Big Bang

PHYSICS • UNIVERSE • BIG BANG

Section 1: How Was the Universe Created?

• What was the Big Bang?

It is thought that the Big Bang occurred 13.8 billion years ago when the Universe expanded from a very hot and very dense state. The Universe is still expanding, but because of this expansion it has cooled significantly.

Big Bang theory explains the origin and evolution of the Universe. In particular, it explains why the distance between clusters of galaxies is increasing.

- **Suggested Films**
  - **Big Bang Theory**
  - **Cold War to Gamma Rays**

Millions of galaxies exist in the Universe, such as this Whirlpool Galaxy M51

Extension Question

Q1. What is inflation?

It is believed that soon after the Big Bang, the diameter of the Universe suddenly increased extremely rapidly: this is known as inflation. It is thought that the diameter of the Universe became more than a trillion, trillion times larger in a very short time, perhaps around 10^{-32} s (or a billionth of a trillionth of a trillionth of a second).

Inflation addresses several issues with the Big Bang model. For example, the Universe appears very uniform in all directions, therefore it is hard to see how this could happen if the opposite sides of the Universe had not been in contact long enough to reach equilibrium: this is known as the horizon problem. Inflation solves this by suggesting that the Universe was once very small, and all parts were in close enough contact for them to reach the same temperature, before rapid expansion occurred. Thus causing this uniformity to be preserved as the Universe continued expanding much more slowly.

Although it is not certain exactly what could have caused inflation, predictions made by this theory do seem to have been confirmed by observations of the cosmic microwave background. Measurements are currently being conducted to try and test the predictions made by the theory of inflation.

DIAGRAM 01:

• Are there other theories than the Big Bang?

Steady state theory was developed in the late 1940s. It was meant to provide an alternative to the Big Bang theory and suggested that instead of the Universe being created as the result of an event billions of years ago, creation has been occurring continuously, with new matter coming into creation and allowing the density of the Universe to remain constant.

The discovery of the cosmic microwave background in the 1960s resulted in the Big Bang theory gaining acceptance, as there was no obvious reason for steady state theory to account for the form of the radiation that was detected.

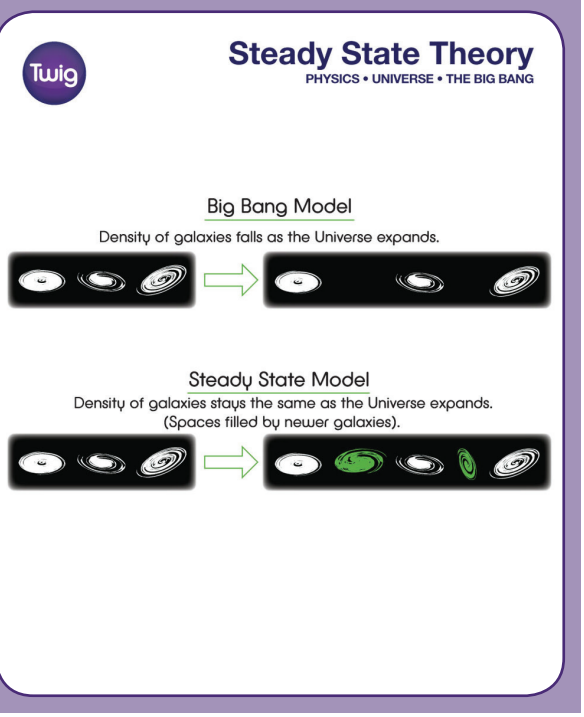
In the 1990s a new version of steady state theory was proposed. This new theory, quasi-steady state cosmology, proposed that mini-creation events, or 'minibangs', occurred over the lifetime of the Universe. However, this theory is not widely accepted.

• Suggested Films

– Big Bang Evidence

– FactPack: Big Bang Scientists

DIAGRAM 02:



• What was there before the Big Bang?

The usual answer to this is that there was nothing before the Big Bang 13.8 billion years ago. More accurately, as time itself was created in the Big Bang the question is meaningless as there was no 'before'. However, there are some models of the very early stages of the Universe that do not require that time was created in the Big Bang. If these models are correct, it is not impossible that the Universe existed in some form before the Big Bang. Some theories propose that the Universe could be cyclical, with a new Big Bang being triggered each time the Universe 'ends'. If this is true the Universe could be far older than 13.8 billion years.

