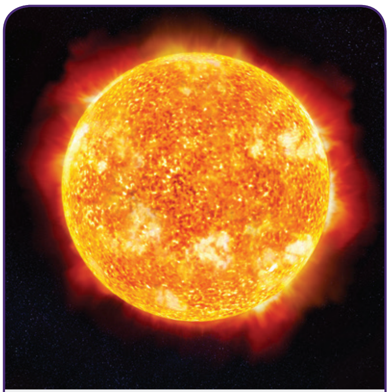
Sun and Stars

PHYSICS • OUR SOLAR SYSTEM • SUN AND STARS

Section 1: Life Cycle

• How are stars formed?

Stars are formed when large clouds of gas and dust begin to collapse due to their own gravity. As the dust accelerates towards the centre it gains kinetic energy (movement energy). As the dust collides and comes to a halt at the centre of the cloud, this energy is converted to heat through friction, and the temperature of the dust increases. When the core temperature becomes high enough, nuclear fusion begins to occur. At this point the collapse is halted, as energy is released from the core of the new star. The remaining dust surrounding the star is blown away.



Our Sun is a star that has existed 4.5 billion years

Throughout its lifetime the star's state will be determined by a struggle between two opposing forces. Gravity will continue to pull the material in the star towards the core and the heat generated in the star will push the material outwards. The more heat the star generates the larger it will be.

• Suggested Films

- **– What Are Stars?**
- **– Constellations**

Extension Questions

Q1. What is nuclear fusion?

In nuclear fusion small atomic nuclei are pushed together until they fuse into larger nuclei. This is very difficult to achieve. The nuclei need to be very close together before they can fuse, but as the nuclei are positively charged and, because like charges repel, it is usually very difficult to force them together. The force of gravity in very large dust clouds can be enough to force the nuclei together. Hydrogen atoms have the smallest nuclei, containing only one proton, and are forced together in a three step process to create the next heaviest element, helium.

Q2. Why are there no green stars?

It is obvious, even to the naked eye, that some stars in the sky are different colours. Some are clearly red, some blue. In fact, stars come in many different colours, but there are no green stars.

When matter is heated it glows, emitting electromagnetic radiation. The higher the temperature, the higher the frequency of radiation emitted. The visible spectrum contains the colours red, orange, yellow, green, blue, indigo and violet in order of increasing frequency. Warm objects emit infrared radiation. At around 500°C objects begin to glow red; at 1000°C objects glow orange/yellow. For this reason, the colour of a star depends on its temperature; the hottest stars are blue. However, a spread of frequencies is emitted, so a red star would also emit some infrared and some orange light. A green star would not only emit green light, it would also emit some red and blue. This would be seen by us as white light, thus explaining why we do not see green stars.

• How do stars change?

The life cycle of a star varies depending on the mass present at the start. However, in general, throughout most of their lifetime stars will burn hydrogen to make helium. Eventually the star exhausts its supply of hydrogen. It is more difficult to achieve fusion with helium, and so the star cools, as fusion shuts down and gravity begins to dominate, pulling material towards the core. Soon the core is compressed sufficiently for helium fusion and a helium flash may occur. The energy released is much greater than that from hydrogen fusion, and the outward force begins to dominate, pushing the material further away from the core. This causes the star to swell and become a giant.

Stars with very low mass will never be able to fuse helium, and so will continue slowly burning hydrogen until it collapses. We do not know for sure what happens to stars like these, as the Universe has not been in existence long enough for any of these stars to complete their life cycle.

The constellation Leo

• Suggested Films

- What Are Stars?
- Constellations

Extension Question

Q3. What is the largest star?

It is not always easy to measure the mass and diameter of stars which are a large distance from Earth. However, VY Canis Majoris is thought to be the largest known star. A red hypergiant, it is thought to be around 5000 light years away, with a radius 2000 times that of the Sun. This means that if our Sun were represented by a sphere 1cm across, VY Canis Majoris would be 20m across.

Although VY Canis Majoris is thought to be the largest star, it is not the most massive star. This is a blue hypergiant star, R136a1, over 150,000 light years away. It has a mass over 250 times that of the Sun and is around 9,000,000 times more luminous.

This must be close to the largest possible size for a star, as it is thought that stars larger than this would shed enormous amounts of mass from its outer layers.

• How do stars die?

