UNIT 3 WORLD MODELS

Contents

3.0 OBJECTIVES

- To study some of the theories or models – ancient and modern - universe.
- To see how our view of the world keeps on evolving.
- To a brief study the most important world model we have today.

3.1 INTRODUCTION

"Cosmos" is just another word for universe, and "cosmology" is the study of the origin, evolution and fate of the universe. Some of the best minds in history - both philosophers and scientists - have applied themselves to an understanding of just what the universe is and where it came from, suggesting in the process a bewildering variety of models, theories and ideas, from the Cosmic Egg to the Big Bang and beyond. Below are some of the main ones, in approximate chronological order. The main purpose of this unit is to see how our present world model is the result of continuous evolution of older ones. For convenience sake we have divided the different world models into a. ancient, b. philosophical, c. early scientific and d. contemporary scientific theories. For this part we shall base ourselves on "The Physics of the Universe" website (CTH 2011). After studying these models we focus a bit more on Big Bang model and beyond.

3.2 ANCIENT THEORIES

Brahmanda (Cosmic Egg) Universe: The Hindu Rigveda, written in India around the 15th - 12th Century B.C., describes a cyclical or oscillating universe in which a "cosmic egg", or Brahmanda, containing the whole universe (including the Sun, Moon, planets and all of space) expands out of a single concentrated point called a *Bindu* before subsequently collapsing again. The universe cycles infinitely between expansion and total collapse and so the process goes on without end.

Anaxagorian Universe: The 5th Century B.C. Greek philosopher Anaxagoras believed that the original state of the cosmos was a primordial mixture of all its ingredients which existed in infinitesimally small fragments of themselves. This mixture was not entirely uniform, and some ingredients were present in higher concentrations than others, as well as varying from place to place. At some point in time, this mixture was set in motion by the action of “nous” (mind), and the whirling motion shifted and separated out the ingredients, ultimately producing the cosmos of separate material objects, all with different properties, that we see today (CTH 2011).

Atomist Universe: Later in the 5th Century B.C., the Greek philosophers Leucippus and Democritus founded the school of Atomism, which held that the universe was composed of very small, indivisible and indestructible building blocks known as atoms (from the Greek “atomos”, meaning “uncuttable”). All of reality and all the objects in the universe are composed of different arrangements of these eternal atoms and an infinite void, in which they form different combinations and shapes.

3.3 PHILOSOPHICAL THEORIES

Aristotelian Universe: The Greek philosopher Aristotle, in the 4th Century B.C., established a geocentric universe in which the fixed, spherical Earth is at the centre, surrounded by concentric celestial spheres of planets and stars. Although he believed the universe to be finite in size, he stressed that it exists unchanged and static throughout eternity. Aristotle definitively established the four classical elements of fire, air, earth and water, which were acted on by two forces, gravity (the tendency of earth and water to sink) and levity (the tendency of air and fire to rise). He later added a fifth element, ether, to describe the void that fills the universe above the terrestrial sphere.

Stoic Universe: The Stoic philosophers of ancient Greece (3rd Century B.C. and after) believed in a kind of island universe in which a finite cosmos is surrounded by an infinite void (not dissimilar in principle to a galaxy). They held that the cosmos is in a constant state of flux, and pulsates in size and periodically passes through upheavals and conflagrations. In the Stoic view, the universe is like a giant living body, with its leading part being the stars and the Sun, but in which all parts are interconnected, so that what happens in one place affects what happens elsewhere. They also held a cyclical view of history, in which the world was once pure fire and would become fire again, which is an idea borrowed from Heraclitus. (CTH 2011)

Heliocentric Universe: The 3rd Century B.C. Greek astronomer and mathematician Aristarchus of Samos was the first to present an explicit argument for a heliocentric model of the Solar System, placing the Sun, not the Earth, at the center of the known universe. He described the Earth as rotating daily on its axis and revolving annually about the Sun in a circular orbit, along with a sphere of fixed stars. His ideas were generally rejected in favour of the geocentric theories of Aristotle and Ptolemy until they were successfully revived nearly 1800 years later by Copernicus. However, there were exceptions: Seleucus of Seleucia, who lived about a century after Aristarchus, supported his theories and used the tides to explain heliocentricity and the influence of the Moon; the Indian astonomer and mathematician Aryabhata described elliptical orbits around the Sun at the end of the 5th Century A.D.; as did the Muslim astronomer Ja’far ibn Muhammad Abu Ma’shar al-Balkhi in the 9th Century (CTH 2011).

