PEARSON

Science

STUDENT BOOK | WESTERN AUSTRALIA

10

WESTERN AUSTRALIAN • CURRICULUM •

Topic 7 Big bang theory and the evolution of the universe

Prior knowledge

Light

1 Light is a form of electromagnetic radiation. Energy is transferred through the interaction of electric and magnetic fields; hence light can travel through a vacuum.

2 Radiowaves, microwaves, infrared, visible light, ultraviolet, x-rays and gamma rays. All forms of light travel at the same speed in a vacuum – the speed of light. Radiowaves have longer wavelengths and smaller frequencies. The wavelength decreases and the frequency increases as you move from radiowaves through to gamma rays.

The structure of the solar system

3 Gravity, which is an attractive force between two objects of mass.

4 Planets are much larger than asteroids. Additionally, planets orbit the sun in very specific, stable orbits, whereas asteroids can have their orbit impacted by other larger planets.

Gravity

5 The relevant law is Newton's second law which states that force is equal to mass times by acceleration. The acceleration due to gravity near Earth's surface is a constant 9.80 m/s^2. Therefore, as mass and the force due to gravity are proportional, an increase in mass increases the force due to gravity.

6 This famous experiment was conducted on the Moon. The experiment provided confirmation that objects, regardless of their mass, will fall at the same rate when there are no other external forces applied (i.e. when there is no air resistance).

7.1 Observing space

Check your understanding

SC 1: I can explain how historical models of the universe were supported by the evidence available at the time, such as the apparent motion of the Sun, Moon and stars

The Sun, Moon and stars can be seen to move through the sky from Earth in predictable patterns. Therefore, this supported the idea that Earth was stationary and central, with the Moon, Sun and stars orbiting around Earth.

SC 2: I can explain an example of how a key observation was used to develop a hypothesis about a component or structure of the universe

By observing that Jupiter's moons orbit around Jupiter and not Earth, it can be inferred that not all celestial bodies orbit Earth. This highlights a limitation of the geocentric model and so supports the heliocentric model.

SC 3: I can explain an example of where an observation of an event, or series of events, in space has been used to make a prediction as to future events

Answers may include the appearance of Halley's Comet, Lunar or Solar eclipses, or the identification of asteroids.

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Lesson review

1 the geocentric model

2 By studying the regular intervals at which solar eclipses occur and understanding the orbital mechanics of Earth, Moon, and Sun, scientists can predict the timing and locations of future solar eclipses.

3 First Nations Australians track when different celestial objects are visible at different times of the year. They use these objects as markers to assist with navigating. This knowledge is passed down through the generations.

4 **a** Nicolaus Copernicus

b The phases of Venus contradicted the Geocentric model because at times Venus was fully illuminated by the Sun, whilst at time it was partially illuminated. The partial Illumination of Venus can only occur if Venus orbited the Sun, not Earth.

c The shift in model (from Geocentric to heliocentric) was significant as it laid the foundation for modern astronomy and changed our understanding of our place in the universe.

7.2 Distances in space

Check your understanding

SC 1: I can describe the concept of a light year and explain why this unit is used to measure distances in space

A light year is the distance that light travels in one year, which is approximately 9.46 trillion kilometres.

SC 2: I can use light years to compare distances between celestial bodies in space

Galaxies are very far away from each other. A light year measures a greater distance than a light second, so is more appropriate to use when measuring these larger distances.

SC 3: I can explain how stellar parallax can be used to measure the distance of objects from Earth, including limitations of the method

Stellar parallax is effective for relatively nearby stars (within a few hundred light years). It is not suitable for measuring vast distances to galaxies and other distant objects due to the limitations of parallax angles becoming too small to measure accurately at greater distances.