A dying star in the Butterfly nebula, taken by the Hubble telescope

Eventually the star will consume its helium and will begin burning carbon. Carbon burning proceeds very quickly, as particles called neutrinos are produced, which barely interact with the material in the star. These escape from the star, taking energy with them, resulting in a faster rate of energy loss. Gravity begins to dominate again and compresses the core. This results in a higher rate of burning, which maintains the size of the star. Because of this the star burns its fuel much faster.

At this point the outer layers of the star may be blown away, leaving the core which will continue to burn as a white dwarf. Energy from the star may make the gas glow, resulting in a planetary nebula.

If a star is large enough it may continue fusion after carbon burning, and fuse heavier and heavier elements until eventually it has to fuse iron. The fusion of iron consumes energy instead of releasing it. This results in the core of the star rapidly cooling. As there is very little heat being radiated outward, gravity is now unopposed, and the outward layers of the star begin to collapse in towards the core at a speed approaching a quarter of the speed of light.

As the material heads in towards the centre of the star, the core becomes so compressed that the material in the core is transformed into neutrons, giving the core a density comparable to that of an atomic nucleus.

As this material reaches the core it is unable to compress it any further and rebounds, causing a shockwave heading out from the core. The material then detonates, creating an enormous explosion known as a supernova. A supernova shines billions of times brighter than our Sun, outshining the star's entire galaxy.

The core remains as a neutron star unless the star is so large that this is compressed further to form a black hole. The core is ejected away from its original position by a process which is not well understood, and continues at high speed.

Dust remains of a Supernova, taken by the Hubble Telescope

• Suggested Films

– What Are Stars?

– Constellations

Extension Questions

Q4. What is a planetary nebula?

A planetary nebula has nothing to do with planets. They are created when a star throws off its outer layers, and ultraviolet (UV) radiation emitted by the remaining core is absorbed by the material, and makes it glow. Planetary nebula got their name because the astronomers who first observed them thought they looked similar to large planets like Uranus.

Planetary nebula are usually around a light year across, and will last for around 10,000 years before the star reaches a stage in its life cycle where it no longer emits enough radiation to make the material around it glow.

Q5. What is a neutron star?

Neutron stars can form after a supernova. They are composed entirely of neutrons and are similar to giant atomic nuclei. They have a mass around twice that of the Sun, but a diameter of only about 20km. The matter at the core of a neutron star is so dense that a cubic centimetre of this material would have a mass of more than a hundred billion tonnes.

Q6. What is a black hole?

If a star goes supernova, and the mass of the star is very large, it is thought that the core of the star can collapse to become a black hole. The gravitational pull of a black hole is so great that even light cannot escape from it. The centre of a black hole is known as the singularity, a point with no volume, and hence infinite density. The border of a black hole is called the event horizon. Anything within the event horizon cannot escape from the black hole.

Most scientists agree that black holes exist. They have not been directly observed, but effects have been observed which are consistent with predictions of black hole behaviour.

Extension Question

Q7. What would happen if a supernova were to occur close to Earth?

If a supernova were to occur close to Earth the effects could be catastrophic. The gamma rays released in the explosion could damage the Earth's atmosphere, destroying the ozone layer and endangering life on Earth. It is difficult to estimate how close the supernova would have to be to present a danger. However, it is estimated that a supernova might have to be as close as 30 light years. This is fairly close in interstellar terms, as the nearest star to the Sun is around 4 light years away.

Supernovae can be observed from Earth. In 1006 an extremely bright supernova was recorded by Arab and Chinese astronomers. The brightest stellar event in recorded history, it was visible for months, and could even be seen during the daytime. This supernova was around 7000 light years from Earth, and the remnant can still be seen today.

Section 2: The Sun

• What type of star is our Sun?

Our Sun is a second generation star, which is thought to have formed following the supernova of a nearby star. Although the Sun has a diameter more than 100 times that of the Earth, it is a relatively small star and is classed as a yellow dwarf. It formed 4.6 billion years ago and is now roughly halfway through its life, still fusing hydrogen into helium. In around 5 billion years it will begin fusing helium and will become a red giant, swelling until its radius is approximately equal to the orbit of the Earth. Life as we know it on Earth will long ago have become impossible. The Sun is increasing in luminosity and in only 1 billion years the Sun will have become so hot that the temperature on Earth will be too high for liquid water to exist.

