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.

WHAT IS A THEORY

In science, a theory is an attempt to explain a particular aspect of the universe. Theories can’t be proven, but they can be disproven. If observations and tests support a theory, it becomes stronger and usually more scientists will accept it. If the evidence contradicts the theory, scientists must either discard the theory or revise it in light of the new evidence.

While many people believe that the big bang theory refers to an explosion, it actually refers to the expansion of the universe.

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 proven 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.

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 was compressed to an area of zero volume and infinite density.

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.

Where the Big Bang Theory Came From

The big bang theory is the result of two different approaches to studying the universe: astronomy and cosmology. Astronomers use instruments to observe stars and other celestial bodies. Cosmologists study the astrophysical properties of the universe.

Light travels in waves too, and astronomers discovered that some stars had more light falling into the red side of the spectrum than they expected. They theorized that this meant the stars were moving away from Earth. As
the stars move away, the wavelengths from the light they emit stretch. They shift to the red end of the spectrum because that end has longer wavelengths. Cosmologists call this phenomenon the **redshift**. A star’s redshift is an indication of how quickly it is moving away from Earth. The further toward the red end of the spectrum the light shifts, the faster the star is moving away.

In the 1920s, an astronomer named Edwin Hubble noticed something interesting. The velocity of a star appeared to be proportional to its distance from the Earth. In other words, the further away a star was from Earth, the faster it appeared to move away from us. Hubble theorized that this meant the universe itself was expanding.

Hubble theorized that the universe expands as time passes. That meant that billions of years ago, the universe would have been much smaller and more dense. If you go back far enough, the universe would collapse into an area with infinite density, containing all the matter, energy, space and time of the universe. In a way, the big bang theory came as a result of backwards engineering.

Another prediction was that the universe would have been intensely hot during the earliest stages of the big bang. The radiation from this period would have been phenomenally large, and there would have to be some evidence of this radiation left over. Since the universe must be homogeneous and isotropic, the evidence should be evenly distributed throughout the universe. Scientists discovered evidence of this radiation as early as the 1940s, though at the time they didn’t know what they had found. It wasn’t until the 1960s when two separate teams of scientists discovered what we now call the **cosmic microwave background radiation (CMB)**. The CMB is the remnants of the intense energy emitted by the primordial fireball in the big bang. It was once intensely hot, but now has cooled to a chilly 2.725 degrees Kelvin (−270.4 degrees Celsius or −454.8 degrees Fahrenheit).

These observations helped solidify the big bang theory as the predominant model for the evolution of the universe.

**ONE OF THESE DAYS**

Scientists use Hubble's observations to estimate the age of the universe. Current estimations based on the Hubble constant are at 13.7 billion years, give or take 200 million years. Other methods for estimating the age depend on determining the ages of stars and elements. Those methods give us a range that tops out at around 15 billion years.

**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.

Cambridge University refers to the study of these earliest moments as quantum cosmology [source: Cambridge University]. At the earliest moments of the big bang, the universe was so small that classical physics didn’t apply to it. Instead, quantum physics were in play. Quantum physics deal with physics on a subatomic scale. Much of the behavior of particles on the quantum scale seems strange to us, because the particles appear to defy our understanding of classical physics. Scientists hope to discover the link between quantum and classical physics, which will give us a lot more information about how the universe works.

At \( t = 1 \times 10^{-43} \) seconds, the universe was incredibly small, dense and hot. This homogenous area of 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. The temperature of this universe was \( 1 \times 10^{32} \) degrees Kelvin (1 x 10^{32} degrees Celsius, 1.8 x 10^{32} degrees Fahrenheit). 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 decoupled. Cosmologists call this baryogenesis -- baryonic matter is the kind of matter we can observe. In contrast, we can’t observe dark matter, but we know it exists by the way it affects energy and other matter. During baryogenesis, 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.

A period of particle cosmology followed the quantum age. This period starts at \( t = 1 \times 10^{-11} \) seconds. This is a phase that scientists can recreate 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. 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.

Next came the period of standard cosmology, which begins .01 second after the beginning of the big bang. From this moment on, 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 during baryogenesis 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.

HOW COLD IS ABSOLUTE ZERO?
Atoms and molecules oscillate within matter. Even objects that seem inert, like rocks, are composed of atoms that are moving around. As matter cools, atoms move less and less. At a certain temperature, atoms move as slow as they’ll ever move. Scientists call this temperature absolute zero -- or 0 degrees Kelvin (-270 degrees Celsius, -460 degrees Fahrenheit).

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.