Worked example: Calculating light speed distances

Try yourself

Thinking	Working
The average distance is stated in kilometres, so you must ensure the speed of light is in kilometres per second when using the formula.	In a vacuum, light travels at 299 792 kilometres per second.
Divide the given distance by the speed of light to get light seconds. (Note that 5 billion is the same as 5 000 million.)	$\frac{5000000000}{299792} = 16678.32$ light seconds
Divide by 60 to get the answer in light minutes.	$\frac{16678.32}{60} = 277.97$ light minutes

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Lesson review

1 A light year is useful because it represents vast distances in a comprehensible way, allowing astronomers to describe the enormous spaces between celestial objects more conveniently than using kilometres.

2 In 5 years, light travels 5 light years, which is approximately 47.3 trillion kilometres. $5 \times 365.25 \times 24 \times 60 \times 60 = 157\,788\,000$ seconds in 5 years; $157\,788\,000 \times 299\,792 = 4.730 \times 10^{13}$ km

3 By measuring the angle of apparent shift of a star at two different points in Earth's orbit six months apart, astronomers can use trigonometry to calculate the distance to the star.

4 **a** Proxima Centauri is 4.24 light years away.

b The Andromeda Galaxy is approximately 2.537 million light years away.

c The distance to Proxima Centauri is much shorter compared to the distance to the Andromeda Galaxy, highlighting the immense scale difference between interstellar and intergalactic distances.

d Using light years helps in simplifying and understanding the vast distances in space, making it easier to comprehend the scale of the universe.

7.3 Big bang theory

Check your understanding

SC 1: I can explain the characteristics and source of cosmic microwave background radiation

The existence of CMB is significant because it provides evidence for the big bang theory.

SC 2: I can explain how observation of cosmic microwave background radiation supports the big bang theory

The background radiation is fairly constant across the universe. This shows that it must have come from a single hot dense point. This radiation is an afterglow from the Big Bang and is still identifiable today.

SC 3: I can compare the big bang theory to steady state theory

The discovery of CMB is evidence of a hot, dense early universe, which contradicts the steady state theory's claim of a constant, unchanging universe. Additionally, the discovery of quasars also challenges the steady state theory by showing extremely distant (and therefore extremely old) object indicating the universe has changed over time rather than remaining constant.

Lesson review

1 The CMB radiation originated from the hot, dense state of the early universe, approximately 380 000 years after the Big Bang, when atoms first formed and the universe became transparent to radiation.

2 The Big Bang theory accounts for the observed expansion by proposing that the universe began from a singularity and has been expanding ever since, with galaxies moving away from each other as space itself expands.

3 The Big Bang theory predicts that the universe began from an infinitely dense and hot point, has been expanding, and will continue to evolve over time. It also predicts the existence of the CMB radiation and the formation of galaxies and structures over time. The steady state theory, on the other hand, predicts a constant universe with continuous creation of matter to maintain a constant density, and does not predict the CMB radiation or a changing universe.

4 The Big Bang theory explains the CMB radiation as the afterglow of the initial explosion and subsequent cooling of the universe. In contrast, the steady state theory does not predict the existence of the CMB radiation, as it posits a constant, unchanging universe without a beginning, making it inconsistent with the observed CMB.

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7.4 The early universe

Check your understanding

SC 1: I can use visual representations to show the key events in the first few seconds after the Big Bang

Nucleosynthesis is the process where protons and neutrons combined to form the nuclei of the first simple elements, such as hydrogen and helium.

SC 2: I can describe how gravity caused matter to condense into galaxies

Gravity caused regions of higher density in the early universe to attract more matter, eventually leading to the formation of stars and galaxies as these regions collapsed under their own gravitational pull.

SC 3: I can describe how gravity caused solar systems to form

The process is called accretion.