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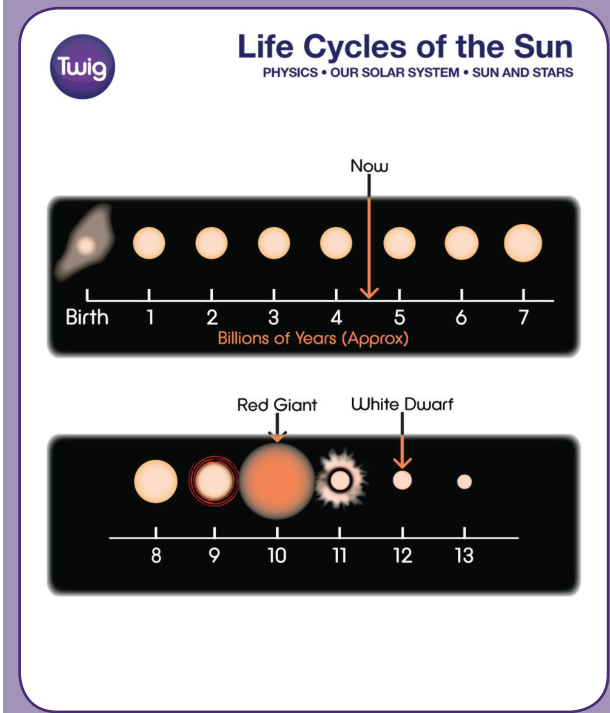

• Suggested Films

- **– The Sun**
- **– Death of the Sun**

Extension Question

Q8. Where do heavy elements come from?

If stars can fuse some elements, like hydrogen, helium and carbon to make heavier elements, but cannot make elements heavier than iron, where do the other elements like gold come from?

The only place these elements can be created is in large stars as they go supernova. Long ago a supernova must have occurred, which spread out the heavy elements it created, which were then incorporated into the Solar System when it formed. This means that any gold you are wearing must have been formed inside an ancient star as it exploded.

• How hot is the Sun?

The core of the Sun is around 15,000,000°C. The energy produced here takes hundreds of thousands of years to make its way to the surface, due to the enormous density of the Sun. The surface of the Sun is much cooler than the core: around 5500°C. The corona of the Sun extends millions of kilometres into space, and is much hotter than the surface for reasons that are still not fully understood.

A constant stream of hot particles flow out from the Sun at hundreds of kilometres per second. This is known as the solar wind and is the reason why comets develop tails which point away from the Sun. As well as the solar wind, solar flares also occur when the magnetic fields in the Sun rearrange themselves. These are explosions which send energetic particles out from the Sun at very high speed. Coronal mass ejections also occur for a similar reason, and send enormous amounts of matter out from the Sun.

These phenomena can affect the Earth, disrupting satellite communication and radio transmissions.

• Suggested Films

- – The Sun
- – Northern Lights and Solar Flares

DIAGRAM 02:

Structure of the Sun

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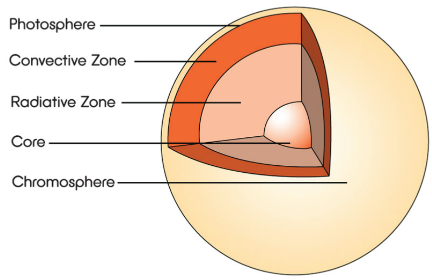

Extension Questions

Q9. How large is the Sun's influence?

The region where the solar wind exerts its influence is known as the heliosphere, and extends far beyond the orbits of the planets. The boundary where the heliosphere ends is called the heliopause, and is thought be around three times as far from the Sun as the most distant planet in the Solar System, Neptune. Before the heliopause, there is a boundary known as the termination shock. This is where the particles from the solar wind slow to subsonic speed.

It is believed that the Voyager spacecrafts have already passed the termination shock and are now heading out towards the heliopause.

Q10. What are sunspots?

There are areas on the Sun's surface where the magnetic fields are very intense. This limits convection, the transfer of heat through movement, so these areas are cooler than the rest of the surface (around 4000°C instead of 5500°C), and they appear darker. These are known as sunspots and have been observed for hundreds of years. They can be tens of thousands of kilometres in diameter, larger than Earth. The number of sunspots increases and decreases over an 11-year cycle, for reasons that are still not completely understood. There have been attempts to link sunspot activity to weather on Earth, but no definite link has ever been shown.

