THE STUFF OF THE UNIVERSE*
(How far is Science in her Quest?)

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INTRODUCTION

In the course of human history, the overlap between science and religion has ranged from zero, i.e., the two being absolutely independent, non-intersecting areas, to that of the two mutually containing each other. The latter case is exemplified by the remark of a physics Nobel laureate, "Science is our religion." This curious relation between science and religion arises from the fact that, in the final analysis, each area seeks to know the "whole truth". Their perspectives and standpoints, as well as their methods of arriving at the truth may vastly differ and, therefore, there is always the risk of a head-on collision between science and religion. But there is also the possibility of one enriching the other.

A well known example of a science-religion conflict is that of the Italian physicist Galileo Galilei (1564–1642 A.D.) who was placed by the Catholic church under house arrest for the final eight years of his life for having advocated the Copernican system. This system was based on the findings of the Polish astronomer Nicolaus Copernicus (1473–1543 A.D.) which stated that the earth, and other planets, revolved around the sun. The church formally acknowledged its error in condemning Galileo in 1992.

The idea that science need not be in conflict with religion perhaps motivated the Jesuits in the Vatican to organize in 1981 a conference[1] on cosmology where leading scientists in the world participated. It was, in fact, in this Vatican conference[1] where the "no-boundary proposal" was introduced by one of the participants, Stephen W. Hawking of Cambridge University, which stated that the universe had no beginning and, therefore, no moment of creation[2].

In this paper, the authors join this dialogue between science and religion since, in the end, the truth is their common goal. In the following sections, we provide an outline of the origin of the universe, its evolution and fate as well as the origin of life from a scientific standpoint. In particular, sections 2 to 4 address the issue on how our universe may have begun. This is followed in section 5 with a brief discussion of how the galaxies, stars, and the earth could have arisen. Section 6 tackles the origin of life which may have started on earth about 3.5 billion years ago. Sections 7 and 8 delve into the topic of what could differentiate humans from animals, and section 9 briefly discusses some possible frontiers in science research. Section 10 illustrates how our universe may end. The authors give the concluding remarks in section 11.

THE GENERAL RELATIVITY OF EINSTEIN

The theory of general relativity has enjoyed a remarkable agreement with numerous experiments that have been performed since its formulation by Albert Einstein in 1915. One of the early predictions from general relativity was a universe that expands. This was shown by the Russian physicist and mathematician Alexander Friedmann in 1922 and, independently, by the Belgian cleric Abbé Georges Lemaître in 1927. An experimental proof for an expanding universe was provided in 1929 by Edwin P. Hubble, a lawyer turned astronomer. Similar models of an expanding universe based on general relativity were discovered in 1935 by the American physicist Howard Robertson and the British mathematician Arthur Walker. Experimental observations accumulated through the years show that our expanding universe can be described by the Friedmann-Lemaître-Robertson-Walker universe, or the FLRW model.

One of the immediate implications of an expanding universe is that if a movie of this universe is played backwards, then one sees a universe that is contracting. One sees the galaxies, and clusters of galaxies, moving closer to each other as if rushing and collapsing towards a single point. How did the universe look like in the past? Physics tells us that when the universe was about 10^{-34} second old (i.e., one second divided by 10,000,000,000,000,000,000,000,000,000,000,000) the size of the whole universe was roughly 10^{-29} centimeter (i.e., one cm divided by a number 1 followed by 29 zeroes). To realize how small this is, consider Table 1 which shows a progression of smaller and smaller objects.

ITEM TO BE MEASURED	Approximate size in centimeter
Thickness of a piece of chalk	10^{0} cm = 1 cm
Thickness of human hair	10^{-2} cm = 1 cm / 100
Size of an atom	10^{-8} cm
Size of proton	10^{-13} cm
Size of electron	Less than 10^{-17} cm
Size of universe at time 10^{-34} second	10^{-29} cm
Planck scale	10^{-33} cm

Table 1. Typical scales and sizes of objects. Present-day experiments can make measurements up to 10^{-17} cm.

One, therefore, obtains a picture where all the matter, radiation, and energy that comprise the whole universe were compressed into a very, very small size very early in its history. When the age of the universe was 10^{-43} second (the Planck time), we have an extremely dense, and very hot universe with its size at the Planck scale of 10^{-33} cm. Mathematical theorems proved by Roger Penrose and S. W. Hawking show that this situation leads to an initial space-time singularity (or infinities in space-time)[3]. One refers to this era as the Big Bang. Right after the Big Bang, a rapid inflation of the size of the universe followed and, up to the present, the universe continues to expand. Just like gas which expands, the expanding universe has cooled down from its very hot early beginning to the present-day temperature of the cosmic microwave background (CMB) radiation of 3 Kelvin[4].

The experimentally observed CMB radiation provides a snapshot of the universe 300,000 years after the Big Bang when the universe had cooled down to around 3,000 Kelvin.[5] Although the universe at early times was extremely smooth, the CMB radiation indicates that there were very small density variations which manifest as temperature variations. These density inhomogeneities (departures from homogeneity of magnitude as small as 1 / 100,000) are the seeds for the formation of galaxies, and clusters of galaxies. The attractive power of gravity allows these inhomogeneities to gradually grow for billions of years leading to the structure of the universe that we now observe.