• Suggested Film

– Big Bang Theory

Extension Question

Q2. How will the Universe end?

If we accept that the Universe had a beginning, it is reasonable to ask whether it will have an end, and what form this might take. There are several possibilities, but it is thought that the ultimate fate of the Universe will depend on the geometry of space, or the 'shape' of the Universe.

In simple terms, if gravity is able to slow, and eventually stop the expansion of the Universe, it is possible that the Universe could contract, perhaps ending in a 'Big Crunch'. It is even possible that this could lead to another Big Bang, resulting in a Universe which continually expands and contracts.

Alternatively, the Universe may continue expanding forever. Eventually, stars will no longer be able to form as all the available fuel is exhausted. After the last stars die, the remnants will slowly decay, and after an enormous amount of time the temperature across the entire Universe will become uniform. This is known as 'heat death'.

Section 2: Expansion

• What is redshift?

The redshift of light from distant galaxies shows that they are travelling away from each other and provides evidence for the Big Bang.

When waves are emitted by a moving object, the wavelength and frequency will appear to change. For example, if a train is heading towards a stationary observer, the sound from the train will sound as if it has a higher frequency than if the train were not moving. As the train moves away from the observer the frequency of the sound will appear to have been reduced. This is because as the moving train emits sound, it is either catching up on or travelling away from the waves already emitted, which either reduces or increases the distance between the waves. This means the time between the waves arriving is either reduced or increased. The speed of an object can be calculated by measuring the change in frequency.

This effect also occurs for light. If an object is travelling towards an observer, the wavelength will appear to decrease, shifting the light towards the short wavelength, 'blue', end of the spectrum. If the object is moving away from an observer it will instead appear 'redshifted'.

When distant galaxies are observed they are seen to be redshifted. There are two reasons for this: firstly, the galaxies are travelling away from each other; secondly, as light travels through expanding space, its wavelength is increased, also causing redshift.

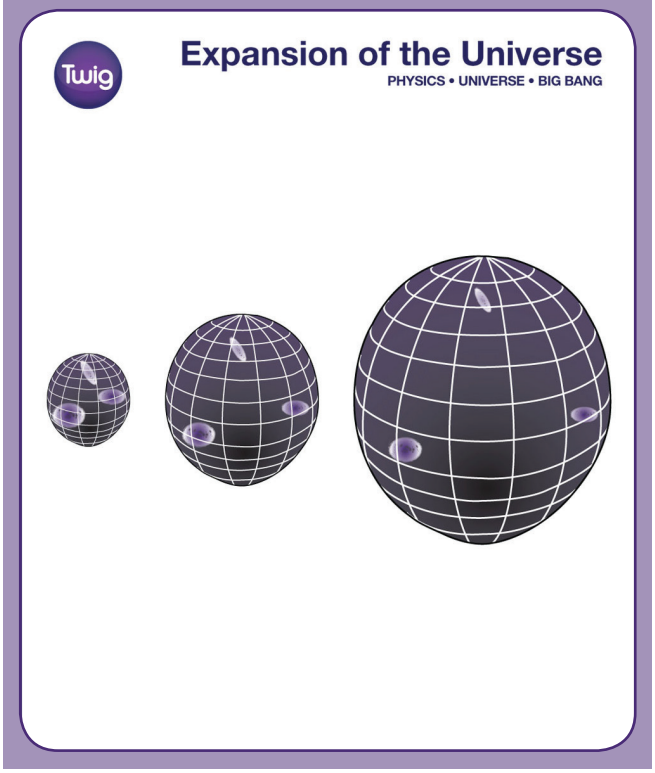
- **Suggested Films**
  - **– Big Bang Evidence**
  - **– FactPack: Redshift**

Extension Question

Q3. Where did the Big Bang happen?

