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THE BIG BANG THEORY: THE MOST IMPACTFUL OCCURRENCE IN THE FIRST MINUTE AFTER THE BIG BANG

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ABSTRACT

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INTRODUCTION

What was the most impactful occurrence in the first minute after the Big Bang?

The way the universe came into existence – the Big Bang theory – is a theory both widely accepted and rejected, for which evidence has been provided, nonetheless for which alternative theories have been proposed. It is important to consider the different occurrences in the first minute after the Big Bang, chain reactions and processes, the big picture and connections and theories to argue the most important occurrence based on its short-term and long-term impacts, supported by a comparison and contrast between all the important occurrences to reach plausible conclusions. It is also important to consider all the important occurrences in generic terms.

[1]According to the standard theory, the universe came into existence as a singularity around 13.7 billion years ago. Singularities are thought to exist at the core of black holes. The universe is thought to have begun as an infinitesimal singularity. The singularity inflated, expanded ("Big Bang") and cooled, becoming the size and temperature of the universe currently. It continues to expand to this day, fascinating us more and more.

[1]A misconception is the theory being perceived as a giant explosion, when there was, is and will continue to be, an expansion. Additionally, the singularity did not appear in space – space began inside of the singularity. According to the calculations of astrophysicists Steven Hawking, George Ellis, and Roger Penrose, time and space had a finite beginning that relates to the origin of matter and energy. Prior to the singularity, nothing existed, not space, time, matter, or energy. The question that remains is where and in what did the singularity appear, if not space? – something that is unknown to this date.

[2]10^{-11} seconds after the Big Bang (10^{15} degrees) collisions between particles were slightly weaker than the strongest ones we can produce today using particle accelerators. The universe was a collection of elementary particles too hot to bond into larger units.

[2]10^{-5} seconds after the Big Bang (10^{10} degrees) (a million times longer than the time before the electroweak phase transition, longer than most particle physics processes) the universe was too cold to produce most unstable particles like Higgs bosons and almost all unstable particles had decayed; what remained were the few stable particles. The universe consisted primarily of the same particles and other forms of energy it does today – quarks, electrons, electromagnetic radiation, dark matter, dark energy, and antimatter. The biggest difference between particles then and today is that then quarks flew about freely; now all the quarks are bound up in protons and neutrons. As the temperature and density dropped quickly the quarks were moving more and more slowly unable to resist the forces pulling them together forming color balanced triads (protons and neutrons), which is the form most quarks in the universe have been in ever since.

[2]After the formation of protons and neutrons, the next big change was about particles being destroyed. Most particles have corresponding antiparticles with the same mass but opposite charge (e.g. electrons and positrons), collectively these particles are called antimatter. When two antiparticles collide, they can annihilate and release their energy as electromagnetic radiation. If high energy electromagnetic radiation is highly concentrated in a small region, it can create a particle-antiparticle pair (e.g. electrons-positron or quark-antiquark). When the universe was initially filled with a dense collection of elementary particles, these particles included almost identical amounts of matter and antimatter. At the same time as quarks combining into protons and neutrons, antiquarks combined into antiprotons and antineutrons. Matter and antimatter was constantly annihilating, creating high energy electromagnetic radiation, which was creating new matter and antimatter. The annihilation and creation processes were in equilibrium. As the temperature decreased, the radiation became less intense as creation of matter and antimatter pairs became less likely. The equilibrium was broken, and annihilation began to outpace creation. This happened first with protons and antiprotons, and neutrons and antineutrons as they were heavier and harder to produce than electrons and positrons.

[2]10-1 seconds after the Big Bang (10^{10} degrees) all the antiprotons and antineutrons were gone. The electrons and positrons remained in equilibrium for most of the first second.

[2]One second after the Big Bang (10^{9} degrees), the equilibrium was broken, and annihilation began to outpace creation.

[2]Three to ten seconds after the Big Bang (10^9 degrees), the positrons were gone. From that moment onwards, the universe has had no antimatter. The matter had lasted because before annihilation there was slightly more matter than antimatter – for every billion antiquarks and positrons there were a billion and one quarks and electrons.

