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THE BIG BANG THEORY

The universe as it is interpreted today from earth is a result of an extremely violent event, which if repeated now would be cataclysmic. The energy density of this event has not been matched since and probably never will be. Some theorize that it was infinitely dense at the start of its duration (Hawking). Much funding has gone into research both on earth and in space to determine the science behind the cause of the universe. The theory that is most widely accepted today by scientists and other groups of people is the Big Bang Theory. I want to explore the theory of the Big Bang and learn what scientists have discovered. Though I know I won't learn or cover everything that is known of it here in this small amount of information, you have to start somewhere.

The Big Bang Theory began with a catholic priest named Georges Lemaitre (Lemaitre). Lemaitre was an astronomer as well as a professor of physics at the Catholic University of Louvain. As he looked into the night sky he observed that cosmic objects were moving away. This led him to believe that at an initial point they were very close together (Defining Moments in Science). Although he did not coin the concept of singularity, he did invent the term "Primeval Atom." This led to the Big Bang Theory as it is known today.

Let us set off by looking at the timeline of the Big Bang. The topic of the Big Bang allows some good fortune when introducing the subject. There is only one place to begin: the beginning. At the start of the universe, every particle and energy that exists today was one. The size of this conglomeration of “stuff” was as small as anything could possibly be. Singularity is the word used to describe this gathering of all things at a single point. I do not mean point as in generally the same location. Imagine a point on a graph. It does not matter what the location of the point is, just make sure that the coordinates of the number are finite. Now hone in on this point. Does the point cover more area now? No. The point is still just a point with no definite area. That is what singularity was. The distance from one side of the singularity to the other is equivalent to the ratio of one to infinity. Though this number approaches zero if a limit is taken, it is not zero. Similarly, though the size of the singularity is infinitely small, it exists. How this singularity came into existence is unknown and not relevant to the Big Bang Theory. This theory addresses what happened after this extremely dense singularity had already been brought into the picture. (Though on a side note, an appearance of something, for instance singularity, from nothing is arguably an even *bigger bang*!)

This compact energy began to expand. And it did so with haste. The first epoch reached is called the Planck Epoch. This epoch’s duration was between the beginning of time and 10^{-43} seconds after the universe’s expansion began. At the end of this epoch, the temperature of the universe was estimated to have been some 10^{32} Kelvin, 10 trillion times hotter than the deep interior of our sun (Greene). There is little known about the Planck Epoch because the current laws of physics do not apply. Remember that a short time ago, these laws just had the ability to exist over a finite distance. There just is not a quantum mechanical explanation for gravity, the force that would have played the major role in this era. Maybe when we find the Higgs Boson, right? What we do know is that protons, neutrons, and electrons did not exist at this point in time. The universe was just a “primordial cosmic plasma” says Brian Greene. The matter of the universe was energetic enough to overpower the force that binds particles together today.

Here, matter and antimatter existed in relatively equivalent amounts, but were both dwarfed by the amount of energy the universe contained (A Brief History of the Universe). The common belief is that during this era, the four fundamental forces (strong nuclear force, weak nuclear force, electromagnetic force, and gravity) acted as one single force. They acted alike due to the incredibly hot temperature. As the universe continued to expand, it cooled.

From 10^{-43} seconds old to 10^{-35} seconds old, the universe was in the Grand Unification Epic. This epic is named so because the gravitational force had become separate from the other “grand unified force.” This other force was a made up of the unification of the strong nuclear force, the weak nuclear force, and the electromagnetic force. The gravitational force had separated because the temperature had decreased to an amount that was suitable for two unique fundamental forces. A good illustration of a universe’s tendency to cool as it expands is an aired up balloon’s temperature in proportion to its volume. If an aired up balloon is tied, and you squeeze the balloon and decrease its volume, the temperature will rise because the particles inside it are colliding with each other more often (the same amount of energy is in a smaller volume and is therefore at a higher density). When the temperature is higher, the particles are more energetic in the system of the balloon. If you increase the volume of the balloon by releasing the pressure caused by your squeezing hand on the balloon, the balloon will cool. This is what happened as the universe expanded. As the volume increased, the temperature decreased. Temperature and volume are inversely proportional ($PV=nRT$). If you think about it, this is also good evidence that everything that is here today existed as a part of the singularity. For the temperature to decrease as it has done, the energy in the universe would have had to remain constant.

This would be a good place to define the strong nuclear force. Strong nuclear force is “The short-range interaction between hadrons responsible for the force that binds the nucleus of an atom together: it is the strongest of all known forces” (Webster's New World College Dictionary Fourth Edition).