As the Universe is expanding outwards in all directions, it seems to make sense that they are all heading away from a central point, and that we should be able to say where this point is. If we imagine points drawn on the surface of a balloon, we can imagine them moving further apart as it expands. It seems to make sense that the centre of the balloon is where the expansion started, but space is only like the surface of the balloon. Although the points on the surface are all moving apart, there is no point on the surface where we can say the expansion started. In the same way, there is no point in space where we can say that the Big Bang happened; instead we say that it happened everywhere.

DIAGRAM 03:



• Why are some galaxies heading towards each other?

As space expands, we might expect that all galaxies should be heading away from each other. This is generally true but on a smaller scale (a few million light years). The gravitational attraction between neighbouring galaxies can pull them towards each other, and so galaxies are often found in clusters.

- **Suggested Film**
  - **Big Bang Evidence**

Extension Question

Q4. Why do some galaxies appear to be travelling faster than light?

The size of the redshift is related to the velocity of the object. Some distant galaxies have redshifts, which are so large that they suggest the galaxies are travelling faster than the speed of light.

Although it is not possible for objects to travel faster than light this occurs because the space between the galaxies is expanding. This can mean that the distance between galaxies can increase faster than the speed of light even though the galaxies are not travelling at this speed.

• What is the Hubble constant?

As the Universe expands, galaxies appear to be travelling further away from each other. The apparent velocity of distant galaxies is related to their distance from us. As the distance increases, the apparent velocity of the galaxy also increases. This velocity can be calculated using Hubble's Law: the velocity of a distant object is given by the distance multiplied by the Hubble constant, which is often given in kilometres per second per Megaparsec. Current measurements of the Hubble constant suggest that it has a value of around 70km/s per Megaparsec, although different methods of measurements produce different values ranging from around 50 to 100km/s per Megaparsec.

This means that for every million parsecs (about three million light years) an object is from our position, its apparent velocity increases by around 70km/s. By comparison, our galaxy is about 30,000 parsecs across, and the distance to the nearest galaxy is around 0.8 million parsecs.

- **Suggested Film**
  - **Big Bang Evidence**

Extension Question

Q5. Who was Edwin Hubble?

Edwin Hubble was an American astronomer. In the early 1920s Hubble proved that some stars were located far outside the galaxy we live in, the Milky Way. This discovery settled the debate over whether the entire Universe consisted only of the Milky Way, as was widely believed at the time. He also examined the redshift of galaxies, work that led to Hubble's Law. In 1983, the proposed Large Space Telescope was renamed the Hubble Space Telescope in recognition of Edwin Hubble's contribution to astronomy. The telescope was launched in 1990.

The Hubble Space Telescope

Section 3: Researching the Big Bang

• What is the cosmic microwave background?

The area of the sky between stars 'glows' faintly. This is at a wavelength which is not visible to us, and these parts of sky appear black. This 'glow' is a remnant from a time when the Universe was much hotter, about 400,000 years after the Big Bang. At around this time atoms formed for the first time. This meant that light was no longer absorbed as effectively, and so light from this time can now be detected. However, the expansion of the Universe has increased the wavelength of the light, and it is now only visible as microwaves.

The form of this radiation agrees very well with Big Bang theory and it is considered to be strong evidence that Big Bang theory is correct.

The microwaves detected in outer space are similar to the waves emitted by microwave ovens

- **Suggested Films**
  - **Big Bang Evidence**
  - **Nobel Prize By Chance**

Extension Question

Q6. What does the cosmic microwave background tell us?

Although the cosmic microwave background appears to be very uniform, there are small fluctuations that tell us about the conditions following the Big Bang and the evolution of the Universe. For this reason, measurements are continually being improved. The Planck space observatory was launched in 2009 to study the cosmic microwave background, and is expected to test aspects of Big Bang theory and help us understand exactly how the Universe began.

• How does the abundance of light elements support Big Bang theory?

It is believed that light elements like hydrogen, helium and lithium were created following the Big Bang but that heavier elements were not created. Big Bang theory predicts that the period when elements were created is thought to have ended twenty minutes after the Big Bang, too short a time for heavy elements to be created.

Measurements of the abundance of elements have shown good agreement with the predictions of Big Bang theory and this is considered further evidence that the theory is correct.

- **Suggested Films**
  - **Big Bang Theory**
  - **Big Bang Evidence**

• What can the Large Hadron Collider tell us about the Big Bang?