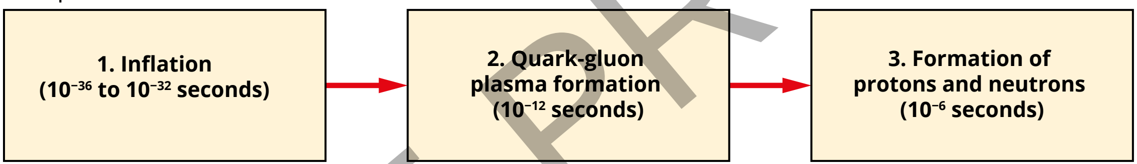
Lesson review

1 During inflation, the universe was extremely hot and dense, expanding exponentially. During nucleosynthesis, the universe had cooled enough for protons and neutrons to combine and form the first atomic nuclei, leading to the creation of light elements like hydrogen and helium.

2 **a** The first event after the Big Bang was inflation.

b During inflation, the universe was extremely hot, dense, and expanded exponentially.

c Sample timeline:



d Inflation smoothed out initial irregularities and set the stage for structure formation. Quark-gluon plasma formation marked the era when fundamental particles began to form. The formation of protons and neutrons allowed for the creation of atomic nuclei, leading to the formation of matter in the universe.

3 A region with higher matter density would experience stronger gravitational forces, causing it to attract more matter and collapse into a dense clump. This clump would eventually form stars and galaxies as matter continued to accumulate and contract under gravity.

4 **a** Gravitational collapse is the process by which a cloud of gas and dust contracts under gravity to form a dense core and surrounding structures.

b Step 1: A cloud of gas and dust begins to collapse under gravity.

Step 2: The collapsing material forms a dense core that ignites nuclear fusion, becoming a star.

Step 3: The remaining material forms a rotating disk around the star.

Step 4: Planets, moons, and other bodies form from the disk material.

c Gravity pulls the gas and dust inward, increasing pressure and temperature until nuclear fusion is triggered, forming the star.

d In solar system formation, gravity acts on a smaller scale to form a star and planets. In galaxy formation, gravity acts on a larger scale to form stars and galaxies. Both processes involve gravitational collapse but result in different structures.

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7.5 Light spectra

Check your understanding

SC 1: I can explain how the presence of chemical elements can be seen in a star's spectrum

Absorption lines are dark lines in the spectrum where light at specific wavelengths has been absorbed by elements in the star's atmosphere. Each element absorbs light at characteristic wavelengths, allowing identification of the elements present.

SC 2: I can explain how a star's spectrum can be used to provide information about other properties including temperature

The peak wavelength of a star's spectrum is inversely proportional to its temperature. A shorter peak wavelength indicates a higher temperature, while a longer peak wavelength indicates a lower temperature.

Lesson review

1 A star's spectrum is observed with a spectroscope.

2 A star's temperature determines the peak wavelength of its emitted light, with hotter stars emitting more light at shorter (bluer) wavelengths and cooler stars emitting more light at longer (redder) wavelengths.

3 The blue star's spectrum will peak at shorter wavelengths, indicating a higher temperature, while the red star's spectrum will peak at longer wavelengths, indicating a lower temperature. This comparison shows that the blue star is hotter than the red star.

4 **a** Absorption spectra show black lines of absorbed wavelengths on a full colour spectrum. Emission spectra show the coloured lines of emitted wavelengths of light on a black background.

b An absorption spectrum is produced as light passes through the atmosphere of a star. The atmosphere absorbs wavelengths of light, so they are 'missing' from the full spectrum when analysing the light. An emission spectrum is the wavelengths of light produced by the movement of electrons in atmospheric particles from higher to lower energy levels after being excited.

7.6 Practical investigation: Using a spectrometer

Results

Answers should show the different bands of colour for each spectra.

Conclusion

- Light seen through a red filter has only light from the red part of the visible spectrum; light seen through a blue filter has only light from the blue part of the spectrum.
- Sunlight includes light from all parts of the visible spectrum, whereas light from a fluorescent tube or globe has light from parts of the spectrum (red, blue and green bands).
- Light from an incandescent globe includes light from all the visible spectrum, whereas light from a fluorescent tube or globe has light from parts of the spectrum (red, blue and green bands).