The following epoch was the Inflationary Epoch. The Inflationary Epoch is the first part of the Electroweak Epoch. This epoch is called the inflationary epoch because the size of the universe expanded an incredible amount in a short period of time. This period was between 10^{-35} seconds and 10^{-32} seconds after the Big Bang. The driving force of this inflation was the separation of the strong nuclear force from the electroweak force, which was the union of the weak nuclear force and the electromagnetic force (A Brief History of the Universe). The separation of the strong nuclear force from the electroweak force caused the inflation field (inflaton field) to fall from a positive energy towards a lower and more stable vacuum state in which energy was released as it lowered. It released energy by expanding! Though we have never seen the inflaton field, inflation predicts values of peaks in the cosmic background. When the background radiation was observed around 1990 by COBE (COsmic Background Explorer), it reported peaks that corresponded to those predicted by the inflation theory (An Introduction to the Big Bang Theory).

It was during this time that Baryogenesis occurred. Baryogenesis is the hypothetical process of how an asymmetry was created between baryons and antibaryons. A baryon is a "subatomic particle that is both a hadron and a fermion, as a nucleon or hyperon: the proton is the baryon with the smallest mass" (Webster's New World College Dictionary Fourth Edition). This theory of inflation had to violate the Baryon number (B) symmetry (to allow the universe to exist materially as it does today), the Charge conjugation and Charge-Parity symmetries, and depart from the thermal equilibrium (matter and energy ratios). The inflation particle theory was introduced to pick up the slack of the Standard Model of particle physics. The Standard Model could not sufficiently explain the asymmetry between baryons and antibaryons (Trodden). The Standard Model of particle physics "includes the electromagnetic, strong and weak forces and all their carrier particles, and explains extremely well how these forces act on all the matter particles." The Standard Model cannot answer "what happened to the missing antimatter" (What do we really know? The standard package)?

The Electroweak Epoch was between 10^{-32} seconds and 10^{-12} seconds after expansion began. We have already covered the first moments of the Electroweak Epoch, so we will move on to reheating. Reheating is where inflation of space-time stops and the potential energy of the inflaton field is released "filling the Universe with a dense, hot quark-gluon plasma" (Terzic). The interactions of particles were at such high energies, that a high amount of "exotic particles" were created such as the W, Z, and Higgs bosons. Just as the particles inside the balloon collided less and less as the volume increased, the interactions between particles became less and less along with a decrease in their energy. Because the interactions were less frequent and less energetic, W and Z bosons were no longer being created (Terzic).

The rest of the history of the universe is described with various names and unique time divisions. So if the names of the periods that I discuss do not seem familiar, you are not the first to encounter this lack of followed systematic naming.

Now, gravitational force, strong nuclear force, weak nuclear force, and electromagnetic force all have their own individual roles to play. Weak nuclear force is “the short-range interaction between leptons responsible for beta decay and the decay of many long-lived elementary particles” (Webster's New World College Dictionary Fourth Edition). It is mediated by W and Z boson particles (Ford). The electromagnetic force is “the relatively long-range interaction between elementary particles resulting from their electric and magnetic fields, responsible for molecular structure, chemical reactions, and other electromagnetic phenomena” (Webster's New World College Dictionary Fourth Edition). This force is as strong as it is because its carrier, a photon, has no mass (Ford).

After a long trip from the time of the Big Bang to a short 10^{-12} seconds after the Big Bang, we finally have the same number of forces present in the universe as we do today. All is accounted for… well, not quite. Time goes on.

Returning to the history of the universe, the next epoch to discuss will be the Quark Epoch (10^{-12} seconds to 10^{-6} seconds after the Big Bang). Remember that the universe is currently filled with that “quark-gluon plasma.” Gluons are like “glue.” They allow for the strong interaction. Quarks, on the other hand, are particles that experience strong interactions (as opposed to weak interactions) and are what combine to create baryons and mesons. We don’t actually know the mass of a quark because we never see them alone today. I’m guessing that if we were around a millionth of a second after the Big Bang that we could ascertain the actual masses of the various types of quarks with little problem. Why would it be easy? These quarks were too energetic to clump together to form particles such as protons and neutrons, so they continued to be excited loners and roamed around the universe ungrouped. But very little mass of protons and neutrons actually comes from the quarks themselves. On the atomic level, mass behaves differently. No surprise there. Most of the mass comes from the pure energy trapped in the atom (Ford).

The next epoch is called the Hadron Epoch, which lasted between 10^{-6} seconds and a whole second after the beginning of expansion of the universe. The universe cooled for a time of about 10^{6} seconds. This was sufficient enough time to allow the temperature to reach a level that did not interfere with quarks clumping together into hadrons. A hadron is a particle composed of quarks that are "glued" by the strong nuclear force. There are two types of hadrons; those that are baryons and those that are mesons. Baryons are made up of three quarks and mesons are made up of a quark and an antiquark (Ford). Something very interesting occurred during this epoch. At the beginning of this era, the temperature was at a high enough value to allow hadron and antihadron pairs to exist. However, as the universe expanded, the temperature cooled. This cooling prevented the creation of more hadron and antihadron pairs. "Most of the hadrons and anti-hadrons were then eliminated in annihilation reactions, leaving a small residue of hadrons." This elimination was completed by one second after the beginning of the expansion of space-time (Terzic). Just to give a picture of how many antiparticles there were originally, here is the estimated ratio. "At 1 millisecond there were roughly a billion and one protons in the universe for every billion antiprotons" (Trefil). These remaining protons are the "residue of hadrons."