Extension Question

Q11. What are the Northern Lights?

The Northern Lights (Aurora Borealis) are visible from northerly latitudes. They are caused by particles from the solar wind interacting with the Earth's magnetic field. The particles spiral inwards along the Earth's magnetic field at the North Pole, and excite atoms in the atmosphere. When the atoms return to their normal state they emit light. This produces a natural light show. A similar effect, Aurora Australis, occurs around the South Pole. Increased solar activity increases the intensity and visibility of Aurorae.

The spectacular Northern Lights occur when particles emitted from the Sun collide and interact with the Earth's atmosphere

• What is the Sun made of?

The Sun is made of hydrogen and helium and also contains small amounts of oxygen, carbon, iron and other elements. The Sun is too hot for these to exist as solids, liquids or gases. Instead the atoms have become ionised, which means they have lost their electrons. This state is known as plasma and is sometimes considered a fourth state of matter. It is the most common state of matter in the Universe.

• Suggested Film
– The Sun

Extension Question

Q12. What are neutrinos?

Neutrinos are tiny, almost massless, particles which are produced in nuclear reactions. Because neutrinos are so small and have no charge, they are very difficult to detect. Trillions of neutrinos from the Sun pass through each one of us every second. Neutrinos also pass through the Earth, usually without interacting with anything on their way through.

Neutrino detectors consist of vast amounts of liquid surrounded by detectors, which detect the small number of events caused by the tiny proportion of neutrinos, which interact with the detector.

In the 1960s it was noticed that the number of neutrinos being emitted by the Sun was far lower than expected. This was the solar neutrino problem, and was not solved for over 30 years. There are three kinds of neutrinos, and early detectors only detected one type. It was suggested that neutrinos may be able to change from one type to another. This required neutrinos to have non-zero mass. However, the standard model, which is the theory describing the interactions between all known particles, predicts that neutrinos are massless. Neutrino oscillation was eventually observed and the solar neutrino problem was solved.

Extension Question

Q13. Have we ever sent spacecraft to the Sun?

NASA's planned Solar Probe Plus mission will travel 96% of the distance from the Earth to the Sun. It will pass within 6 million kilometres of the Sun and probe its outer corona. This requires a large heat shield to survive the intense heat.

Many spacecraft have been launched to study the Sun. The European Space Agency and NASA launched the SOHO spacecraft in 1995 to study the outer layer of the Sun and the solar wind. The spacecraft was originally supposed to only last for two years, but actually collected data for more than 15 years.

Several other spacecraft have been launched to study the Sun. Most are designed to monitor the activity of the Sun and the solar wind over a long period of time, and are situated close to the Earth. Often they are situated at the L1 Lagrange point. At this point the gravitational attraction of the Earth and the Sun are balanced. As the Sun is much larger than the Earth, this point lies much closer to the Earth than the Sun. Spacecraft placed at this point can observe the Sun constantly without the Earth or Moon ever getting in the way.

Section 3: The Sun and the Earth

• Why is the Sun important to Earth?

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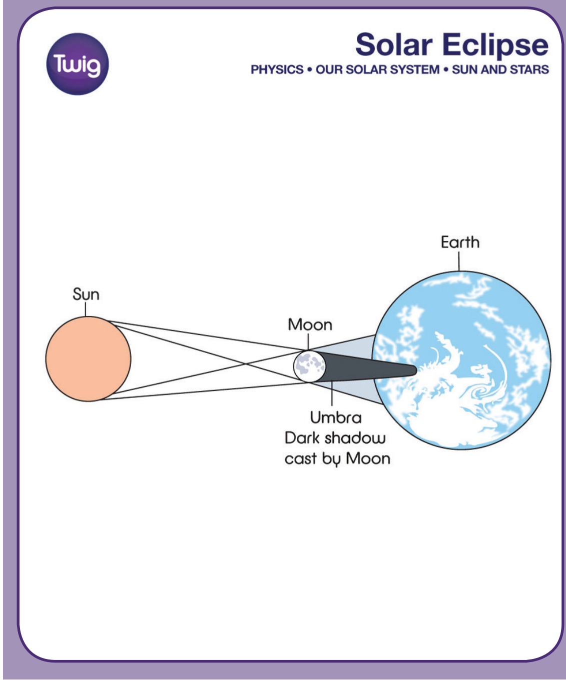

The Sun is required for all life on Earth. World human energy usage is approximately 15 terawatts, or 15 million, million joules per second. More than 100 terawatts is used by plants for photosynthesis. By comparison, the Sun delivers around 170,000 terawatts to the Earth.