What was the cause of the Big Bang? How did our universe begin? Based on general relativity alone, there could be pin-pointed a moment of creation which may be the Big Bang that occurred about 13 billion years ago. The Big Bang may be viewed by some as the birth of the universe, and the beginning of space and time. There is, however, a hitch to this picture. As has been observed, general relativity predicts its own downfall. It is a bad theory to deal with during the Big Bang when the universe was extremely dense, because it would be plagued with infinities (space-time singularities) and, therefore, loses all its predictive and descriptive power. The theory of general relativity becomes unreliable when the size of the universe is down to 10^{-33} cm (the Planck scale), or when the universe was 10^{-43} second old. This brings us back to the question: "Was there really a Big Bang?" To shed light on this question we turn to another physical theory called quantum mechanics which has proved powerful in dealing with the micro-world.

THE QUANTUM UNIVERSE

Quantum mechanics is a theory which correctly describes and predicts the behavior of the atom, and even the particles which make up an atom: the electrons, protons, and neutrons. Quantum mechanics, in fact, is necessary to describe the smallest and most basic constituents of matter which are the quarks and leptons. It was Murray Gell-Mann of California Institute of Technology who discovered in 1964 that protons, as well as neutrons, are made up of three types of quarks. The quantum theory for quarks reveals that quark interactions are mediated by what physicists call the *strong force.*

Noting that the success of quantum mechanics has been in the micro-realm, its application to the universe as a whole was initially perceived as far-fetched. This drastically changed with the works of Stephen W. Hawking, Alexander Vilenkin, and others in the 1980's. The idea was simply that, right after the Big Bang, the whole universe was much smaller than a proton. A thorough description of the very early and extremely small universe should, therefore, involve quantum physics. Only after the Planck time, or when 10^{-43} second has elapsed, reliable. A theory which would consistently combine quantum mechanics and general relativity is referred to as quantum gravity[6], or sometimes quantum cosmology when applied to the early universe[7]. Although an acceptable theory of quantum gravity still has to be formulated, one could already invoke certain properties and principles of quantum mechanics, such as quantum tunneling (see Figure 1), the uncertainty principle, and others, in order to investigate the very early universe.

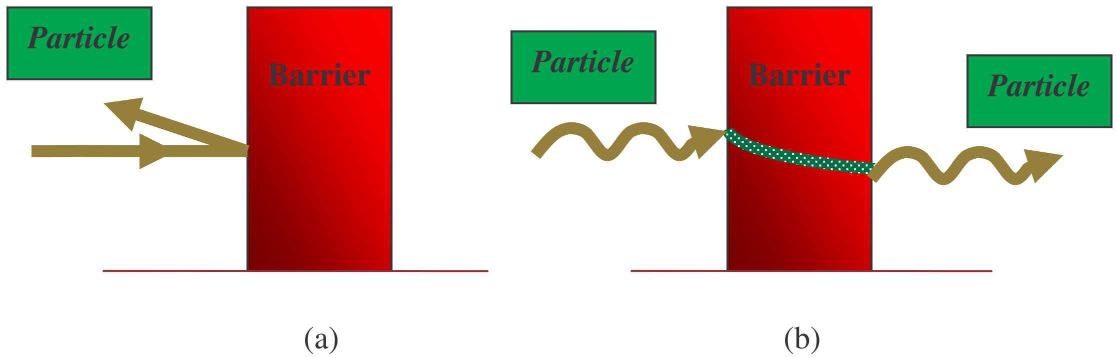


Figure 1. (a) In classical physics, a particle travels from the left, and bounces off the barrier, or wall, that it hits. This is what we ordinarily observe. (b) In quantum physics, a particle which hits the barrier can actually "tunnel" through, and appear on the other side of the wall. For the quantum case, we represented the particle with a wavelike structure. Numerous experiments have provided evidence for quantum tunneling.

The experimentally verified uncertainty principle, for instance, tells us that the vacuum is not really empty. From nothing, a particle together with its anti-particle can be spontaneously created in a vacuum. The lifetimes of the particle and anti-particle are, of course, dictated by the uncertainty principle. There could be a huge number of these particle and anti-particle pairs such that the vacuum is really far from empty. Is the uncertainty principle crucial to our understanding of the early universe? One way of avoiding an initial space-time singularity is a spontaneous creation of a universe of finite size from the vacuum. The idea that our universe might be a vacuum fluctuation has been suggested as early as 1973, but the initial condition involved at the moment of creation was still unclear.[8] We shall now consider two scenarios which use quantum mechanics to address the initial condition that may be required to describe the origin of the universe.