Evaluation

Answers may include how the experiment uses a spectrometer to split up the observed light in the same way that spectrometers analyse light from stars. They may compare the use of the two different types of globes to be like looking at the spectra from two different stars that contain a different mix of elements. Differences could be that the visible light from stars is very dim and not as intense as the light sources used in this experiment; that in the universe there may be thousands of different stars, all at different ages, with potentially a huge range of possible combinations of elements releasing radiation with a large range of energies/wavelengths, including radiation that is not visible light. Answers may also mention that, in astronomy, the data from spectroscopes will be processed by computers, allowing for a much greater amount of data to be analysed and compared.

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7.7 Inquiry activity: The Doppler effect and redshift

Plan

Sample materials list and instructions for a physical model:

Materials

- stretchable fabric (e.g. elastic fabric)
- Styrofoam balls
- marker pens
- string or thread
- tape or glue

Instructions

- Cut a piece of stretchable fabric and draw a grid on it using a marker pen.
- Attach a Styrofoam ball to the fabric to represent a distant galaxy (or star) emitting light.
- Attach a string or thread to the fabric to represent the observer (Earth).
- Stretch the fabric gently to simulate the expansion of the universe.
- Observe how the gridlines representing light waves change their spacing, demonstrating redshift due to the fabric's stretching.

Improve

Suggestions for improvements based on the materials and instructions above may include:

- Use different-coloured Styrofoam balls to represent galaxies emitting light of varying wavelengths, improving the visual representation of redshift.
- Add labels and/or captions to explain how the stretching of the fabric simulates the expansion of the universe and causes redshift.
- Create a step-by-step guide or video to ensure accurate and understandable model demonstrations.
- Include a graph or chart to illustrate the relationship between fabric stretching and wavelength changes.

Evaluate

In the same way that we observed the stretching of light waves represented by the fabric, astronomers observe light from distant galaxies shifted towards longer wavelengths, indicating that these celestial objects are moving away from us. This correlation aligns with the expanding universe theory, substantiating the notion that galaxies are continually moving apart as the universe expands over time.

7.8 Evidence for an expanding universe

Check your understanding

SC 1: I can describe Hubble's observation that most galaxies are moving away from the Earth and that more distant galaxies are moving away more quickly

Hubble observed that the light from most galaxies is redshifted, indicating they are moving away from Earth. He also found that more distant galaxies have a greater redshift, meaning they are moving away more quickly.

SC 2: I can explain how Hubble's observations indicate that the universe is expanding

The Hubble constant is the number that can be used to predict the velocity of a galaxy based on its distance from Earth, thereby quantifying the rate of the universe's expansion.

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SC 3: I can explain how Hubble's observations support the big bang theory of the origin of the universe

The redshift indicates that galaxies are moving away from each other, suggesting that the universe is expanding from an initial hot, dense state, as proposed by the Big Bang theory.

Lesson review

1 Hubble observed that the light from distant galaxies is redshifted, indicating they are moving away from us, and that the farther the galaxy, the faster it is moving away.

2 Convert 100 million light years to megaparsecs (Mpc):

$1\,\text{Mpc} = 3\,260\,000$ light years

Therefore,

$$\frac{100000000}{3260000} \approx 30.7\,\text{Mpc}$$

Using Hubble's Law:

$v = H_0\,d$

$v = (67)(30.7) = 2055\,\text{km/s}$

3 Hubble's observations show that galaxies are moving away from each other, implying that the universe is expanding. If we reverse this expansion, it suggests that all matter and energy were once concentrated in a single point, supporting the idea of a singular beginning as proposed by the big bang theory.

4 Hubble's observations imply that the universe is expanding, with galaxies moving away from each other, which contradicts the steady state theory that posits a constant, unchanging universe. The steady state theory cannot account for the observed redshifts and the relationship between distance and velocity of galaxies.

7.9 The life cycle of stars

Check your understanding

SC 1: I can describe the key stages in the life cycle of a star

A nebula collapses under gravity, forming a protostar. As the protostar's core temperature increases, nuclear fusion begins, and the star enters the main-sequence stage, where it spends most of its life.

