A Voyage Through The Sea Of Time

Exploring the Universe from the Big Bang to a theoritical end

“ The Universe began with a bang, will end in silence, and in between, it mostly ignored our questions. ”

Author: Muhammad

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The Beginning of the Universe

A question that has been asked countless times, "How did our universe come into existence?" An eternal universe was believed to be the answer before 1931, a universe that has no beginning, no end, and that has always existed. In 1931, Georges Lemaitre proposed the theory of Big Bang that challenged this idea of an eternal universe, suggesting an origin for the universe. The term "Big Bang" was coined in 1949, and while it might suggest an explosion, this is not accurate. In reality, the "Big Bang" is a misnomer, as the name was mistakenly coined to describe the event. The theory of the Big Bang suggests an expansion, not an explosion. As J.B.S. Haldane writes:

"The universe is not only stranger than we imagine, it is stranger than we can imagine."

Big Bang:

The story starts from a point called Singularity, a point that has infinite density and temperature, and has zero volume. Our whole universe was trapped within this point. In this singularity, laws of physics as we know them break down, making it a point of great interest and mystery in cosmology. This singularity starts to expand, forming our universe this expansion continues to this day.

This event marks the beginning of time and space. It was a long process that can be divided into seven eras:

- Plank Era
- Grand Unification Era
- Electroweak Era
- Particle Era
- Era of Nucleosynthesis
- Era of Nuclei
- Present Era

1) Plank Era:

The first era after the big bang is known as the Plank Era, it refers to the time period from t=0 to approximately 10^{-43} seconds after the big bang. During this era, the universe was so hot and dense that neither general relativity nor quantum mechanics separately could fully describe the conditions. Instead the effects of quantum gravity were significant because a unified theory combining both was needed. We'll dive into these concepts in detail shortly.

In today's world we witness four fundamental forces that shape everything around us. While during Plank's Era all four forces were unified into a single superforce, making it hard to describe this stage of universe by using present physics understanding. As the universe expanded and cooled, this superforce began to separate into the distinct forces we recognize today:

- Gravitational Force
- Electromagnetism Force
- Strong Nuclear Force
- Weak Nuclear Force

i. Gravitational Force:

Gravitational force governs the attraction between objects with mass. Every object with some mass attracts another object with a force. It was described by Isaac Newton in the 17th century, led to the foundation of ***classical mechanics*** also known as Newtonian Mechanics.

The range of gravitational force is considered to be infinite, meaning it can affect objects regardless of how far apart they are. If we discuss the strength of gravitational force, it is surprising to note that it is the weakest of the four fundamental forces.

ii. Electromagnetic Force:

Next one is the electromagnetic force. The term electromagnetism combines two words electricity and magnetism, to describe the force that governs interaction between charged particles, leading to attraction and repulsion. Magnetism arises from moving electric charges, and the two phenomena are interconnected through Maxwell's equations, which describe how changing electric fields produce magnetic fields and vice versa.

The electromagnetic force uses photons as the carriers to transmit the force between charged particles. Photons are massless and chargeless particles that carry energy and information in the forms of light and other electromagnetic radiations. The range of the electromagnetic force is also considered to be infinite. In strength, it's the second strongest force after the strong nuclear force, yet it's 137 times weaker than the strong nuclear force.

iii. Strong Nuclear Force:

Have you ever wondered why similarly charged protons stay together in the nucleus of an atom and don't repel each other due to electromagnetic force? Exploring this question led to the discovery of the strong nuclear force. A force that is stronger than the electromagnetic force and has the power to overcome its effects. It is the force that binds protons and neutrons together, making it possible to form nuclei and further, atoms.

Strong nuclear force is the strongest of all four fundamental forces. It has short range and can affect as far as nucleus. The strong nuclear force uses gluons as the carriers to transmit the force between quarks within nucleons i.e. protons and neutrons. Gluons are elementary particles that acts as the carriers of strong nuclear force. Gluons are massless and travel at the speed of light, playing a crucial role in the stability of atomic nuclei.

iv. Weak Nuclear Force:

So the final one is weak nuclear force, it is responsible for beta decay, a type of radioactive decay where a neutron decays into a proton or a proton decays into a neutron. This force is crucial for the process of nuclear fusion in stars and plays a key role in the formation of elements in the universe. We'll dive into these concepts in detail in third chapter.

The weak nuclear force has the shortest range among all four fundamental forces. It is the second weakest force after the gravitational force. It is mediated by the Z boson, which is electrically neutral, and the positively and negatively charged W bosons.