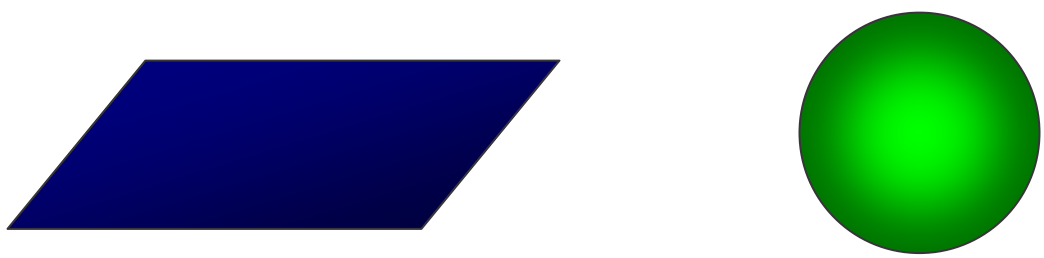
The "No Boundary" Proposal

With the path integral formulation of quantum mechanics, a quantum version of general relativity was used by Hawking and applied to the universe at the Planck scale. This approach of Hawking advocates the "no-boundary" proposal for the early universe. For example, when one deals with one-dimensional objects, a distinction between those with boundaries and those which have none can be made. A line segment for instance would have two endpoints, labeled **A** and **B** (see Figure 2), where **A** and **B** are the edges, or boundaries. In contrast, a circle is a one-dimensional object with no boundary. An ant can walk continuously around the circle without encountering an edge, or a wall, or a boundary.

(a) (b)

Figure 2. Examples of a one-dimensional object: (a) a line segment with endpoints labeled by **A** and **B**; (b) a circle which has no endpoint, or boundary.

In a two-dimensional world, one could think of the surface of a sheet of paper whose edges, or boundaries, are its four sides. An ant walking on the surface of this sheet would sooner, or later, encounter the edge, or boundary, from which it can fall. In contrast, the surface of a sphere, or a ball, is a two-dimensional object with no boundaries (see Figure 3). The ant can walk around the ball as long as it wants and it will never encounter a boundary, or an edge from which it may fall.



(a) (b)

Figure 3. Examples of two-dimensional objects: (a) the surface of a sheet of paper with four sides or edges; (b) the surface of a sphere or a ball which has no boundary.

The distinction of geometries, i.e., with or without edges and boundaries, can be extended to four dimensions. The four-dimensional space-time of the universe may, or may not, have a boundary which would be the edge of space, and the edge of time. An example of a space-time which has no boundary is called a *closed* universe in the FLRW model (see also Section 10). E. P. Tryon was the first to suggest in 1973 that a closed universe could arise as a vacuum fluctuation[9]. S. W. Hawking, however, went further and used a closed universe scenario to extract information about the initial condition for the universe. The "no boundary" proposal[10] of Hawking means that the space-time of the universe has no edge and, therefore, one cannot assign the "beginning" of time[11]. There was no *moment of creation*.

A Universe which Tunneled out of Nothing

In 1982, Alexander Vilenkin of Tufts University wrote a paper describing a "creation-from-nothing" picture of a closed universe.[12] This views creation as a universe starting from a state of vanishing size which tunnels through to a point allowed by general relativity. Using quantum mechanics, a nonzero probability for tunneling from nothing was obtained. Nothing, here, means a state with no space and time. The subsequent evolution of the universe is then described by general relativity which is characterized by an inflation of the size of the universe. This cosmological model does not have a singularity (or infinities) at the big bang. Although this model describes a universe which has a beginning, no initial or boundary condition is required. The laws of physics totally determine the structure and evolution of the universe.

What was before the Creation of the Universe?

In relativity theory, *time* is treated at the same footing as *space* and, hence, it is natural for physicists to refer to an entity called *space-time*. In fact, general relativity views space-time as the fabric with which our universe is made. As the German mathematician Hermann Weyl wrote,[13]

*"**Space** and **time** are commonly regarded as the **forms** of existence of the real world, **matter** as its **substance**. A definite portion of matter occupies a definite part of space at a definite moment of time. It is in the composite idea of **motion** that these three fundamental conceptions enter into intimate relationship."*

From a scientific standpoint, therefore, the creation of the universe can be viewed as an event where space-time was created.

In philosophy or religion, one may encounter the question, "What was before the creation of the universe?" The phrase "*before the creation of the universe*," implies that there is a well-defined concept of time prior to the creation of the universe. St. Augustine (354-430 A.D.) had actually already settled this issue in the 5th century in his book, *Confessions*, when he answered what God did before he created the universe. We quote a few of his passages:

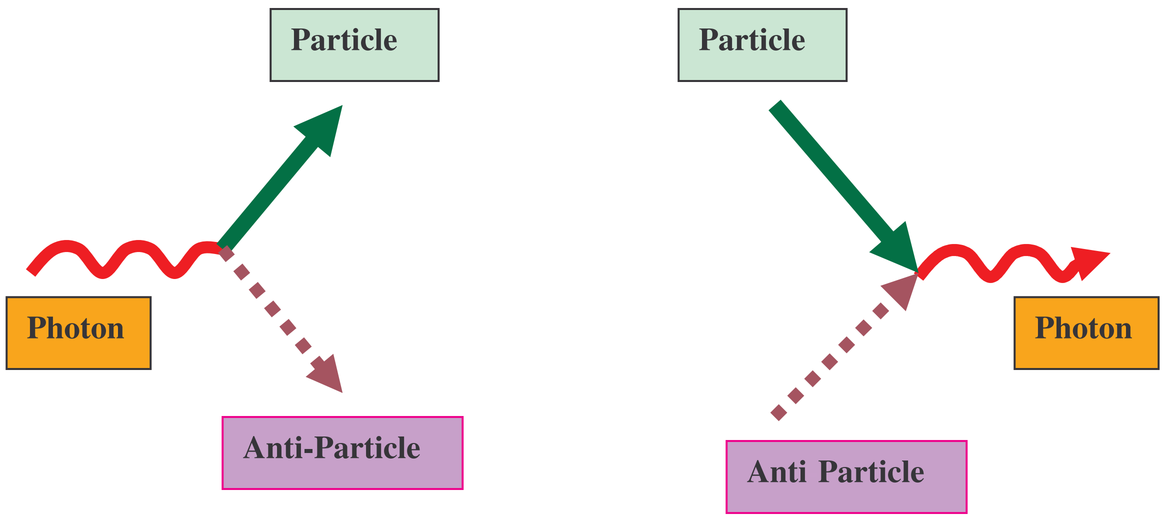
> *My answer to those who ask 'What was God doing before he made heaven and earth?' is not 'He was preparing Hell for people who pry into mysteries.' ... Instead of this I will say that you, my God, are the creator of all creation, and if we mean the whole of creation when we speak of heaven and earth, I unreservedly say that before he made heaven and earth, God made nothing.*

> *You are the Maker of all time…You must have made that time, for time could not elapse before you made it… But if there was no time before heaven and earth, how can anyone ask what you were doing 'then'? If there was no time, there was no 'then.'*

St. Augustine, therefore, looked at time as a property of the universe that God created. Outside of the universe, there is no such thing as time and, therefore, there is no *before* or *after*.

MATTER-ANTIMATTER ASYMMETRY

In quantum mechanics, the uncertainty principle allows for the creation of a particle-antiparticle pair from nothing[14]. Quantum mechanics also allows the reverse to happen: a particle annihilating with its antiparticle (See Figure 4).



(a) Pair Creation (b) Pair Annihilation

Figure 4. From the uncertainty principle, energy in the form of radiation, or photon, may spontaneously appear from the vacuum. (a) Energy is used for creating a particle and its anti-particle. (b) The particle and anti-particle pair can annihilate each other producing a photon, or light.

During the very hot early universe, a huge amount of these pairs – equal numbers of particles and antiparticles – were created. In principle, all of these pairs could also undergo pair annihilation, and nothing would be left, no atoms, no galaxies, no humans to be formed. Particles, however, may decay differently from antiparticles. This has been experimentally proven in studies of the K^0 particle, and its antiparticle $\underline{K}^0$. With this difference in their decay modes, it is surmised that the particles would outnumber the antiparticles. Almost all antiparticles could then annihilate their particle partners converting the pairs into radiation, or photons. The remaining particles, e.g., the quarks and leptons, with no antiparticle partners would then form the protons, neutrons and then later on the atoms. During the first few seconds of the universe, primordial light elements[15] such as D, ^{3}He, ^{4}He, and ^{7}Li were formed[16]. These would later on constitute the building blocks which would form the stars, galaxies, and clusters of galaxies.

FORMATION OF THE STARS, GALAXIES, AND THE EARTH

Our galaxy, the Milky Way, contains around two hundred billion suns,[17] and the sun in our solar system is an ordinary star located near the edge of an ordinary galaxy. There are, in fact, trillions of galaxies similar to ours scattered all over the observable universe. How are these stars, planets, and galaxies formed? Let us first consider the formation of a typical star.

How a Star is Born

Since gravity attracts both matter and radiation, an initial inhomogeneity in a region of the universe would start to attract nearby dust clouds or interstellar gas of particles. For the early universe, these particles would be the light elements formed during the first second. If this gravitational attraction of dust clouds and particles continues for billions of years, the small inhomogeneity would grow into a massive object such that it would now start to collapse under its own gravitational weight. This collapse, or compression, heats up the core of the object, and a thermonuclear fusion of the nuclei of the atoms that make up the massive object takes place. The heat and energy provided by the nuclear fusion “lights up” the object which we call a star. Initially the conversion of hydrogen to helium, which takes a few million years, provides the prime source of energy for the stars. This fusion creates a tremendous amount of heat and energy which then provides a counter-pressure to gravity. The collapse of the object would then temporarily stop as long as there is still hydrogen fuel available.

