balance shifts between gravity and thermal expansion. Eventually, they explode in a supernova.

7) The exploding supernova throws the outer layers of dust and gas into space, leaving a very dense core called a neutron star. If the star is massive enough, it will collapse and become a black hole — a super dense point in space that not even light can escape from.

It's the beginning of the world as we know it...

Pretty neat, seeing how stars like our Sun — which all of us rely on — were made all those years ago.

Q1 Describe the life cycle of a star much larger than our Sun, beginning from a nebula. [6 marks]

Looking Into Space

There are various objects in space, and they emit or reflect different frequencies of EM radiation. And that can be really useful to help us find out what's going on 'out there'.

Telescopes are Used to Observe the Universe

Telescopes help you to see distant objects clearly. There are loads of different kinds (see below) and they all work in different ways. The one you're most likely to have seen is an optical telescope — ones that detect visible light.

Telescopes use refraction (p.34) and reflection (p.38) to allow you to see distant objects. You need to know how to improve the quality of the image you can see using them:

1) Increase the aperture of the telescope. This is the diameter of the objective lens — the big lens at the end of the telescope where light from the distant object enters the telescope.
2) Use a higher quality objective lens.

Space Telescopes Have a Clearer View Than Those on Earth

1) If you're trying to detect light, Earth's atmosphere gets in the way — it absorbs a lot of the light coming from space before it can reach us. To observe the frequencies absorbed, you have to go above the atmosphere.
2) Then there's pollution. Light pollution (light thrown up into the sky from street lamps, etc.) makes it hard to pick out dim objects. And air pollution can reflect and absorb light coming from space.

Night sky in rural area with no light pollution.

Night sky in urban area with light pollution.

3) So to get the best view possible from Earth, a telescope should be on top of a mountain (where there's less atmosphere above it), and in a dark place away from cities (e.g. on Hawaii).
4) To avoid the problem of the atmosphere completely, you can put your telescope in space.

Different Telescopes Detect Different Types of EM Wave

To get as full a picture of the Universe as possible, you need to detect different kinds of EM wave.

1) The earliest telescopes were all optical telescopes. They're used to look at objects close by and in other galaxies. But many objects in the Universe aren't detectable using visible light — so other types of EM telescopes are needed to observe them.
2) From the 1940s onwards, telescopes were developed for all parts of the EM spectrum. These modern telescopes mean we can now 'see' parts of the Universe that we couldn't see before and learn more about the Universe, e.g. its structure.
3) X-ray telescopes are a good way to 'see' violent, high-temperature events in space, like exploding stars.
4) Radio telescopes were responsible for the discovery of the cosmic microwave background radiation (p.61) — this helped scientists to learn more about the origins of the Universe.
5) Telescopes are improving all the time — bigger telescopes give us better resolution (i.e. a lot of detail) and can gather more light, so we can see things we couldn't before as they were too faint. Improved magnification means we can now look further into space — more and more galaxies are being discovered.
6) Modern telescopes often work alongside computers. Computers help create clearer and sharper images and make it easy to capture these pictures so they can be analysed later.
7) Computers make it possible to collect and store huge amounts of data, 24 hours a day, without having to rely on humans. They also make it easier and quicker to analyse all this data.

Now you've got an excuse to stare into space during lessons...

Although you won't see much without a telescope. You need to be able to explain different ways of improving images from telescopes — remember, high up and in a dark place is good, and sticking one in space is even better.

Q1 Give three ways of improving the image you can see through a telescope on Earth. [3 marks]