Most experiments at the Large Hadron Collider (LHC) collide protons at high speed. However, the LHC also conducts experiments with lead ions. These collisions are designed to spread a large amount of energy over a relatively large volume. This is done in an attempt to produce an entirely new form of matter, quark-gluon plasma.

Protons and neutrons are found in the nuclei of atoms. These are composed of quarks, which are bound together very tightly by particles called gluons. It would take an enormous amount of energy to eject a quark from a proton or neutron, and even if this were achieved; for example, in a high energy collision between protons, the quark would instantly decay and produce a 'jet' of other particles. However, if nuclei collide at very high speeds it is possible that the nuclei will create a 'fireball'. Within the volume of hot material which is produced quarks are able to move freely. This is known as quark-gluon plasma. It is thought that around a trillionth of a second after the Big Bang the Universe was composed of quark-gluon plasma. Soon afterwards, a millionth of a second after the Big Bang, the Universe cooled enough for protons and neutrons to form. Studying quark-gluon plasma, by colliding lead nuclei, should help us to better understand the early stages of the Big Bang.

- **Suggested Film**
  - **Large Hadron Collider**

Extension Question

When matter is created, antimatter is also created at the same time. For example, when an electron is created, its antimatter equivalent, the positron, is also created. This will have the opposite charge but the same mass. When these two particles are brought back together they will annihilate, releasing energy.

It appears the Universe is entirely composed of 'normal' matter. It is not entirely clear how this is possible, as we would expect equal amounts of matter and antimatter to have been produced in the Big Bang. It is hoped that experiments at the LHC may give some clue as to how this could have happened.

• Quizzes

Big Bang Theory

Basic

• How long ago did the Big Bang occur?

A – around 65 million years

B – around 14 billion years

C – around 46 billion years

• How long did it take for the first tiny particles to form?

A – 1 second

B – 1 year

C – 1 million years

• What were the first clouds of gas which formed called?

A – clusters

B – nebulae

C – galaxies

• Which atoms were the first to form?

A – lithium and boron

B – carbon and nitrogen

C – hydrogen and helium

Advanced

• How long did it take before the Universe was cool enough for atoms to form?

A – 15,000 years

B – 380,000 years

C – 2 million years

• How long after the Big Bang did the first clouds of gas form?

A – 380,000 years

B – hundreds of millions of years

C – billions of years

• Approximately how long after the Big Bang did the Milky Way form?

A – hundreds of millions of years

B – 1 billion years

C – 5 billion years

• How long after the Big Bang was Earth formed?

A – 1 billion years

B – 5 billion years

C – 9 billion years

Big Bang Evidence

Basic

• When was the expansion of the Universe first discovered?

A – 1750

B – 1810

C – 1929

• Who first discovered the expansion of the Universe?

A – Edmund Halley

B – Edwin Hubble

C – Fred Hoyle

• What sort of radiation suggested evidence for the Big Bang?

A – microwaves

B – infrared

C – ultraviolet

• When was this background radiation detected?

A – 1817

B – 1965

C – 1993

Advanced

• What are almost all galaxies doing?

A – moving closer to each other

B – moving away from each other

C – growing

• Why does light from distant stars and galaxies appear "redshifted"?

A – some light is absorbed by dust clouds

B – the expansion of space has caused the wavelength of the light to change

C – galaxies and stars usually emit red light

• What is the cosmic microwave background?

A – the afterglow of the Big Bang

B – the light being emitted by all stars and galaxies

C – the radiation emitted by radio transmissions from Earth

• When was the cosmic microwave background discovered?

A – 1920

B – 1952

C – 1965

Big Bang Evidence

Basic

• The existence of which elements in higher quantities is evidence for the Big Bang?

A – hydrogen and helium

B – carbon and oxygen

C – nitrogen and fluorine

Advanced

• When were heavy elements created?

A – in the Big Bang

B – when light elements collided in gas clouds

C – after stars were formed

• What does the Big Bang Theory say about the creation of the Universe?

A – the Universe has always existed in its present form

B – matter is continually being created

C – the Universe expanded from a single point billions of years ago

• Answers

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