Death of a Star

A star that has consumed all the hydrogen fuel at its center becomes slightly redder and brighter and is called a *red giant*. Helium then becomes the next source of fuel for the star. For instance, 3 helium nuclei can fuse to form carbon. An additional helium nucleus converts some of the carbon atoms to oxygen[18]. During a star’s lifetime, there is a chain of conversion from hydrogen into helium, and then helium to heavier elements which provide fuel for the star. A star, therefore, is the factory which produces the elements found in the periodic table. Carbon, magnesium, and silicon can only be formed inside stars as far as present theories are concerned[19]. There comes a point, however, when the fuel inside a star runs out. The gravitational force again begins to dominate leading to a further collapse of the star which induces a process called inverse beta decay[20]. A sub-nuclear interaction mediated by what is called the *weak force* is responsible for beta decay. This beta decay produces a huge amount of neutrino particles that would blast out the outer layers of a star. We refer to this as a supernova explosion signaling the death of a star.

Our sun is around 4.7 billion years old[21]. Just like any star, the sun in our solar system would run out of fuel. When our sun meets its inevitable end, we would not know it until eight minutes later. It takes that time for light to travel from the sun to the earth. The death of our sun, however, should not worry our generation. Scientific estimates show that our sun should have a total life span of around 10 billion years[22], or about 100,000,000,000,000,000 seconds.

The debris blown away in a supernova explosion could also later form into meteors, planets, or a second generation star. Again with the help of gravity. A conglomeration of hundreds of billions of stars glued together by gravity can form a galaxy. The galaxies, in turn, are the basic building blocks of our universe.

The Young Earth

The Earth was probably formed from the debris ejected out by a dying star. This would explain why the Earth contains elements that could only be manufactured by a star. The age of the Earth is around 4.5 billion years[23], which makes it a bit younger than our sun. From the fossil remains, it appears that liquid water was present on Earth at least for the past 3.5 billion years[24]. The atmosphere[25] of the primitive Earth was characterized by a lack of molecular oxygen, but an abundance of hydrogen, methane (CH_4), ammonia (NH_3), water vapor, and ethane (C_2H_6). Is this environment conducive to the start of life on Earth? We now present a discussion on the origin of life.

THE BEGINNING OF LIFE ON EARTH

According to most scientists, there are three fundamental properties which characterize living systems. These are[26]: (a) *metabolism*, which is the process of obtaining from the environment the substances necessary for sustenance, energy, and growth; (b) *replication*, which is the ability to reproduce and propagate; and (c) *regeneration*, which is the ability to repair itself. Life has existed on Earth for the past 3.5 billion years.[27] How did life begin?

From the biological point of view, there are three basic things needed for life to start and develop[28]: (a) a reasonably uniform temperature; (b) a solvent such as water; and (c) an atom like carbon which is capable of forming complex chains of molecules. For requirements (a) and (b), paleontological evidence shows that the temperature of the sun could not have greatly varied for the past 3.5 billion years, or more[29]. If the sun were a little hotter, the oceans on earth would have evaporated. If it were colder, water would have frozen which could be hostile to the development of life. Requirement (c), on the other hand, leads us to the question of how complex molecules can be formed which are the bases of life.

It is known that the building blocks of life are chainlike molecules called proteins whose basic structural units are the amino acids. In living organisms, amino acids are found in just 20 different varieties.[30] There are several ways, in fact, wherein complex molecules and amino acids can be created in the primitive Earth. We shall mention here two examples.

When Lightning Strikes

In the 1950's, Harold Urey and his student Stanley Miller performed laboratory experiments[31] which simulated the conditions of the primitive earth. They collected a gas mixture resembling the atmosphere of the primitive earth, and subjected it to electrical discharges and flashes of ultraviolet radiation. It was discovered that these types of experiments produce many different amino acids, and other organic compounds that form the basic constituents of the genetic material.

For the young earth, lightning storms where electrical discharges pound on the primitive atmosphere, could have given the original stimulus for life. Rains would then bring these complex molecules from the atmosphere down into the ocean where they can be protected from solar radiation. The oceans, therefore, could serve as primordial wombs that would allow long chains of molecules to undergo different types of chemical combinations, until the first-replicating system signals the origin of life[32]. Through billions of years further mutation, which can be induced by ultraviolet light[33], and natural selection at the molecular level could lead to clever replicating molecules. Complex molecules which are capable of getting sustenance from its environment, and molecules which have developed the capability to repair itself, would have better chances of further developing and surviving for billions of years.

From the Depths of the Ocean

An interesting remnant of the Earth's formation is its very hot core which is sometimes manifested in volcanic eruptions, or the hot springs that we see around us. Deep in the ocean floors, one also finds hot springs called hydrothermal vents[34]. Since the hot water coming out of these vents is rich in minerals, this area is full of marine life including those representing a very primitive class called archaebacteria. This type of bacteria possesses a trait necessary for the earliest organisms to survive – it does not need oxygen. The hydrothermal vents, therefore, are also ideal locations for life on Earth to begin. This idea was first proposed by John Corliss of NASA's Goddard Space Flight Center, who belonged to the team which discovered hydrothermal vents in the 1970's.