Ptolemic Universe: The 2nd Century A.D. Roman-Egyptian mathematician and astronomer Ptolemy (Claudius Ptolemaeus) described a geocentric model largely based on Aristotelian ideas, in which the planets and the rest of the universe orbit about a stationary Earth in circular epicycles. In terms of longevity, it was perhaps the most successful cosmological model of all time. Modifications to the basic Ptolemic system were suggested by the Islamic Maragha School in the 13th, 14th and 15th Centuries including the first accurate lunar model by Ibn al-Shatir, and the rejection of a stationery Earth in favour of a rotating Earth by Ali Qushji.

Abrahamic Universe: Several medieval Christian, Muslim and Jewish scholars put forward the idea of a universe which was finite in time. In the 6th Century A.D., the Christian philospher John Philoponus of Alexandria argued against the ancient Greek notion of an infinite past, and was perhaps the first commentator to argue that the universe is finite in time and therefore had a beginning. Early Muslim theologians such as Al-Kindi (9th Century) and Al-Ghazali (11th Century) offered logical arguments supporting a finite universe, as did the 10th Century Jewish philosopher Saadia Gaon.

Partially Heliocentric Universe: In the 15th and early 16th Century, Somayaji Nilakantha of the Kerala school of astronomy and mathematics in southern India developed a computational system for a partially heliocentric planetary model in which Mercury, Venus, Mars, Jupiter and Saturn orbited the Sun, which in turn orbited the Earth. This was very similar to the Tychonic system proposed by the Danish nobleman Tycho Brahe later in the 16th Century as a kind of hybrid of the Ptolemaic and Copernican models (CTH 2011).

Check Your Progress III

Note: Use the space provided for your answers.

1) How do Brahmanda and Bindu contribute to the ancient Indian view of the cosmos?

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2) What is Partially Heliocentric Universe?

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3.4 EARLY SCIENTIFIC THEORIES

Copernican Universe: In 1543, the Polish astronomer and polymath Nicolaus Copernicus adapted the geocentric Maragha model of Ibn al-Shatir to meet the requirements of the ancient heliocentric universe of Aristarchus. His publication of a scientific theory of heliocentrism, demonstrating that the motions of celestial objects can be explained without putting the Earth at rest in the centre of the universe, stimulated further scientific investigations and became a landmark in the history of modern science, sometimes known as the Copernican Revolution. His Copernican Principle (that the Earth is not in a central, specially favoured position) and its implication that celestial bodies obey physical laws identical to those on Earth, first established cosmology as a science rather than a branch of metaphysics. In 1576, the English astronomer Thomas Digges popularized Copernicus' ideas and also extended them by positing the existence of a multitude of stars extending to infinity, rather than just Copernicus' narrow band of fixed stars. The Italian philosopher Giordano Bruno took the Copernican Principle a stage further in 1584 by suggesting that even the Solar System is not the centre of the universe, but rather a relatively insignificant star system among an infinite multitude of others. In 1605, Johannes Kepler made further refinements by finally abandoning the classical assumption of circular orbits in favour of elliptical orbits which could explain the strange apparent movements of the planets. Galileo's controversial support of Copernicus' heliocentric model in the early 17th Century was denounced by the Inquisition but nevertheless helped to popularize the idea.

Cartesian Vortex Universe: In the mid-17th Century, the French philosopher René Descartes outlined a model of the universe with many of the characteristics of Newton's later static, infinite universe. But, according to Descartes, the vacuum of space was not empty at all, but was filled with matter that swirled around in large and small vortices. His model involved a system of huge swirling whirlpools of ethereal or fine matter, producing what would later be called gravitational effects.

Static (or Newtonian) Universe: In 1687, Sir Isaac Newton published his "Principia", which described, among other things, a static, steady state, infinite universe which even Einstein, in the early 20th Century, took as true (at least until events proved otherwise). In Newton's universe, matter on the large scale is uniformly distributed, and the universe is gravitationally balanced but essentially unstable.

Hierarchical Universe and the Nebular Hypothesis: Although still generally based on a Newtonian static universe, the matter in a hierarchical universe is clustered on ever larger scales of hierarchy, and is endlessly being recycled. It was first proposed in 1734 by the Swedish scientist and philosopher Emanuel Swedenborg, and developed further (independently) by Thomas Wright (1750), Immanuel Kant (1755) and Johann Heinrich Lambert (1761), and a similar model was proposed in 1796 by the Frenchman Pierre-Simon Laplace (CTH 2011).