SC 2: I can describe and compare different types of stars including white dwarf, red giant, blue giant and neutron star

A neutron star forms from the supernova explosion of a high-mass star, resulting in an extremely dense core composed mostly of neutrons. A white dwarf forms from the outer layers of a low to medium-mass star being shed, leaving behind a dense core. Neutron stars can further evolve into black holes if they gain enough mass, while white dwarfs gradually cool and fade over time.

SC 3: I can explain the formation and characteristics of a black hole.

A black hole is an extremely dense region of space where the gravitational pull is so strong that not even light can escape from it.

Lesson review

1 A black hole forms from the collapsed core of a massive star after a supernova explosion, when the core's gravity is so strong that it collapses into a singularity.

2 A red giant is a late-stage low-mass star that has expanded and cooled after exhausting its hydrogen fuel. A blue giant is a high-mass, hot star that is in the main sequence stage of its life cycle.

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3 **a** During a star's main sequence stage, hydrogen is fusing to form helium in its core, producing energy and maintaining a stable size and luminosity. This stage lasts for most of a star's life.

b The outwards force due to fusion in the core and the inwards force of gravity are in equilibrium, hence why the star remains a stable size and luminosity.

4 After exhausting its hydrogen fuel, a star like the Sun will expand into a red giant, then shed its outer layers to form a planetary nebula, leaving behind a dense core that becomes a white dwarf.

5 Both black holes and neutron stars form from the collapsed cores of massive stars after supernova explosions. However, a black hole forms when the core's gravity is so strong that it collapses into a singularity, while a neutron star forms when the core's protons and electrons combine to form neutrons, resulting in an extremely dense but not infinitely dense object.

7.10 Practical investigation: Modelling the formation of a neutron star

Results

Model	Mass (g)	Radius (cm)	Volume (cm^3)	Density ($g\ cm^{-3}$)
original star	15	8	2144	0.007
collapsing star	15	4	268	0.056
neutron star	15	1.4	9.43	1.59

Conclusion

The mass does not change as no matter is lost. The volume becomes smaller as the balloon contracts. The density increases significantly from the original, becoming more than 200 times more dense than the original star.

Evaluation

Answers may include how well the model shows the changes in density as an object becomes smaller, just like a collapsing star. They could include the fact that the change in density is significantly less than the real change experienced in the collapsing of the star. The balloon is also hollow, which does not make it a good representation as stars are not hollow within a single 'outer', and the matter inside the star is also contracting.

7.11 Current understandings and futures for the universe

Check your understanding

SC 1: I can explain how evidence about the motion of stars suggests the existence of dark matter and dark energy

Dark matter is a form of matter that does not emit, absorb, or reflect light, making it invisible. Its presence is inferred from its gravitational effects on visible matter.

SC 2: I can explain how gravitational waves can be described as a variation in spacetime which can provide new ways to observe the universe

The detection of gravitational waves confirms predictions made by Einstein's general theory of relativity, which posits that massive objects can cause distortions in spacetime that propagate as waves.

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SC 3: I can describe examples of the contribution of Australian science to current understandings and possible futures of the universe

The Parkes Observatory has been instrumental in radio astronomy and the discovery of pulsars, while SKA provides advanced capabilities for large-scale surveys and studies of the universe's structure, focussing on the evolution of galaxies, the birth and death of stars and the nature of black holes. Both facilities contribute significantly to our understanding of the universe, but they focus on different aspects and techniques in cosmological research.

Lesson review

1 The observed rotational speeds of galaxies and velocities of stars at varying distances from the galactic centre are higher than expected based on visible matter alone. This suggests the presence of additional unseen mass, known as dark matter, providing the necessary gravitational pull to account for the observed motions.

2 The Parkes Observatory has contributed to our understanding by participating in significant discoveries, such as the detection of pulsars.

