**ACTIVITY: Big Bang theory**

**Activity idea**

In this activity, students gain understanding of the role the Large Hadron Collider is playing in exploring the current models for the structure of matter. It is a video clip and science article analysis activity.

Particle physicist Dr David Krofcheck of the University of Auckland is featured in the video clips where he describes the relationship between Big Bang theory and experiments being conducted at the Large Hadron Collider.

The science articles provide information that underpins the video clips.

By the end of this activity, students should be able to:

* explain the main features of the Big Bang theory
* discuss the role the LHC is playing in particle physics research
* describe the structure of the nucleus
* describe how elements are formed deep within stars.

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**Introduction/background**

Our current understanding of how matter originated, what it is made of and what holds it together is incomplete.

Experiments being conducted at the world’s largest particle accelerator, called the Large Hadron Collider (LHC), have been designed to imitate the energy-matter state that existed in the initial few microseconds following the Big Bang origin of the universe.

The structure of the LHC allows counter-circulating beams of charged particles to be accelerated to very high speeds. When the particles are allowed to collide, this energy-matter state is formed. By carefully analysing the collision fragments that condense out, physicists will be able to confirm or dispute some current theories they have about atomic structure and how atoms were formed in the instant of time after the Big Bang.

**What you need**

* Copies of the student worksheet: [Investigating the Big Bang](#investigating)
* Access to the video clips [What is the Big Bang theory](https://www.sciencelearn.org.nz/videos/139-what-is-the-big-bang-theory)?, [What is a particle accelerator?](https://www.sciencelearn.org.nz/videos/1047-what-is-a-particle-accelerator), [David Krofcheck’s core research](https://www.sciencelearn.org.nz/videos/1049-david-krofcheck-s-core-research) and the interactive [Universal element formation](https://www.sciencelearn.org.nz/image_maps/50-universal-element-formation)
* Copies of or access to the articles [The structure of the nucleus](https://www.sciencelearn.org.nz/resources/1731-the-structure-of-the-nucleus) and [How elements are formed](https://www.sciencelearn.org.nz/resources/1727-how-elements-are-formed).

**What to do**

1. Hand out copies of the student worksheet [Investigating the Big Bang](#investigating).
2. View the video [What is the Big Bang theory?](https://www.sciencelearn.org.nz/videos/139-what-is-the-big-bang-theory) and have students answer questions 1–5 on the student worksheet.
3. View the video [What is a particle accelerator?](https://www.sciencelearn.org.nz/videos/1047-what-is-a-particle-accelerator) have students answer questions 6–10 on the student worksheet.
4. Read the article [The structure of the nucleus](https://www.sciencelearn.org.nz/resources/1731-the-structure-of-the-nucleus) and view the video [David Krofcheck’s core research](https://www.sciencelearn.org.nz/videos/1049-david-krofcheck-s-core-research) and have students answer questions 11–15 on the student worksheet.
5. Read the article [How elements are formed](https://www.sciencelearn.org.nz/resources/1727-how-elements-are-formed) and view the interactive [Universal element formation](https://www.sciencelearn.org.nz/image_maps/50-universal-element-formation) and have students answer questions 16–20 on the student worksheet.
6. Discuss the answers.

**Investigating the Big Bang**

***View the video*** [***What is the Big Bang theory?***](https://www.sciencelearn.org.nz/videos/139-what-is-the-big-bang-theory) ***and answer these questions:***

1. According to Big Bang theory, some kind of expansion of space took place at some point in time. What is the estimated date of the start of this expansion?
2. Give two pieces of evidence that point to this idea of Big Bang and expansion of space.
3. The very hot and dense nuclear matter that was present at the beginning of this expansion slowly cooled. Name the two elements first formed as a result of this cooling.
4. What is cosmic background radiation?
5. In this video clip, what is the last thing David says about Big Bang?