3.5 CONTEMPORARY SCIENTIFIC THEORIES

Einsteinian Universe: The model of the universe assumed by Albert Einstein in his groundbreaking theory of gravity in the early 20th Century was not dissimilar to Newton's in that it was a static, dynamically stable universe which was neither expanding or contracting. However, he had to add in a "cosmological constant" to his general relativity equations to counteract the dynamical effects of gravity which would otherwise have caused the universe to collapse in on itself (although he later abandoned that part of his theory when Edwin Hubble definitively showed in 1929 that the universe was not in fact static)

Big Bang Model of the Universe: After Hubble's demonstration of the continuously expanding universe in 1929 (and especially after the discovery of cosmic microwave background radiation by Arno Penzias and Robert Wilson in 1965), some version of the Big Bang theory has generally been the mainsteam scientific view. The theory describes the universe as originating in an infinitely tiny, infinitely dense point (or singularity) between 13 and 14 billion years ago, from where it has been expanding ever since. The essential statement of the theory is usually attributed to the Belgian Roman Catholic priest and physicist Georges Lemaître in 1927 (even before Hubble's corroborating evidence), although a similar theory had been proposed, although not pursued, 1922 by the Russian Alexander Friedmann in 1922. Friedmann actually developed two models of an expanding universe based on Einstein's general relativity equations, one with positive curvature or spherical space, and one with negative curvature or hyperbolic space. (CTH 2011 and Pandikattu 1999)

Oscillating Universe: This was Einstein's favoured model after he rejected his own original model in the 1930s. The oscillating universe followed from Alexander Friedmann's model of an expanding universe based on the general relativity equations for a universe with positive curvature (spherical space), which results in the universe expanding for a time and then contracting due to the pull of its gravity, in a perpetual cycle of Big Bang followed by Big Crunch. Time is thus endless and beginningless, and the beginning-of-time paradox is avoided (Pandikattu 1999).

Steady State Universe: This non-standard cosmology (i.e. opposed to the standard Big Bang model) has occurred in various versions since the Big Bang theory was generally adopted by the scientific community. A popular variant of the steady state universe was proposed in 1948 by the English astronomer Fred Hoyle and the and Austrians Thomas Gold and Hermann Bondi. It predicted a universe that expanded but did not change its density, with matter being inserted into the universe as it expanded in order to maintain a constant density. Despite its drawbacks, this was quite a popular idea until the discovery of the cosmic microwave background radiation in 1965 which supported the Big Bang model. It may be noted that Jayan*t* Narlikar, one of the most famous Indian astronomers is an ardent supporter of a modified steady state universe (Narlikar 2010).

Inflationary (or Inflating) Universe: In 1980, the American physicist Alan Guth proposed a model of the universe based on the Big Bang, but incorporating a short, early period of exponential cosmic inflation in order to solve the horizon and flatness problems of the standard Big Bang model. Another variation of the inflationary universe is the cyclic model developed by Paul Steinhardt and Neil Turok in 2002 using state-of-the-art M-theory, superstring theory and brane cosmology, which involves an inflationary universe expanding and contracting in cycles.

Bubble Universe: Drawing from the recent quantum mechanics Russian-American physicist Andrei D. Linde proposes a "bubble universe." The universe consisting of a whole set of bubbles has no clear development or final state; new bubbles will begin as offspring of others. He therefore argues that life appears again and again in the bubbles. Even more strongly he hints at the possibility of travelling or at least communicating between bubbles. The conditions within the bubbles is that the vacuum energy density is extremely close to zero. This shows the potential practical importance of research on the vacuum energy density. According to Drees, "unfortunately (or, may be, fortunately) it may take as much as 10-5000000 years until the significance of the current work on this problem will be fully appreciated." The pioneering work of physicists Sidney Coleman and Frank De Luccia on "Gravitational Effects on and of Vacuum Decay" throws prospects for the entire cosmos based on such a quantum cosmology. From quantum mechanical perspective what appears to us as vacuum may be in reality "seething with ephemeral quantum activity, as ghostly virtual particles appear and disappear again in a random frolic." Such a vacuum state may not be unique; there could be several quantum states, all apparently empty but enjoying different levels of quantum activity and having different energy levels (Pandikattu 1999).