[2]By a few seconds after the Big Bang, all the antiquarks and positrons were gone, and their energy had been converted into radiation. Most of the original matter was gone too, annihilated in the collisions that eliminated all the antimatter. However, there is still those one in a billion particles of matter left over with nothing to annihilate – which makes up all the matter such stars, galaxies, planets, etc. in the universe today.

[2]For the first second after the Big Bang (10^{10} degrees), the universe was so dense that even neutrinos could not pass, they kept constantly colliding with other particles.

[2]Starting around one second after the Big Bang, the matter was not dense enough to stop the neutrinos. The neutrinos from that time have been moving freely through the universe ever since (in one second, the neutrinos "froze out" – stopped interacting with other matter (decoupled)). Although they have not been interacting with matter, they have slowed down, because of the expansion of the universe. They still fill all of space today. Calculations show that these primordial neutrinos should be coming at us equally from all directions at a temperature about two degrees above absolute zero. In 2015, for the first time, scientists detected this cosmic neutrino background and measured its temperature to be around 1.96˚C, confirming out understanding of what was happening in the first second of the universe.

[2]Protons and neutrons can transform into each other in a process called beta decay. When quarks first combined, they produced equal numbers of protons and neutrons, and for some time, they each transformed into each other at similar rates. But as the temperature dropped, it became more likely for the slightly heavier neutrons to decay into the slightly lighter protons. By one second, the decay of protons into neutrons had stopped, but neutrons were still turning into protons, so the ratio of protons to neutrons was steadily growing. If nothing had happened to preserve the neutrons, they would have all been gone ten to twenty minutes later.

[2]One minute after the Big Bang (10^9 degrees), protons and neutrons began combining into light nuclei in a process called Big Bang nucleosynthesis. The key to this is that protons and neutrons all attract each other through the strong nuclear force. When quarks combine into protons or neutrons, the strong nuclear force between two of those groups mostly cancels out. If two neutrons got remarkably close to each other, some of the quarks in each neutron are closer to other quarks, so the forces between the quarks do not perfectly cancel. The result is a residual strong nuclear force between the two. The same applies to two neutrons or a neutron and a proton. All these particles are attracted to one another through a strong nuclear force that is much weaker than the force between individual quarks, because those quark-on-quark forces do not completely cancel out. However, the residual strong nuclear force between protons and neutrons is still strong enough to hold nuclei together. The attraction between protons and neutrons cannot hold them together if they are moving with extremely high energy. For them to stick together, the temperature had to drop below by around a billion degrees, which happened around a minute after the Big Bang.

[2]Once the temperature was low enough, one proton and one neutron could combine to form a nucleus called hydrogen-2 (deuterium). Two deuterium nuclei could combine to form helium-4. If nucleosynthesis had started out with equal numbers of protons and neutrons, such as at 10^{-1} seconds (10^{10} degrees) after the Big Bang instead of one minute after the Big Bang (10^9 degrees) then all nuclei would have ended up as helium four. If there had been no neutrons and it could not start till twenty minutes after the Big Bang none of it would have happened at all. All nuclei would have ended up as hydrogen.

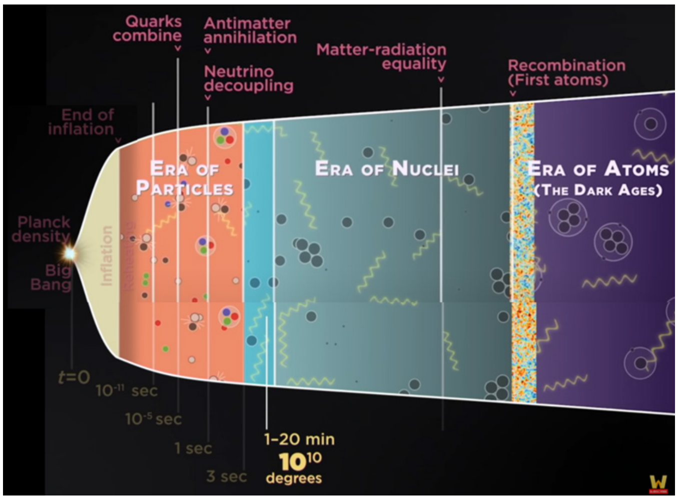
[2]When nucleosynthesis started at around one minute (10^9 degrees) after the Big Bang there were about seven protons for every neutron. So, each set of fourteen protons and two neutrons produced a helium nucleus, and left twelve bare protons, which were hydrogen nuclei. After nucleosynthesis, helium made up about 8% of the nuclei in the universe, and as they are heavier than hydrogen nuclei, they made up around 25% by mass.