Cells from Macromolecules

An important building block found in present-day plants and animals are the cells. How did cells evolve from the macromolecules of the early Earth? For instance, how does one create a cell wall? A useful molecule for building cell walls are those that have a structure where part of it is attracted to water, and another part (which could be its tail) is repelled by water. This attraction for and repulsion from water partly arises from the fact that in electromagnetism, like electrical charges repel, and unlike charges attract. The water-loving part of the molecule is called "hydrophilic" (-phile is from the Greek word "loving"), and the water-fearing part is called "hydrophobic." These types of molecules are also referred to as amphiphilic molecules[35] (-amphi is from the Greek word "both").

Let us consider a large collection of these amphiphilic molecules in the presence of water. Since the hydrophobic tail of each molecule veers away out of contact from water, the net effect of these efforts to avoid water would appear as if the molecules automatically arrange and organize themselves into a specific configuration. To effectively shield the hydrophobic tails from water, the molecules could line up side by side to form sheets. Furthermore, two sheets could lie back to back with the hydrophobic tails pointing inwards and protected between the bi-layer. The tails at the edges of the sheets can further be protected from water if they curl in on themselves. A hollow structure, or spherical vesicle, is then formed. Such *spontaneous* self organization of amphiphilic molecules into vesicles was first observed by Alec Bangham of the Institute of Animal Physiology in Cambridge[36] in 1961. It is therefore possible that, millions of years ago, a similar mechanism which forms a baglike cavity would randomly entrap complex chains of molecules[37]. Further mutations of the trapped molecules inside the vesicle would then be protected by a primitive "cell wall."

The formation of a cell from complex molecules may have taken millions of years, but the first animals[38] which appeared were single-celled oxygen-breathing organisms called protozoa. Millions of years may pass before the first stem cell came into being. How does an organism develop from a single cell? What scientists call stem cells may provide the clue. Let us quote the National Institutes of Health in their description of stem cells[39]:

Stem cells have the remarkable potential to develop into many different cell types in the body. Serving as a sort of repair system for the body, they can theoretically divide without limit. When a stem cell divides, each new cell has the potential to either remain a stem cell or become another type of cell with a more specialized function, such as a muscle cell, a red blood cell, or a brain cell.

How a cell would develop is, of course, encoded in the DNA (Deoxyribonucleic acid) which is a long chainlike molecule. The DNA, however, is commonly found in living things. This brings us to the question of how a human being may be differentiated from the rest of the species.

WHAT MAKES HUMANS HUMAN?

Francis S. Collins, the director of the U. S. National Human Genome Research Institute, has said that:[40]

> *"the entire set of DNA instructions passed on from parent to child had a total of 3.1 billion letters that made up the complex information for each human being. Other animals had the same number, whether they be slime, fish, or chimpanzees."*

As early as 1996, the National Center for Human Genome Research[41] has reported that about 30% of the genes found in yeast are also found in humans. A comparison of the DNA of a fish and that of humans was also made. The Japanese Fugu rubripes (pufferfish), which is a delicacy in Japanese cuisine, has the smallest known genomes among vertebrates. Nonetheless, nearly ¾ of the genes in the human genome have counterparts in the Fugu[42]. Moreover, around 40% of the genes in roundworms, and 75% of those in mouse, also appear in humans. Table 2 illustrates this genetic overlap[43].

ORGANISM	% GENETIC OVERLAP WITH A HUMAN
E. coli	15
Yeast	30
Worm (Nematode)	40
Fruit fly (Drosophila)[44]	70
Fugu rubripes (pufferfish)	75
Mouse	75
Cow	90
Chimpanzee	98.4
Another human	99.9
Sibling	99.95

Table 2. This Table shows the percentage of genes in humans which are also found in other organisms. For example, it shows that 98.4% of our DNA is shared with the chimpanzee.[45]

What is it, therefore, which distinguishes a human being from the other animals? *Intelligence* is not sufficient. Dogs and dolphins have demonstrated a certain level of intelligence. *Memory* is also not a key distinguishing factor. Many animals remember situations dangerous to them. A well-trained dog will always do what it was trained to do. The *Will*, somehow, is also not a trademark of man alone. Animals also demonstrate the will to survive, the will to fight and hunt. What then makes humans human?

In His Own Image and Likeness

We may, perhaps, list some acts of humans which other species are not able to do:

- Whereas birds, for centuries, could only build nests; man has progressively innovated when it comes to building his home – from caves, to huts, to air conditioned buildings, and skyscrapers 110 stories high.

- Unlike animals, man is able to pass on its history to future generations[46], verbally or in written form. We, therefore, learn from past mistakes, build on the works of our predecessors, and progress further.

- Although a man's body was designed not to fly, nor stay underwater for long, he can bypass these limitations. He built planes which could simultaneously fly hundreds of people around the globe. He has even flown men to the moon. He not only designed diving gears which allow him to stay underwater for hours, he also built submarines which stay underwater for days.

- Man has conquered distances by inventing the internet, cellphones, and other gadgets which allow people to communicate *instantaneously* anywhere around the globe.

This list could obviously go on. What is apparent, however, is that man's problem-solving abilities, his creativity**,** sets him apart from the rest of the species. This *creative* feature of man could very well be what is referred to in the phrase, "in God's *own image* and *likeness*."