Multiverse: Going beyond the "bubble universe" the theory of multiverse is proposed, that grew as part of a multiverse owing to a vacuum that had not decayed to its ground state. The American physicists Hugh Everett III and Bryce DeWitt had initially developed and popularized their "many worlds" formulation of the multiverse in the 1960s and 1970s. Alternative versions have also been developed where our observable universe is just one tiny organized part of an infinitely big cosmos which is largely in a state of chaos, or where our organized universe is just one temporary episode in an infinite sequence of largely chaotic and unorganized arrangements (CTH 2011).

Check Your Progress II

Note: Use the space provided for your answers.

1) What is oscillating Universe?

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2) What is the significance of Bubble Universe?

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3.6 THE BIG BANG AND BEYOND

This paper elaborates the theory of Big Bang and later introduces the theory *inflation*, a modification of the standard "big bang" model of the history of the universe.

When Einstein formulated the general theory of relativity, he found that it was incompatible with a static universe; the equations predicted that the universe must either be expanding or shrinking. The prevalent bias against this conclusion was so strong that Einstein altered the equations of relativity in order to allow for a static solution. When Edwin Hubble found that the universe was indeed expanding, Einstein retracted this alteration, calling it the biggest blunder of his life. From that point forward the prevailing scientific viewpoint has been that of an expanding universe that at earlier times was much hotter and denser than it is today. Extrapolating this expansion backwards, we find that at a specific time in the past the universe would have been infinitely dense. This time, the beginning of the universe's expansion, has come to be known as the "big bang." (Felder 2002)

The big bang model has been extremely successful at explaining known aspects of the universe and correctly predicting new observations. Nonetheless, there are certain problems with the model. There are several features of our current universe that seem to emerge as strange coincidences in big bang theory. Even worse, there are some predictions of the theory that are in contradiction with observation. These problems have motivated people to look for ways to extend or modify the theory without losing all of the successful predictions it has made. In 1980 a theory was developed that solved many of the problems plaguing the big bang model while leaving intact its basic structure. More specifically, this new theory modified our picture of what happened in the first fraction of a second of the universe's expansion. This change in our view of that first fraction of a second has proven to have profound influences on our view of the universe and the big bang itself. This new theory is called *inflation.* (Felder 2002)

The Big Bang Model

For most of this century our view of the large-scale structure and history of the universe has been dominated by the big bang model. According to this model the universe at early times was a nearly uniform expanding collection of high energy, high temperature particles. A system that is uniform—the same everywhere—is known in physics as *homogeneous.* The small differences in density that did exist from one point to another are called *inhomogeneities.* As the universe expanded and cooled these small inhomogeneities were then amplified by gravity. The matter in regions with slightly higher than average density collapsed to form the structures we see today such as clusters and galaxies. Extrapolating backwards, on the other hand, that nearly homogeneous fireball would have had higher temperatures and densities at earlier times, ultimately reaching infinite density at a moment about 15 billion years ago. That moment is called the big bang (Ratcliffe 2009).

This model is in perfect accord with the theory of general relativity, which predicts that a homogeneous universe would expand and cool in exactly that way. Moreover, there have been many observational confirmations of the big bang model. These confirmations include the apparent motions of distant objects relative to us, the microwave radiation left over from the early universe, and the abundances of light elements formed in the first few minutes after the big bang. (Felder 2002 and Teerikorpi 2009)

We want to focus momentarily on the latter of these. An element is defined by the number of protons in a nucleus—one for hydrogen, two for helium, and so on. For roughly three minutes after the big bang the temperature of the universe was so high that protons and neutrons couldn’t bind together into nuclei; the particles all had so much energy that the forces that hold nuclei together were too weak to make them stick to each other. Thus for those first three minutes the only element in the universe was hydrogen, i.e. single protons not bound to anything else. (A neutron with no proton is not considered an element.) As the universe expanded and cooled it eventually reached a temperature where the protons and neutrons could bind together, and different elements were formed. The formation of these nuclei from their constituent particles (i.e. protons and neutrons) is known as *nucleosynthesis* (Felder 2002).