[2]Before one minute (10^9 degrees) the universe was too hot for nuclear fusion, so nucleosynthesis did not start, and it stopped a few minutes later because it was too cold. There was still some deuterium left which had not fused into heavier nuclei and since nucleosynthesis was no longer possible, that deuterium just stayed deuterium. This is because for two deuterium nuclei to fuse, they must be remarkably close to each other. When two protons are near each other, they interact in two quite diverse ways – they attract each other through the strong nuclear force and repel each other through the electric force as they are both positively charged. The force that wins depends on how close they are to each other. The strong nuclear force cannot act more than a trillionth of a meter away, so any further it drops to zero and the protons repel each other electrically. Two deuterium nuclei of one proton and one neutron will again be attracted by the strong nuclear force and repelled by the electric force, if they get remarkably close within a couple nuclear diameters the strong nuclear force will take over and they will fuse. The reason they were able to get so close even though at larger distances they were pushing each other away is because they had to be moving fast enough (at an extremely elevated temperature) to overcome the repulsion. There is a narrow range of temperatures in which two deuterium nuclei can collide so hard that they get close enough to fuse but not so hard that they bounce off again. The universe was in this temperature (10^{10} degrees) for about one to three minutes after the Big Bang.

[2]Three minutes after the Big Bang (10^9 degrees) deuterium fusion into helium slowed, which ended ten to twenty minutes later (10^8 degrees). After nucleosynthesis, deuterium accounted

for only one in a billion nuclei. The measurement of that trace deuterium in exactly the amounts predicted by the Big Bang model had been one of the greatest experimental confirmations of the model. The mix of nuclei in the universe was fixed for millions of years until fusion started again in the cores of the first stars.

[2]In summary: At 10^{-11} seconds after the Big Bang (10^{15} degrees), a dense collection of quarks, electrons, and other elementary particles, with equal amounts of matter and antimatter existed. A second later (10^{10} degrees), the quarks had all combined, all the unstable particles like Higgs bosons had all decayed, and the antimatter had annihilated with all the matter. One minute later (10^{9}) degrees), protons and neutrons combined to make nuclei – entirely hydrogen and helium.



If the Big Bang is thought of as, for example, a process such as the growth of a plant, instead as a group of occurrences, the comparison and contrast of these occurrences to decide the most impactful one must be done based on each occurrence's individual impacts, and not in link with previous impacts and consequences. An apple tree cannot bear apples if it was not once a seed that grew into a sapling and eventually a fruit bearing tree.

From the four above described processes (formation of protons and neutrons, antimatter annihilation, neutrino decoupling and nucleosynthesis) each can be isolated for specific impacts:

Firstly, the formation of protons and neutrons 10^{-5} seconds after the Big Bang at 10^{10} degrees was a process a million times longer than the time before the electroweak phase transition and longer than most particle physics processes. Quarks being bound up in protons and neutrons today is the biggest difference between these particles and particles then, which flew about freely. With a dropping temperature and density quarks were moving increasingly slowly unable to resist the forces pulling them together forming color balances triads. This is the form most quarks in the universe have been in ever since. This is a rather huge impact.

Secondly, 10^{-1} seconds after the Big Bang at 10^{10} degrees all the antiprotons and antineutrons were gone, and one second after the Big Bang at 10^{9} degrees the equilibrium was broken and annihilation began to outpace creation. Three to ten seconds after the Big Bang at 10^{9} degrees the positrons were gone. From that moment onwards, the universe has had no antimatter. However, there is still those one in a billion particles of matter left over with nothing to annihilate – which makes up all the matter such stars, galaxies, planets, etc. in the universe today. This is a significant impact.