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 8,726 degrees Celsius. 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 2,727 degrees Celsius. 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.

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 270 degrees Celsius, which is only a couple of degrees above absolute zero.

**What Does the Big Bang Tell Us?**

Some cosmologists use the big bang theory to estimate the age of the universe. But due to different measurement techniques, not all cosmologists agree on the actual age. In fact, the range spans more than a billion years!

The discovery that the universe is expanding led to another question. Will it expand forever? Will it stop? Will it reverse? According to the general theory of relativity, it all depends on how much matter is within the universe.

It boils down to gravity. Gravity is the force of attraction between particles of matter. The amount of gravitational force one body exerts on another depends upon the size of the two objects and the distance between them. If there's enough matter in the universe, the force of gravity will eventually slow the expansion and cause the universe to contract. Cosmologists would designate this as a closed universe with positive curvature. But if there isn't enough matter to reverse expansion, the universe will expand forever. Such a universe would either have no curvature or negative curvature.
If we are in a closed universe, eventually the entire universe will contract and collapse in on itself. Cosmologists call this the **big crunch**. Some theorize that our universe is just the latest in a series of universes generated in a cycle of space expanding and contracting.

There are also some very big questions the big bang theory doesn't address:

- **What happened before the big bang?** According to our understanding of science, we can't know. The very laws of science break down as we approach \( t = 0 \) seconds. In fact, since the general theory of relativity tells us that space and time are coupled, time itself ceases to exist. Since the answer to this question lies outside the parameters of what science can address, we can't really hypothesize about it.

- **What lies beyond the universe?** Again, this is a question science can't address. That's because we can't observe or measure anything that lies outside the boundaries of the universe. The universe may or may not be expanding within some other structure, but it's impossible for us to know either way.

- **What is the shape of the universe?** There are many theories about what shape the universe might have. Some believe that the universe is unbounded and shapeless. Others think the universe is bounded. The big bang theory doesn't specifically address the issue.

Not everyone subscribes to the big bang theory. Why do they disagree with the theory, and what are some of the alternate models for our universe?

Since scientists first proposed the big bang theory, many people have questioned and criticized the model. Here's a rundown on some of the most common criticisms of the big bang theory:

- **It violates the first law of thermodynamics**, which says you can't create or destroy matter or energy. Critics claim that the big bang theory suggests the universe began out of nothing. Proponents of the big bang theory say that such criticism is unwarranted for two reasons. The first is that the big bang doesn't address the creation of the universe, but rather the evolution of it. The other reason is that since the laws of science break down as you approach the creation of the universe, there's no reason to believe the first law of thermodynamics would apply.

- **Some critics say that the formation of stars and galaxies violates the law of entropy**, which suggests systems of change become less organized over time. But if you view the early universe as completely homogeneous and isotropic, then the current universe shows signs of obeying the law of entropy.

- **Some astrophysicists and cosmologists argue that scientists have misinterpreted evidence like the redshift of celestial bodies and the cosmic microwave background radiation.** Some cite the absence of exotic cosmic bodies that should have been the product of the big bang according to the theory.

- **The early inflationary period of the big bang appears to violate the rule that nothing can travel faster than the speed of light.** Proponents have a few different responses to this criticism. One is that at the start of the big bang, the theory of relativity didn't apply. As a result, there was no issue with traveling faster than the speed of light. Another related response is that space itself can expand faster than the speed of light, as space falls outside the domain of the theory of gravity.

There are several alternative models that attempt to explain the development of the universe, though none of them have as wide an acceptance as the big bang theory:

- **The steady-state model of the universe suggests the universe always had and will always have the same density.** The theory reconciles the apparent evidence that the universe is expanding by suggesting that the universe generates matter at a rate proportionate to the universe’s rate of expansion.
The **Ekpyrotic model** suggests our universe is the result of a collision of two three-dimensional worlds on a hidden fourth dimension. It doesn't conflict with the big bang theory completely, as after a certain amount of time it aligns with the events described in the big bang theory.

The **big bounce** theory suggests our universe is one of a series of universes that first expand, then contract again. The cycle repeats after several billion years.

**Plasma cosmology** attempts to describe the universe in terms of the electrodynamic properties of the universe. Plasma is an ionized gas, which means it's a gas with free roaming electrons that can conduct electricity.

There are several other models as well. Could one of these theories (or other ones we haven't even thought of) one day replace the big bang theory as the accepted model of the universe? It's quite possible. As time passes and our capability to study the universe increases, we'll be able to make more accurate models of how the universe developed.