Nuclear theory is well tested and understood. By applying it to a homogeneous, expanding medium at high temperature we can predict what relative abundances of different elements should have emerged when these nuclei were formed in the early universe. It turns out that only the three lightest elements, hydrogen, helium, and lithium, would have been able to form at that time. All of the heavier elements were formed much later in stars, and currently make up a tiny percentage of the matter we see in the universe. The predictions of the relative abundances of these light elements accurately match the observational data. This match is particularly important because it strongly suggests that the big bang model is an accurate description of the universe at least as far back as nucleosynthesis, i.e. three minutes after the predicted moment of the big bang. All of the other evidence for the theory, such as the microwave background and the motions of distant galaxies, relate to the universe at much later times, so we have no direct evidence for the accuracy of the big bang model before nucleosynthesis.

Despite this lack of direct evidence, it would be tempting to extrapolate further backwards and assume the big bang model to be an accurate description of the universe all the way back to the big bang. Such a complete extrapolation of the theory is not possible, however, because of certain limitations of our theories of high energy physics. When we talk about extrapolating backwards in the big bang model we are referring to running the equations of general relativity backwards to earlier times and higher densities. We know, however, that general relativity ceases to be valid when we try to describe a region of spacetime whose density exceeds a certain value known as the *Planck density*, roughly 10^{93} g/cm^3. If we try to consistently apply quantum mechanics and general relativity at such a density we find that quantum fluctuations of spacetime become important, and we have no theory that describes such a situation (Felder 2002).

It is almost certain that the big bang model gives an accurate description of the universe back at least as far as the time of nucleosynthesis. The earliest it could possibly be applied would be the Planck era. If we were to consider it valid all the way back to the Planck era we would have to suppose that all the very fine-tuned initial conditions we observe such as homogeneity and flatness were present from the beginning, presumably as a result of some unknown quantum gravity effects. Even given this assumption, however, it is unclear how the theory could avoid the production of relic particles that would destroy the successful description it has made of the later universe (Ratcliffe 2009).

It would be wonderful if a theory existed that with a minimum of assumptions could explain the initial conditions such as flatness and homogeneity, eliminate all high energy relic particles, and then segue into the big bang model itself by the time of nucleosynthesis. In 1980 Alan Guth proposed such a theory, known as *inflation.*

Inflation

The basic idea of inflation has to do with the rate at which the universe is expanding. When I use the term "rate" in this context I don't mean a speed. In an expanding universe the distances between galaxies are increasing, and the rate of expansion essentially refers to how long it takes for all of those distances to double. In the standard big bang model the universe experiences *power law expansion*, meaning the doubling time gets longer as the universe expands. For example, in our current power law expansion distances in the universe were roughly half their current value about 10 billion years ago, but they won't be twice their current value until about 30 billion years from now. By contrast, if the doubling time stays constant then the expansion is referred to as *exponential.* Inflationary theory says that before our current power law expansion there was a brief period of exponential expansion (Felder 2002).

Exponential growth can be much faster than power-law growth. In the simplest models of inflation the universe would have expanded by a factor of over ten to the ten million in a fraction of a second. There are two obvious questions raised by this idea: What mechanism would cause such an expansion to occur and what would be the consequences if it did?

It is nothing short of remarkable that from our vantage point, sitting at one point in space and at one time in cosmic history, we have been able to discover as much as we have about the history of our universe. While there is a great deal we do not understand about the very early times after the moment we call the big bang, the last twenty years have seen an explosion of progress in both our theories and our observations. As we improve in both of these arenas our understanding will undoubtedly change.

Will the theory of inflation survive those changes? I believe it's too early to answer that question with any confidence. As a model it has great appeal for a number of reasons. In particular, it explains a lot of features of the universe in a simple way with relatively few assumptions, and it seems to arise naturally in the context of our current theories of physics. In other words it seems highly likely that inflation would have occurred in the early universe, and if it did it would give rise to a universe much like the one we see. Moreover no other known theory can explain these features. Andrei Linde, one of the leading experts in inflation, once told me "Inflation hasn't won the race, but so far it's the only horse." My personal suspicion is that if in a hundred years the theory of inflation isn't part of our understanding of the early universe then it will have to have been replaced by something very similar to it.

In the meanwhile we can look forward to a lot of good tests of early universe physics in the next couple of decades. High sensitivity probes of the microwave background, searches for waves of gravity surviving from the early universe, and many other experiments are going to give us excellent tests, not only of inflation, but of our understanding of the universe in general (Felder 2002).