Thirdly, for the first second after the Big Bang at 10^{10} degrees, the universe was so dense that even neutrinos could not pass, they kept constantly colliding with other particles. Starting around one second after the Big Bang, the matter was not dense enough to stop the neutrinos. The neutrinos from that time have been moving freely through the universe ever since (in one second, the neutrinos "froze out" – stopped interacting with other matter (decoupled)). Although they have not been interacting with matter, they have slowed down, because of the expansion of the universe. They still fill all of space today. Calculations show that these primordial neutrinos should be coming at us equally from all directions at a temperature about two degrees above absolute zero. In 2015, for the first time, scientists detected this cosmic neutrino background and measured its temperature to be around 1.96˚C, confirming out understanding of what was happening in the first second of the universe. This occurrence cannot be considered as impactful as the previous two.

Finally, one minute after the Big Bang at 10^{9} degrees, protons and neutrons began combining into light nuclei in a process called Big Bang nucleosynthesis. The lasting strong nuclear force between protons and neutrons is still strong enough to hold nuclei together. The attraction between protons and neutrons cannot hold them together if they are moving with extremely high energy. For them to stick together, the temperature had to drop below by around a billion degrees, which happened around a minute after the Big Bang. Once the temperature was low enough, one proton and one neutron could combine to form a nucleus called hydrogen-2 (deuterium). Two deuterium nuclei could combine to form helium-4. If there had been no neutrons and it could not start till twenty minutes after the Big Bang, none of it would have happened at all. All nuclei would have ended up as hydrogen. After nucleosynthesis, helium made up about 8% of the nuclei in the universe, and as they are heavier than hydrogen nuclei, they made up around 25% by mass. After nucleosynthesis, deuterium accounted for only one in a billion nuclei. The measurement of that trace deuterium in exactly the amounts predicted by the Big Bang model had been one of the greatest experimental confirmations of the model. The mix of nuclei in the universe was fixed for millions of years until fusion started again in the cores of the first stars. Without nucleosynthesis, the fundamental elements would not have been created, and as also suggested if there had been no neutrons and nucleosynthesis could not start till twenty minutes after the Big Bang none of it would have happened at all.

[3]The Goldilocks planet – our planet – the earth is made entirely of what we consider to be the smallest unit of matter: protons,

neutrons, and electrons. Without these, we would frankly not exist, and it is rather unfathomable as to what would have occurred instead. Much of our knowledge on physics today is entirely dependent on these subatomic particles and what they have created in every expanding universe. As stated by Space.com "Protons are tiny particles just a femtometer across, but without them, atoms wouldn't exist". From the lightest element of hydrogen with merely a single proton in its nucleus to oganesson with 118 of these protons in its nucleus, atoms make up everything and nothing would be possible without them.

[4]The visible universe is made entirely of matter and there is more matter present than antimatter. Matter and antimatter particles are always produced as a pair and if they come in contact, annihilate one another, leaving behind pure energy. However, if matter and antimatter are created and destroyed together, it seems the universe should contain nothing but leftover energy. It is thus considered that some unknown mechanism may have interfered with the oscillating particles to cause a slight majority of them to decay as matter. This leads to the interesting conclusion that it is perhaps a good thing that the ratio of matter to antimatter is asymmetrical, which made way for the creation of stars, planets, and life, instead of a universe filled with energy.

If neutrinos had not decoupled, they would have affected the expansion of the universe by increasing the rate at which this happened by providing energy through interaction with matter. The universe would have been less dense seeing that it would be expanding at such a high rate. However, it is worth noting that there is still no certainty of any exact consequences of if neutrinos had not decoupled and any theories proposed are pure fruits of thought experiments. Neutrinos exist today as insignificant particles having no mass and charge and no effect on the normal interaction of matter.