3 Australian scientists, have contributed by mapping the distribution of galaxies and measuring the expansion rate of the universe, helping to understand the nature of dark energy.

4 **a** Gravity waves, or gravitational waves, are ripples in spacetime caused by the interactions of massive objects, such as merging black holes or neutron stars.

b Gravitational waves are detected using instruments like LIGO and Virgo, which measure tiny disturbances in spacetime caused by passing gravitational waves using laser interferometry.

c The collision and merger of two black holes can produce gravitational waves, creating ripples in spacetime that can be detected by gravitational wave observatories.

d Gravitational waves provide information about the dynamics of massive objects and events not accessible through electromagnetic waves, such as black hole mergers. Electromagnetic waves provide information about the composition, temperature, and motion of objects that emit or reflect light. Both types of waves complement each other in understanding the universe.

Topic review

Remember

1 Cosmic microwave background radiation is the radiation left over from the Big Bang, now observed as a faint glow in all directions in the microwave part of the electromagnetic spectrum.

2 Approximately 9.46 trillion kilometres.

Understand

3 The heliocentric model proposed by Copernicus suggested that the Sun, not Earth, was at the centre of the universe, and that Earth and other planets orbited around the Sun.

4 Gravity waves, or gravitational waves, are ripples in spacetime caused by accelerating massive objects. Their detection allows us to observe and study cosmic events like black hole mergers that are not visible through traditional electromagnetic observations.

5 As a neutron star collapses, its volume decreases, its mass remains approximately constant, and its density increases significantly due to the compression of matter.

Apply

6 A low-mass star evolves from a main sequence star to a red giant and then to a white dwarf. A high-mass star becomes a supergiant and may undergo a supernova explosion, resulting in either a neutron star or a black hole.

7 Hubble's law states that the velocity of a galaxy is directly proportional to its distance from us, meaning that more distant galaxies are moving away faster.

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8 Answers may be in the form of a timeline, for example. A timeline or diagram should include references to rapid expansion, cooling, and formation of fundamental particles. The timeline or diagram should look similar to Figure 7.5.3.

9 Place two markers a known distance apart, approximately the same distance to the tree. Stand at one marker and sight the tree against a distant background. Move to the second marker and sight the tree again. Measure the apparent shift in the tree's position against the background by measuring the angle between the tree and the other marker. Use trigonometry to calculate the distance to the tree.

Analyse

10 a After the Big Bang, regions of higher density in the universe began to attract more matter due to gravity, leading to the formation of stars and galaxies.

b Gravity caused matter to condense and form stars and galaxies by pulling matter together and overcoming other forces.

c The presence of chemical elements can be identified by the dark absorption lines in a star's spectrum, corresponding to specific wavelengths absorbed by those elements.

d The study of star spectra has revealed the chemical composition of stars, provided insights into nuclear fusion processes, and helped astronomers understand the life cycles and evolution of stars.

11 a By observing a star from two different positions in Earth's orbit around the Sun, the apparent shift in the star's position against a distant background can be measured, and this shift can be used to calculate the star's distance from Earth.

b Stellar parallax is limited to measuring distances to relatively nearby stars because the parallax angles become too small to measure accurately for distant stars.

c The Doppler effect causes the wavelength of light to change depending on the relative motion of the source and observer. If the source is moving away, the light is redshifted (wavelength increases); if the source is moving towards the observer, the light is blueshifted (wavelength decreases).

d Redshift measurements have been used to determine the velocities of galaxies and, combined with their distances, have helped create a map of the expanding universe, leading to the discovery of the accelerating expansion driven by dark energy.

Extension

12 Australia is a geologically stable continent, with a sparse population. This allows for sites with little interference. There will be a variety of organisations that can be researched. These may include individual universities (e.g. ANU, University of Sydney, Macquarie University, Monah University etc), ARC centre of Excellence for Gravitational Wave Discovery, CSIRO, Australian Space Agency, Australian Square Kilometre Array (or other observatories).

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