***View the video*** [***What is a particle accelerator?***](https://www.sciencelearn.org.nz/videos/1047-what-is-a-particle-accelerator) ***and answer these questions:***

1. In your own words, explain in simple terms what a particle accelerator is.
2. LHC stands for ‘Large Hadron Collider’. What is meant by each of these terms?
3. What is the main advantage a circular particle accelerator has over a linear accelerator?
4. Protons at full energy in the LHC will be travelling so fast that each proton will go round the 27 km ring 11,000 times per second. Calculate the speed in km/s of each proton. Compare this with the speed of light in a vacuum, which is 300 000 km/s.
5. Construction of the LHC has allowed particle physicists to explore particle collisions in new regions of energy. What might this lead to?

***Read the article*** [***The structure of the nucleus***](https://www.sciencelearn.org.nz/resources/1731-the-structure-of-the-nucleus) ***and view the video*** [***David Krofcheck’s core research***](https://www.sciencelearn.org.nz/videos/1049-david-krofcheck-s-core-research) ***and students answer these questions:***

1. What has Westpac Stadium in Wellington got to do with the structure of a hydrogen atom?
2. Scientists now believe that protons and neutrons are made of even smaller particles known as quarks. ‘Up’ quarks have a charge of plus two-thirds and ‘down’ quarks have a charge of negative one-third. If both protons and neutrons are made up of three quarks each, what must be the combination of quarks for a proton and a neutron? (Remember: a proton carries a single positive charge and a neutron zero charge.)
3. What have freckles on the faces of people got to do with quarks?
4. What is it about David Krofcheck’s research project at the LHC that is different from the standard proton-proton collisions?
5. What are ‘gluons’ and what is their function?

***Read the article*** [***How elements are formed***](https://www.sciencelearn.org.nz/resources/1727-how-elements-are-formed) ***and view the interactive*** [***Universal element formation***](https://www.sciencelearn.org.nz/image_maps/50-universal-element-formation) ***and answer these questions:***

1. Give the names and symbols of the elements formed during the formation of the universe some 14 billion years ago.
2. Explain how the other 86 elements found in nature were created.
3. Super red giants are the element factories of our universe due to nuclear fusion reactions. Explain what happens in a nuclear fusion reaction.
4. What happens to a star when its core runs out of hydrogen?
5. Only 90 of the 116 known elements occur naturally. Where have the other 26 elements come from?

**Answers to student worksheet**

1. According to Big Bang theory, some kind of expansion of space took place at some point in time. What is the estimated date of the start of this expansion?

*13–14 billion years ago.*

1. Give two pieces of evidence that point to this idea of Big Bang and expansion of space.

* *“We can tell that from the light that gets emitted and detected back on Earth through telescopes, that light is moving away from us, so stars and galaxies and planets are generally expanding away from us.”*
* *“Big Bang also produced all the hydrogen and most of the helium that we have in the universe. The ratio of helium to hydrogen can be predicted very well with high accuracy by measuring nuclear reactions, and we find that’s just the amount we see when we look out into space. The ratio of the two is just what you would expect from the Big Bang theory.”*
* *“And there is a left-over signature of the Big Bang as well – cosmic microwave background radiation.”*

1. The very hot and dense nuclear matter that was present at the beginning of this expansion slowly cooled. Name the two elements first formed as a result of this cooling.

*Hydrogen and helium.*

1. What is cosmic background radiation?

*Radiation left over from an early stage in the development of the universe. Its discovery is considered a landmark test of Big Bang theory.*

1. In this video clip, what is the last thing David says about Big Bang?

*“Big Bang is how matter came about.”*

1. In your own words, explain in simple terms what a particle accelerator is.

*A device/machine that can accelerate charged particles like protons to very high kinetic energies and then allow them to collide either with a target or themselves.*

1. LHC stands for ‘Large Hadron Collider’. What is meant by each of these terms?

*Large means 27 km in circumference. Hadron means a strongly interacting particle like a proton. Collider means that the proton beams after being accelerated to very high speeds are allowed to collide with one another.*

1. What is the main advantage a circular particle accelerator has over a linear accelerator?

*Much higher particle speeds can be obtained with a circular accelerator.*

1. Protons at full energy in the LHC will be travelling so fast that each proton will go round the 27 km ring 11,000 times per second. Calculate the speed in km/s of each proton. Compare this with the speed of light in a vacuum, which is 300 000 km/s.