It is estimated that the energy contained in all remaining fossil fuels on Earth, is equivalent to less than the solar energy incident on the Earth for three months. Fossil fuels are derived from the Sun's energy, as they are made from plants and animals that lived long ago, which obtained their energy from sunlight.

If solar energy were ever to be used on a large scale, this would present a problem as the Sun does not shine across the entire Earth 24 hours a day. As the Earth orbits the Sun, it also rotates on its own axis once every 24 hours. This is what gives us night and day. The side which is facing away from the Sun, and thus in shadow, experiences night. The Moon can reflect light from the Sun onto the darkened side if it is in the right position, but even during a full Moon the light is half a million times dimmer than the light from the Sun during the day.

To use only solar energy, we would require systems of energy storage so that energy could be stored during the day for use at night.

• Suggested Films

– Day and Night

– Why Is the Sky Blue?

Extension Questions

Q14. Why is the sky blue?

Interactions between sunlight and the Earth's atmosphere can make the sky look blue

The sky is not always blue. The colour depends on exactly how light is scattered in the atmosphere. If the Earth had no atmosphere the sky would appear black, and the Sun would appear as a bright object against this dark sky.

However, because the Earth has an atmosphere, light strikes molecules in the atmosphere and scatters in all directions. This is called Rayleigh scattering, and is more effective for short wavelengths of light. Although sunlight appears white it actually contains a full spectrum of colours. Blue light has a short wavelength and scatters in all directions, making the sky appear blue. Red light has a long wavelength and does not scatter well.

When the Sun is low in the sky it appears red. This is because the sunlight has to pass through more of the atmosphere and almost all of the blue light is scattered, leaving only the red. This is the reason the sky can appear red at night.

Q15. What is the ozone layer?

Oxygen molecules are diatomic, which means they contain two atoms bonded together. Ozone is a form of oxygen, containing three atoms of oxygen bonded together. It is much less stable than the diatomic form, but is present in large quantities in the upper atmosphere in a region known as the ozone layer. This performs a function vital to life on Earth.

Sunlight contains a range of electromagnetic radiation. The light peaks in the yellow-green part of the spectrum, but only half of all light incidents on the Earth are in the visible region. The Sun also produces large amounts of infrared as well as some ultraviolet. We consider that there are three categories of ultraviolet radiation: UV-A, UV-B and UV-C.

UV-C is very harmful and is entirely removed by the ozone layer. It also removes large amounts of UV-B, which can cause sunburn, and eventually some forms of skin cancer.

In the 1980s there was concern that some industrial chemicals were causing depletion of the ozone layer, and a hole in the ozone layer was discovered over Antarctica. The use of these chemicals has been greatly reduced, but the area where the ozone layer has thinned is expected to persist for decades.

Extension Question

Q16. Why does sunlight cause tanning?

Sunlight contains UV light, and not all of it is absorbed by the ozone layer.

A few millimetres of glass can absorb UV light, and this is why we do not tan through glass. Air also absorbs some UV light, but when it reaches our skin it causes damage, destroying cells and causing our capillaries to dilate, which is what causes the redness associated with sunburn. To prevent damage, cells release a pigment, melanin, which partly blocks UV; this is what causes tanning.

When the Sun is directly overhead the light passes through less air in the atmosphere than when the Sun is low in the sky. For this reason it is hard to develop a tan late in the afternoon. This is also why it is almost impossible to tan in winter, unless you are close to the equator, because the Sun never appears high in the sky. It is also why it is easy to tan at the equator, because the Sun is often overhead.

• How do eclipses help us to learn about the Sun?

The Moon also orbits the Earth once a month and when it passes directly in front of the Sun it can leave areas of the Earth in shadow. From the Earth it would appear that the Sun was blocked out by the Moon passing in front of it.