Creativity may be Mimicked

One needs to be extremely creative to become a world chess champion. The game of chess exacts from the player all his problem-solving abilities. On February 10, 1996, however, the reigning world chess champion, Garry Kasparov, was beaten by a chess playing computer, named Deep Blue[47], under standard chess tournament time controls. Are computers more creative than man? Is the mind of man just a highly sophisticated and advanced computer? Deep Blue, which was developed by IBM, was heavily upgraded after the match, and yet by June 1997, it was only the 259th most powerful supercomputer[48]. In principle, other supercomputers could have been programmed to beat Deep Blue in a game of chess.

It is interesting to note that scientists are now building computers using the DNA. The DNA, of course, contains the program for life. The way the DNA stores information about our genes has, in fact, some similarity to a computer's hard drive. The acknowledged inventor of the DNA computer is Leonard Adleman[49], a computer scientist at the University of Southern California, who first wrote about it in 1994. Although a workable DNA computer may still take years to fully develop, researchers at the University of Rochester have already fabricated logic gates made of DNA. Logic gates are necessary for a computer to carry out its function.

Just as man built submarines and planes to overcome his physical limitations, building computers may be viewed as man's way of overcoming some of his mental limitations. Computers can calculate and analyze data faster. In 1997, Deep Blue was capable of evaluating 200 million positions per second[50]. At present, there is now an on-going race to build the fastest and smallest computers called quantum computers. Computers are obviously *inanimate*, but they can mimic creativity. What is it that humans have those computers seem not to have?

On Feelings and Intuition

A scientist's creative solution of a long-standing problem may manifest initially as an intuition. Feelings and intuitions are normally attributed by many as the factors which set humans apart from robots and computers. It is possible, however, that this emotional tug, and flashes of intuition, which humans experience are due to signals and messages that surface to the conscious mind from the subconscious part of our brain. The intuitions and gut feelings that we have may be an outcome of the *logical* workings of our subconscious mind, even before our conscious mind has thought about it, or is aware of it. Our conscious mind may look at an intuition as illogical, simply because it may not have all the data that the subconscious mind has ready access to. The conscious mind may have already "forgotten" some important details needed to solve a problem.

The exploration and investigation of the subconscious mind is also an active area in brain research. If the subconscious mind operates logically, then its operation is, in principle, also attainable by computers. As science continues to build faster and "more intelligent" computers with a large memory base the following question may become relevant: "Will the future computer-run robots exhibit actions which we would perceive as a display of emotion?" The robot's act may be completely logical based on its huge memory base. This same act, however, may be seen by humans as illogical (which normally characterize emotions) simply because the complete data of the situation may not be accessible to us. A robot programmed to protect itself may appear "angry" if we try to destroy it.

THE MIND OF MAN

Creativity of the human mind appears to be the highest manifestation of man's intellectual activities. Although probing the mind of man is probably one of the most difficult areas of research, we shall present in this section some of our thoughts on this topic.

The First Level of Creativity

After Garry Kasparov lost the first game in 1996 against the chess-playing computer Deep Blue, Kasparov went on to win 3 games and drew 2. The six-game match went in favor of Kasparov with a score of 4 – 2. The following year, a six-game rematch[51] was again played and, this time, Deep Blue won with a score of 3.2 – 2.5. One could learn something from what happened between games. According to the rules, the developers of Deep Blue can modify the computer's program between chess games. In fact, before the second match in 1997, Deep Blue was heavily upgraded. This means that new information regarding Kasparov's playing style, e.g. what traps to avoid, has been fed into Deep Blue's memory bank. The computer, therefore, can *learn from its mistakes*. Since Deep Blue can evaluate 200 million positions per second, it can go through the different priorities it was programmed to do, and select the best strategy. In principle, all the creative series of moves of past chess grandmasters can be stored in a computer's memory and retrieved when necessary. One could imagine a computer surpassing the creativity of any future chess grandmaster once it recognizes familiar chess configurations.

As Kasparov himself remarked, he saw deep intelligence and creativity in the moves of Deep Blue. This kind of creativity is what we would call in this paper as the *first level of creativity*. It is creativity manifested *within* a given set of rules. In this case, the rules are those for the game of chess. There is, however, a *second and higher level* of creativity that is difficult to mimic. This second level is manifested when the human mind allows itself to *shift*, *adapt*, or *re-position* itself to work with a new set of rules or environment. The computer which is programmed to play chess under the standard rules would flounder if, suddenly, we modify the game such that the elimination of the two rooks determines who wins or loses.

Intellective Phase Transitions

In a logical argument, one normally has a premise, as well as the sequence of logical steps that proceeds from the premise to a conclusion. The premise could be a set of axioms or postulates. A computer is a highly logical machine that can outperform humans in speed and breadth of know-how (memory), on the condition that the premise is set and the rules to be followed are laid down. In contrast, humans are extremely far more adept at creating a new premise, or creating a different set of logical rules. This capacity of the human mind to *create a completely different environment*, and still be logically consistent, is what we call the *second level of creativity*. It manifests when one thinks "out of the box." Let us consider some examples.