*Speed = distance/time = (27 x 11 000)/1 = 297 000 km/s*

*This is very close to the speed of light. (99%)*

1. Construction of the LHC has allowed particle physicists to explore particle collisions in new regions of energy. What might this lead to?

*“You can explore physics in new regions of energy for which we can only theorise what might happen, and maybe we can find some new ways in which the particles interact and new particles that cause the interaction.”*

1. What has Westpac Stadium in Wellington got to do with the structure of a hydrogen atom?

*A grain of rice placed in the centre of the field represents the nucleus. The outer row of seats in the stadium is the limit of the electron’s influence. The rest of the atom is empty space. The electron seems to be everywhere at once like seats around the playing area.*

1. Scientists now believe that protons and neutrons are made of even smaller particles known as quarks. ‘Up’ quarks have a charge of plus two-thirds and ‘down’ quarks have a charge of negative one-third. If both protons and neutrons are made up of three quarks each, what must be the combination of quarks for a proton and a neutron? (Remember: a proton carries a single positive charge and a neutron zero charge.)

* *Let ‘U’ and ‘D’ represent the quarks. ‘U’ has a charge of plus two-thirds and ‘D’ a charge of negative one-third.*
* *The proton has a charge of plus one and must consist of 2@’U’ + 1@’D’.*
* *The neutron has zero charge and must consist of 1@’U’ and 2@’D’.*

1. What have freckles on the faces of people got to do with quarks?

*Picture a large city, like Christchurch, with people moving in the central city square:*

* *The outer boundary of the city is the limit of the atom.*
* *The central city square is the nucleus.*
* *The people in the city square are the protons and neutrons.*
* *Freckles on the faces of the people are the quarks.*

1. What is it about David Krofcheck’s research project at the LHC that is different from the standard proton-proton collisions?

*David’s research project focuses on lead ion collisions rather than proton collisions. Lead has 208 protons and neutrons – compared to just one proton and one proton colliding, lead will collide 208 protons and neutrons with 208 other protons and neutrons. 416 protons and neutrons give you a lot of quarks colliding at the same time and that sets off the herd behaviour of the quarks.*

1. What are ‘gluons’ and what is their function?

*The quarks are bonded very tightly together by another type of particle called a gluon. The gluons effectively ‘glue’ the quarks together. Gluons are thought to be responsible for the strong nuclear force that binds the nucleus together. They are called force carrier particles.*

1. Give the names and symbols of the elements formed during the formation of the universe some 14 billion years ago.

*Hydrogen (H), helium (He), lithium (Li) and beryllium (Be).*

1. Explain how the other 86 elements found in nature were created.

*The other 86 elements found in nature were created in nuclear reactions in stars and in huge stellar explosions known as supernovae.*

1. Super red giants are the element factories of our universe due to nuclear fusion reactions. Explain what happens in a nuclear fusion reaction.

*In a nuclear fusion reaction, the nuclei of atoms are effectively welded together to make a heavier element. For example, the element carbon is produced deep within the core of stars by fusing atoms of helium together. 3 @ 4He → 12C*

*During the course of such reactions, some of the mass of the reacting particles is converted into energy, which keeps the star ‘burning’.*

1. What happens to a star when its core runs out of hydrogen?

*As stars run out of hydrogen to fuel the nuclear fusion reactions, they expand by up to 100 times their size to become red giants. Our Sun will follow this path over the next 5 billion years.*

1. Only 90 of the 116 known elements occur naturally. Where have the other 26 elements come from?

*The other elements have been formed in nuclear power plants and particle accelerators. For example, element number 106 seaborgium was created in a particle accelerator by bombarding atoms of curium with atoms of neon. Element number 94, plutonium, is formed in nuclear power plants when atoms of uranium are bombarded with fast-moving neutrons.*