2) GUT Era:

The second era is known as the Grand Unification Era, or simply the GUT Era. It refers to the time period from approximately 10^{-43} to 10^{-36} seconds after the Big Bang. The GUT Era is when three of the four fundamental forces are combined, but gravity has become distinct. Near the end of this era, the universe cooled to the point that the nuclear strong force began to freeze out, leaving three fundamental forces: gravity, the strong force, and the still combined electroweak force.

Grand Unification Theory (GUT) is a theoretical framework that seeks to unify three of the four fundamental forces of nature: the strong nuclear force, the weak nuclear force, and electromagnetism.

3) Electroweak Era:

The third Era, known as the Electroweak Era, refers to the time period from approximately 10^{-36} to 10^{-12} seconds after the big bang. Near the end of this era, the unified electroweak force splits into electromagnetism and weak nuclear force, making all four fundamental forces distinct. Therefore, the name of this era is the Electroweak Era. At this point the temperature of the universe had dropped from Infinity to approximately 10^{15} kelvin. There are no matter particles, just photons and energy.

4) Particle Era:

After approximately 10^{-12} seconds from the big bang, all the four fundamental forces had become distinct, allowed particles to form. As the universe expanded and cooled enough, energy was converted into particles of matter and antimatter through processes described by Einstein's equation $E = mc^2$. This equation shows that energy E and mass m are interchangeable, with c being the speed of light.

At this moment, matter and antimatter were produced in nearly equal quantities. The universe was intensely dense, leading to frequent collisions between particles of matter and their corresponding antiparticles. When matter and antimatter met, they annihilated each other in a burst of energy, forming photons. This cycle of creation and annihilation continued for the first 0.001 seconds of the universe's existence. If the numbers had been exactly the same, there would be only photons in the universe.

When the universe was only one millisecond old, the amount of matter formation slightly increased compared to antimatter, by one billion and one matter particles for every billion antimatter particles. If this change had not occurred, the universe would have been filled with just photons. This slight change made the formation of atoms possible.

5) Era of Nucleosynthesis:

The era of nucleosynthesis refers to the period shortly after the Big Bang, from about 1 millisecond to 3 minutes after, when the universe was hot and dense enough for nuclear reactions to occur. During this time, matter existed in the form of a quark-gluon plasma, a state of matter where quarks (the building blocks of protons and neutrons) and gluons (the mediators of the strong nuclear force that bind quarks together) were present.

As the universe expanded and cooled, quarks combined to form protons and neutrons, which then combined to form atomic nuclei in a process known as nucleosynthesis. This led to the creation of light elements like hydrogen, helium, and small amounts of lithium. At this point, about 75% of ordinary matter was hydrogen, 25% was helium, and there were trace amounts of lithium.

6) Era of Nuclei:

The universe has cooled enough for nuclei to form, but not enough for neutral atoms. At this stage, matter exists as plasma, where electrons are not bound to nuclei and move freely. This plasma consists of a hot, ionized gas of protons and electrons. The high temperatures and densities of this plasma prevent the formation of stable atoms, as the electrons are not able to combine with the nuclei to form neutral atoms. As a result, the universe is in a state where atomic structure is not yet complete.

Recombination:

About 380,000 years after the Big Bang, the universe cooled enough for electrons to combine with protons to form neutral atoms. This process, known as **recombination**. The high density of the universe was preventing photons from escaping and causes the universe to stay dark, as photons are constantly blocked and bounced around by the dense plasma. It allowed photons to travel freely through space for the first time. This event marked the release of the first light in the universe, which we still observe as the cosmic microwave background (CMB) radiation.

Cosmic Microwave Background:

For 380,000 years, the universe was completely dark. There was no light because light is produced when photons travel, and the high density of the universe was not allowing photons to travel freely, keeping them in equilibrium. It was after 380,000 years that the universe had cooled and expanded enough for the event of recombination to take place, during which electrons settled into orbits around nuclei, forming neutral atoms. This event of recombination allowed photons to travel freely, and the first light in the universe was released, which can still be observed as the Cosmic Microwave Background.

What does the term "Cosmic Microwave Background" refer to?

Cosmic: Cosmic refers to anything that exists throughout the entire universe. When we use this word in Cosmic Microwave Background, it means this phenomenon is not just happening in one location, but it is present everywhere in the universe. It found in every direction we look in space.

Microwave: A type of light that is invisible to the human eye but can be detected by special instruments. It has longer wavelengths than visible light but shorter than radio waves. Originally, the light was very bright and high-energy, in the range of ultraviolet, but as the universe expanded over billions of years, this light stretched into the microwave range.

Background: Something that is always there in the background, not in the forefront. It's a faint glow that is present everywhere, all the time. The CMB is not something you see with your eyes, but can be detected by using instrument.