What followed the Hadron Epoch was the Lepton Epoch (between one and ten seconds after the Big Bang). Leptons, unlike hadrons, do not feel the strong nuclear force. Instead they feel the weak nuclear force. This means that leptons do not group together. An example of a lepton is an electron (Ford). Just like in the Hadron Epoch, lepton and antilepton particles annihilated one another. This occurred due to the continued cooling of the universe via expansion. Once this annihilation was complete, few leptons were left (Terzic). At this point in time there were lone protons, neutrons, electrons, and photons.

The Photon Epoch lasted from between ten seconds and three-hundred and eighty-thousand years after the Big Bang. This period involved photon interaction between particles. These particles were protons, electrons and after Nucleosynthesis, nuclei. The early stage of the Photon Epoch occurred at the same time as the process of Nucleosynthesis (Mays).

The Nucleosynthesis Epoch is the next epoch covered. The neutrons floating freely in the universe, which were too energetic to react, were now able to start the process that would lead to helium nuclei. The temperature that allowed this series of reactions was around one billion degrees Kelvin. The first reaction involved a neutron capturing a proton and binding via the strong nuclear force. This made a deuterium nucleus, ^2H, which is an isotope of hydrogen. The deuterium atom absorbed an additional neutron to yield a tritium nucleus, ^3H, which is another isotope of hydrogen. This tritium nucleus and a proton reacted with one another to create a helium nucleus. The process of nucleosynthesis favored a higher amount of hydrogen nuclei than helium nuclei; about ten to one respectively. This was due to the fact that a helium nucleus required two protons and two neutrons (Silk).

Now there are photons, electrons, and nuclei zooming around the universe. As we all know, electrons are nucleophilic. So why are they mentioned separate from the atomic nuclei? The photons at this time were very energetic. Electrons would be captured by the electrophilic nuclei, but these high energy black-body photons would knock the electrons loose from the atoms; a process that is called *ionization* (Webster's New World College Dictionary Fourth Edition). As the universe expanded, cooling continued. And with a cooler universe came less energetic photons. Just like in a balloon, more volume means fewer collisions. This is exactly the relationship between photons and atoms here. Now, electrically neutral atoms were favored over charged lone particles. This process is referred to as recombination. This process began quite suddenly when the universe was near 300,000 years old, and was complete almost by the time the universe was one million years old. A ratio of ionized particles follows. “The process was so efficient that only one electron and proton remained apart for roughly every 100,000 atoms” (Silk).

These periods of our universe are the highpoints of their time. There is still much that is to be learned about each. The history of the universe is now behind us. The following topic will take into consideration the accuracy of this historical account given by the Big Bang Theory.

In the 1940s, a Russian astrophysicist George Gamow was given credit for the belief that there was a “cosmic background radiation” in space left over from the Big Bang. It is often told that Gamow estimated that by the time that this radiation reached Earth, it should have been in the electromagnetic wavelength of microwaves (Bryson). These calculations were actually performed by Ralph Asher Alpher and Robert Herman. The 1960s came, and, by serendipity, a faint hiss was stumbled upon by Arno Penzias and Robert Wilson. This hiss was a result of black-body radiation and a temperature of only three degrees Kelvin coming from all points in the cosmos. It was this discovery, published in 1965, that began to make people take a second look at the Big Bang Theory (Gribbin).

Some thirty years later in 1992, the COBE (COsmic Background Explorer) findings were announced. COBE was a satellite sent into space whose mission was to study the cosmic background radiation that was found earlier. COBE measured the black-body radiation to be just 2.725 Kelvin. This is considered by many to be the single most powerful evidence that the Big Bang Theory is an accurate description of the early universe (Gribbin).

Another piece of evidence for the Big Bang is the ratio of hydrogen to helium found all throughout the universe. In all parts of the cosmos, when the abundance of hydrogen is compared to that of helium, the results fluctuate very, very little. There are almost always ten times as many hydrogen atoms as helium atoms. This is not the case with heavier atoms. Heavy atoms are formed during supernovae. The amount of heavy elements decreases the further you look from the center of the Milky Way, or any galaxy for that matter. The distribution of heavy elements in the universe is not uniform, while the distribution of hydrogen and helium is uniform. This is important information because the initial conditions of the Big Bang, namely the high temperatures and high densities, are highly productive of synthesis of the lighter elements. Also, “there appear to be no other plausible astrophysical sources for at least one light element, helium, and one isotope of hydrogen, deuterium" (Silk).

The findings above are only two of the many cases that point toward a universe formed by the process and under the conditions that the Big Bang Theory presents.

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