[5]If Big Bang nucleosynthesis had not occurred, we would not have all the elements we do today. The Big Bang produced hydrogen along with minute amounts of helium and lithium, and without nucleosynthesis, the universe would have stayed that way. Elements such as oxygen and carbon are essential for life and without these all living phenomena would be unheard of. The inner planets, terrestrial planets, include Mercury, Venus, Earth, and Mars, consisting of elements with high melting points such as iron, silicon, magnesium, sulfur aluminium, calcium, and nickel. Seeing that these elements would not exist if nucleosynthesis had not occurred, neither would have these planets, theoretically. The outer planets, gas giants, include Jupiter, Saturn, Uranus, and Neptune, consisting of hydrogen and helium. Seeing that these elements are the only ones that existed if nucleosynthesis had not occurred, they would have formed too, theoretically. [6]Stars are made of hydrogen and helium, with smaller amounts of carbon, nitrogen, oxygen, and iron. These celestial bodies too would have existed seeing that they are made of hydrogen and helium. However, all the above speculations are also thought experiments.

The aspects discussed above include the occurrences in the first three minutes after the Big Bang particle collisions, decay of unstable particles, formation of protons and neutrons, matter-antimatter annihilation, neutrino decoupling, Big Bang nucleosynthesis and formation of deuterium and fusion into helium. [2]In summary, to restate, at 10^{-11} seconds after the Big Bang (10^{15} degrees), a dense collection of quarks, electrons, and other elementary particles, with equal amounts of matter and antimatter existed. A second later (10^{10} degrees), the quarks had all combined, all the unstable particles like Higgs bosons had all decayed, and the antimatter had annihilated with all the matter. One minute later (10^{9}) degrees), protons and neutrons combined to make nuclei – entirely hydrogen and helium.

Out of the above occurrences, four were discussed in more depth, formation of protons and neutrons, matter-antimatter annihilation, neutrino decoupling and Big Bang nucleosynthesis. Statements have been made for each topic, including "atoms make up everything and nothing would be possible without them" for formation of protons and neutrons, "it is perhaps a good thing that the ratio of matter to antimatter is asymmetrical, which made way for the creation of stars, planets, and life, instead of a universe filled with energy" for matter-antimatter annihilation, "insignificant particles having no mass and charge and no effect on the normal interaction of matter" for neutrino decoupling and "If Big Bang nucleosynthesis had not occurred, we would not have all the elements we do today", "Elements such as oxygen and carbon are essential for life and without these all living phenomena would be unheard of", "Seeing that these elements would not exist if nucleosynthesis had not occurred, neither would have these planets, theoretically" making a reference to inner planets, "Seeing that these elements are the only ones that existed if nucleosynthesis had not occurred, they would have formed too, theoretically" making a reference to outer planets, and "These celestial bodies too would have existed seeing that they are made of hydrogen and helium" referring to stars.

Based on these statements, it can be said that the most impactful occurrence in the first minute after the Big Bang, considering that the comparison and contrast of these occurrences to decide the most impactful one being based on each occurrence's individual impacts, and not in link with previous impacts and consequences, is matter-antimatter annihilation. This is justified as the visible universe is made entirely of matter and there is more matter present than antimatter. Matter and antimatter particles are always produced as a pair and if they come in contact, annihilate one another, leaving behind pure energy. However, if matter and antimatter are created and destroyed together, it seems the universe should contain nothing but leftover energy. It is thus considered that some unknown mechanism may have interfered with the oscillating particles to cause a slight majority of them to decay as matter. This leads to the interesting conclusion that it is perhaps a good thing that the ratio of matter to antimatter is asymmetrical, which made way for the creation of stars, planets, and life, instead of a universe filled with energy.

Though many would argue that the most undisputedly impactful occurrence in the first minute after the Big Bang is the formation of protons and neutrons, it is important to think about how, according to our assumption, if some unknown mechanism had not interfered with the oscillating particles to cause a slight majority of them to decay as matter, the universe would just be a pool of energy. There would be no value in terms of stars, planets and most importantly, life. Matter-antimatter annihilation made way for the formation of protons and neutrons, which we can credit with for everything in the universe. Thus, after detailed description, analysis, evaluation, and formation of conclusions, it can be said the most important occurrence in the first minute after the Big Bang is matter-antimatter annihilation, having occurred 10^{-1} seconds after the Big Bang at 10^{10} degrees (antiprotons and antineutrons were gone), one second afterwards (annihilation began to outpace creation), three to ten seconds afterwards (positrons were gone) and a few seconds afterwards (antiquarks and positrons were gone).

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