The Inflationary Theory

In 1981, a particle physicist named Alan Guth created a new theory. Guth knew about the matter in physics that explained how elementary particles got their mass. This matter is called scalar field matter. Combining the mathematical equations for scalar field with Einstein's equations describing the expansion of the universe, Guth developed a theory in which large amounts of matter and energy were created from nothing! After matter and energy were created, the universe experienced an accelerated expansion, becoming exponentially large prior to continuing its evolution according to the big bang model. This theory has been worked on and modified by many cosmologists since its introduction (Felder 2002?).

3.7 CONCLUDING COMMENTS

Most scientists now believe that we live in a finite expanding universe which has not existed forever, and that all the matter, energy and space in the universe was once squeezed into an infinitesimally small volume, which erupted in a cataclysmic "explosion" which has become known as the Big Bang. Thus, space, time, energy and matter all came into being at an infinitely dense, infinitely hot gravitational singularity, and began expanding everywhere at once. Current best estimates are that this occurred some 13.7 billion years ago, although you may sometimes see estimates of anywhere between 11 and 18 billion years. The Big Bang is usually considered to be a theory of the birth of the universe, although technically it does not exactly describe the origin of the universe, but rather attempts to explain how the universe developed from a very tiny, dense state into what it is today. It is just a model to convey what happened and not a description of an actual explosion, and the Big Bang was neither Big (in the beginning the universe was incomparably smaller than the size of a single proton), nor a Bang (it was more of a snap or a sudden inflation) (BBBC 2010).

In fact, "explosion" is really just an often-used analogy and is slightly misleading in that it conveys the image that the Big Bang was triggered in some way at some particular centre. In reality, however, the same pattern of expansion would be observed from anywhere in the universe, so there is no particular location in our present universe which could claim to be the origin. It really describes a very rapid expansion or stretching of space itself rather than an explosion in pre-existing space. Perhaps a better analogy sometimes used to describe the even expansion of galaxies throughout the universe is that of raisins baked in a cake becoming more distant from each other as the cake rises and expands, or alternatively of a balloon inflating. Neither does it attempt to explain what initiated the creation of the universe, or what came before the Big Bang, or even what lies outside the universe (BBBC 2010). All of this is generally considered to be outside the remit of physics, and more the concern of philosophy. Given that time and space as we understand it began with the Big Bang, the phase "before the Big Bang" is as meaningless as "north of the North Pole".

Therefore, to those who claim that the very idea of a Big Bang violates the First Law of Thermodynamics (also known as the Law of Conservation of Energy) that matter and energy cannot be created or destroyed, proponents respond that the Big Bang does not address the creation of the universe, only its evolution, and that, as the laws of science break down anyway as we approach the creation of the universe, there is no reason to believe that the First Law of Thermodynamics would apply. (BBBC 2010)

The Second Law of Thermodynamics, on the other hand, lends theoretical (though inconclusive) support to the idea of a finite universe originating in a Big Bang type event. If disorder and entropy in the universe as a whole is constantly increasing until it reaches thermodynamic equilibrium, as the Law suggests, then it follows that the universe cannot have existed forever, otherwise it would have reached its equilibrium end state an infinite time ago, our Sun would have exhausted its fuel reserves and died long ago, and the constant cycle of death and rebirth of stars would have ground to a halt after an eternity of dissipation of energy, losses of material to black holes, etc.

The Big Bang model rests on two main theoretical pillars: the General Theory of Relativity (Albert Einstein's generalization of Sir Isaac Newton's original theory of gravity) and the Cosmological Principle (the assumption that the matter in the universe is uniformly distributed on the large scales, that the universe is homogeneous and isotropic). The Big Bang (a phrase coined, incidentally, by the English astronomer Fred Hoyle during a 1949 radio broadcast as a derisive description of a theory he disagreed with) is currently considered by most scientists as by far the most likely scenario for the birth of universe. However, this has not always been the case, as the following discussion illustrates (BBBC 2010).

Check Your Progress III

Note: Use the space provided for your answers.

1) How do you respond to the question: 'What happened before the Big Bang?'?

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2) How is the first law of thermodynamics related to Big Bang?

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3.8 LET US SUM UP

We have studied the different world models. History tells us that best model we have (the modified standard model) will give way to a better one in the near future.

3.9 KEY WORDS

Brahmanda : "Egg of God," or "Cosmic egg." The cosmos; inner and outer universe. It also designates a division of infinite time.

3.10 FURTHER READINGS AND REFERENCES

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