Eclipses let astronomers observe the Sun's corona. Usually the Sun is so bright that it's only at an eclipse that the corona becomes visible. In 1919, Arthur Eddington travelled to Africa to view an eclipse and conduct measurements to confirm Einstein's theory of general relativity. Eddington measured the position of stars during an eclipse to show that they appeared to shift in position when the Sun was about to pass in front of them. The theory of relativity predicted that the light from the stars would be deflected by the Sun's gravitational field and the stars would appear to shift in position. This can only be observed during an eclipse as at other times the Sun is too bright to view the stars.

The last total solar eclipse which lasted more than seven minutes was in 1973. A Concorde flying at Mach 2 was used to fly along the path of the shadow cast by the Moon and was able to stretch totality to 74 minutes and allow measurements to be taken over a longer period.

The solar corona during a solar eclipse

• Suggested Films

– What Are Eclipses?

– Shadow Chasers

Extension Question

Q17. How dangerous is it to look at the Sun directly?

Viewing the Sun with the naked eye for long periods can be dangerous, as UV light from the Sun can cause eye damage. Viewing the Sun through a telescope or a pair of binoculars is far more dangerous, and even looking at the Sun for very brief periods can cause blindness.

Viewing the Sun during eclipses can be particularly dangerous. When the Sun is partially covered, the eye will adapt to lower levels of light by allowing the pupil to expand, allowing more light to enter the eye. Although less of the Sun is visible, the uncovered part will still be as bright and the increased amount of light entering the eye can cause damage.

• Quizzes

Day and Night

Basic

• How long does the Earth take to complete one rotation?

A – 12 hours

B – 24 hours

C – 1 month

• Why does the Sun appear to drop out of the sky at sunset?

A – because the Earth rotates

B – because the Sun orbits around the Earth

C – because the Earth's axis is tilted

• Why are the stars and the Moon bright?

A – they both reflect light from the Sun

B – they both emit light

C – the stars emit light and the Moon reflects light from the Sun

Advanced

• Why does the Moon appear to move across the sky each night?

A – because the Moon is orbiting the Sun

B – because the Earth is spinning

C – because the Moon is orbiting the Earth

• How fast does a point on the equator travel as the Earth spins?

A – around 160 km/hour

B – around 900 km/hour

C – around 1600 km/hour

• What is the speed of the Earth's poles as the Earth spins?

A – around 900 km/hour

B – around 1600 km/hour

C – almost zero

The Sun

Basic

- What is the Sun mostly made of?

  A – hydrogen

  B – carbon

  C – oxygen

- How much wider is the Sun than the Earth?

  A – twice as wide

  B – ten times as wide

  C – over 100 times as wide

- How old is the Sun?

  A – 1.2 billion years

  B – 4.6 billion years

  C – 10 billion years

Advanced

- How much of the Sun is composed of helium?

  A – 2.3%

  B – 7.8%

  C – 12.4%

- What is the temperature at the core of the Sun?

  A – 5400°C

  B – 25,000°C

  C – 15,000,000°C

- How far is the Sun from the Earth?

  A – 300,000km

  B – 93,000,000km

  C – 147,000,000km

What Are Stars?

Basic

• How many main types of star are there?

A – 1

B – 3

C – 10

• What percentage of stars are found in the main sequence?

A – 20%

B – 70%

C – 90%

• How large are red giants?

A – 5 times the size of the Sun

B – 30 times the size of the Sun

C – 50 times the size of the Sun

• How large are supergiants?

A – 30 times the size of the Sun

B – 100 times the size of the Sun

C – 300 times the size of the Sun

Advanced

• Which are the hottest stars on the main sequence?

A – blue stars

B – yellow stars

C – red stars

• What is the source of heat inside stars?

A – nuclear fission

B – nuclear fusion

C – burning with oxygen

• How much energy does a supernova release?

A – the same amount a star normally gives out in a year

B – the same amount a star normally gives out in 1000 years

C – the same amount a star normally gives out in 10 billion years

• After a supernova what could the core of the star become?

A – a red giant

B – a black hole

C – a white dwarf

What Are Stars?

Basic

Advanced

- How large is a white dwarf?

  A – about the same size as the Earth

  B – about twice the size of the Earth

  C – half the size of the Sun

- What happens when a Supergiant dies?

  A – it gradually becomes cooler until it becomes cold and black

  B – it explodes in a supernova

  C – it contracts and becomes a white dwarf

• Answers

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