How the Big Bang Theory Works
by Jonathan Strickland

For centuries, humans have gazed at the stars and wondered how the universe developed into what it is today. It's been the subject of religious, philosophical, and scientific discussion and debate. People who have tried to uncover the mysteries of the universe's development include such famous scientists as Albert Einstein, Edwin Hubble and Stephen Hawking. One of the most famous and widely accepted models for the universe's development is the big bang theory.

Although the big bang theory is famous, it's also widely misunderstood. A common misperception about the theory is that it describes the origin of the universe. That's not quite right. The big bang is an attempt to explain how the universe developed from a very tiny, dense state into what it is today. It doesn't attempt to explain what initiated the creation of the universe, or what came before the big bang or even what lies outside the universe.

Another misconception is that the big bang was a kind of explosion. That's not accurate either. The big bang describes the expansion of the universe. While some versions of the theory refer to an incredibly rapid expansion (possibly faster than the speed of light), it's still not an explosion in the classic sense.

Summing up the big bang theory is a challenge. It involves concepts that contradict the way we perceive the world. The earliest stages of the big bang focus on a moment in which all the separate forces of the universe were part of a unified force. The laws of science begin to break down the further back you look. Eventually, you can't make any scientific theories about what is happening, because science itself doesn't apply.

The Short and Skinny on the Big Bang
The big bang theory describes the development of the universe from the time just after it came into existence up to today. It's one of several scientific models that attempts to explain why the universe is the way it is. The theory makes several predictions, many of which have been supported through observational data. As a result, it's the most popular and accepted theory regarding our universe's development.

The most important concept to get across when talking about the big bang is expansion. Many people think that the big bang is about a moment in which all the matter and energy in the universe was concentrated in a tiny point. Then this point exploded, shooting matter across
space, and the universe was born. In fact, the big bang explains the expansion of space itself, which in turn means everything contained within space is spreading apart from everything else. The illustrations to the right should help a little.

Today, when we look at the night sky, we see galaxies separated by what appears to be huge expanses of empty space. At the earliest moments of the big bang, all of the matter, energy and space we could observe were compressed to an area of zero volume and infinite density. Cosmologists call this a singularity.

What was the universe like at the beginning of the big bang? According to the theory, it was extremely dense and extremely hot. There was so much energy in the universe during those first few moments that matter as we know it couldn't form. But the universe expanded rapidly, which means it became less dense and cooled down. As it expanded, matter began to form and radiation began to lose energy. In only a few seconds, the universe formed out of a singularity that stretched across space.

One result of the big bang was the formation of the four basic forces in the universe. These forces are:

- Electromagnetism
- Strong nuclear force
- Weak nuclear force
- Gravity

At the beginning of the big bang, these forces were all part of a unified force. It was only shortly after the big bang began that the forces separated into what they are today. How these forces were once part of a unified whole is a mystery to scientists. Many physicists and cosmologists are still working on forming the Grand Unified Theory, which would explain how the four forces were once united and how they relate to one another.

The First Second

Because of the limitations of the laws of science, we can't make any guesses about the instant the universe came into being. Instead, we can look at the period immediately following the creation of the universe. Right now, the earliest moment scientists talk about occurs at $t = 1 \times 10^{-43}$ seconds (the "t" stands for the time after the creation of the universe). In other words, take the number 1.0 and move the decimal place to the left 43 times.
At \( t = 1 \times 10^{-43} \) seconds, the universe was incredibly small, dense and hot. The universe spanned a region of only \( 1 \times 10^{-33} \) centimeters (3.9 x \( 10^{-34} \) inches). Today, that same stretch of space spans billions of light years. During this phase, big bang theorists believe, matter and energy were inseparable. The four primary forces of the universe were also a united force. As tiny fractions of a second passed, the universe expanded rapidly. Cosmologists refer to the universe's expansion as **inflation**. The universe doubled in size several times in less than a second [source: UCLA].

As the universe expanded, it cooled. At around \( t = 1 \times 10^{-35} \) seconds, matter and energy separated. During this time, the universe filled with a nearly equal amount of matter and anti-matter. There was more matter than anti-matter, so while most particles and anti-particles annihilated each other, some particles survived. These particles would later combine to form all the matter in the universe.

Starting at \( t = 1 \times 10^{-11} \) seconds the unified force broke down into components. The forces of electromagnetism and weak nuclear force split off. Photons outnumbered matter particles, but the universe was too dense for light to shine within it. Scientists can recreate this in lab conditions with **particle accelerators**. That means that we have some observational data on what the universe must have been like at this time.

Beginning 0.01 second after the beginning of the big bang scientists feel they have a pretty good handle on how the universe evolved. The universe continued to expand and cool, and the subatomic particles formed earlier began to bond together. They formed neutrons and protons. By the time a full second had passed, these particles could form the nuclei of light elements like hydrogen (in the form of its isotope, deuterium), helium and lithium. This process is known as **nucleosynthesis**. But the universe was still too dense and hot for electrons to join these nuclei and form stable atoms.

### The Next 13 Billion Years

A lot happened in that first second of the big bang. But that's just the beginning of the story. After 100 seconds, the universe's temperature cooled to 1 billion degrees Kelvin (1 billion degrees Celsius, 1.8 billion degrees Fahrenheit). Subatomic particles continued to combine. By mass, the distribution of elements was approximately 75 percent hydrogen nuclei and 24 percent helium nuclei (the other percent consisted of other light elements like lithium).

The temperature of the universe was still too high for electrons to bond with nuclei. Instead, electrons collided with other subatomic particles called **positrons**, creating more photons. But the universe was too dense to allow light to shine inside of it.

The universe continued to expand and cool. After about 56,000 years, the universe had cooled to 9,000 degrees Kelvin (8,726 degrees Celsius, 15,740 degrees Fahrenheit). At this time, the density of the matter distribution in the universe matched the density of radiation. After another 324,000 years, the universe had expanded enough to cool down to 3,000 degrees Kelvin (2,727 degrees Celsius, 4,940 degrees Fahrenheit). Finally, protons and electrons could combine to form neutral hydrogen atoms.
It was at this time, 380,000 years after the initial event, when the universe became transparent. Light could shine throughout the universe. The radiation that humans would later identify as cosmic microwave background radiation locked into place. When we study the CMB today, we can extrapolate a picture of what the universe looked like then.

For the next 100 million years or so, the universe continued to expand and cool. Small gravitational fluctuations caused particles of matter to cluster together. Gravity caused gases in the universe to collapse into tight pockets. As gases contract, they become more dense and hot. Some 100 to 200 million years after the initial creation of the universe, stars formed from these pockets of gas.

Stars began to cluster together to form galaxies. Eventually, some stars went supernova. As the stars exploded, they ejected matter across the universe. This matter included all the heavier elements we find in nature (everything up to uranium). Galaxies in turn formed their own clusters. Our own solar system formed around 4.6 billion years ago.

Today, the temperature of the universe is 2.725 degrees Kelvin (-270 degrees Celsius, -455 degrees Fahrenheit), which is only a couple of degrees above absolute zero. The homogenous section of the universe we can theorize about reaches $1 \times 10^{29}$ centimeters across (about $6.21 \times 10^{23}$ miles). That's larger than what we're able to physically observe using our most advanced astronomical instruments.

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