Changing the Premise

The Greek mathematician Euclid (c. 300 B.C.) postulated that two parallel lines will never intersect. With the help of this postulate, many theorems could be proved. What is now known as Euclidean geometry is essentially characterized by this very important postulate regarding parallel lines. The logical edifice built out of Euclid's postulate would naturally fail if one changes the premise. In fact, a completely new type of logical structure would evolve if one allows parallel lines to intersect. An example of this non-Euclidean geometry is Riemannian geometry. This geometry of curved spaces created by the German mathematician Georg Friedrich Bernhard Riemann (1826-1866) is in fact the geometry crucial to Einstein's theory of general relativity.

Changing the Rules

We are all familiar with the commutative property for multiplying two numbers, x and y. We have, $xy = yx$. Hence, if $x = 3$, and $y = 5$, then $(3)(5) = (5)(3) = 15$. The algebra we learned in high school relies on this property. The human mind, however, is capable of changing the rules and still be logical and consistent. The German mathematician, Hermann Gunther Grassmann (1809-1877), defined numbers which satisfy an anti-commutative property. Given the numbers η and ξ, we have, $\eta\xi = -\xi\eta$. From this it follows that any number squared is zero, i.e., $\eta^2 = \xi^2 = 0$. These so-called Grassmann numbers give rise to the Grassmann algebra[52] now used in describing an electron in quantum relativity.

This human capacity to create new structures by changing the premise, or revising the rules, has helped man come up with novel solutions when faced with the unknown. This second and higher level of creativity, characterized by what we call *intellective phase transitions*, has not only allowed man to survive for many millennia, it has also enabled him to dominate the planet we live in.

LOOKING WITHIN AND SEEING BEYOND

Man's natural curiosity, coupled with his creativity, has given birth to numerous theories which explain the how's and why's of nature. Success in science has mainly been due to the fact that, in the end, only those theories which have experimental support can survive. For the coming decades, what would generally be the frontiers of research where theory and experiment may again complement each other? In this paper, we divide these frontiers into two, and refer to them as the *inbound* and *outbound* frontiers of research.

Inbound Frontiers

The *inbound* research frontiers that we refer to are those which involve the puzzles and unknowns related to the inner functions of human beings, as well as animals. In fact, there would be two categories: one related to the mind and the other concerns the body. How the mind actually thinks and creates is still a puzzle. How is the conscious mind related to the subconscious? Why are dreams necessary? What percentage of the human mind belongs to the subconscious? Is the mind a sophisticated computer? How does the mind control our involuntary actions? Why are we capable of undergoing *intellective phase transitions* which thinking machines may not be capable of doing (see, section 8.2)? Is mental telepathy possible? Is there a way of looking into the future?

If an overlap between science and religion is to be considered, more questions arise. How do prophets see the future? Why is it that when certain saints pray, they levitate (e.g., St. Thomas Aquinas)? Records show that St. Benedict and St. Peter were able to bring back a dead man to life. If God works through His creation, how do saints perform miracles? Is there a scientific explanation for miracles? What enabled St. Peter to walk on water? It is said that, faith as big as a mustard seed can move mountains, how powerful really is the mind?

The second category of *inbound* frontiers involves the workings of our body, like the cells, the proteins, and the DNA. How does the cell know when and how to divide and replicate? What drives a stem cell to become a muscle cell, or a blood cell, or a brain cell, or some other cells in the body (see section 6.3)? Scientists now recognize that long chainlike molecules, or polymers like proteins, can carry out their biological functions *only when they are folded* in a particular way, or when they assume a specific shape[53]. One challenging research area today is the search for solutions to this "protein folding" problem[54]. This area is foreseen to be active for decades to come. We also would like to unravel the mysteries involving the DNA and the genes, so that we could combat diseases more effectively.

Outbound Frontiers

There are also two categories for what we shall call the *outbound* frontiers of research for the next decades. The first is space exploration, and the second involves going into the depths of our oceans.

After sending a man to the moon, we have now landed the Sojourner in Mars. The Sojourner is the name of the first Mars Rover that weighs twenty-two pounds and has six wheels, which crawled on the surface of Mars[55]. These interplanetary investigations also try to answer the question of whether life (no matter how primitive) exists outside our planet. The technology that we learn in interplanetary travels would be needed when we go to the next stage: interstellar travel. As mentioned in section 5.2, our sun is a regular star which inevitably would run out of fuel. If mankind outlasts our sun, interstellar travel would be necessary to further survive.

The depths of our oceans also hold surprises. Recently, the wide variety of marine life found in the seas just off the island of Panglao in Bohol, Philippines, caught the attention of international scientists. The Philippine Deep, which is the deepest part on the surface of the earth, still remains to be fully explored and could hold surprises especially for biologists.

THE FATE OF THE UNIVERSE

In the previous sections, we have traced the history of the universe and the origin of life. We now give a pictorial outline of our discussion in Figure 5.

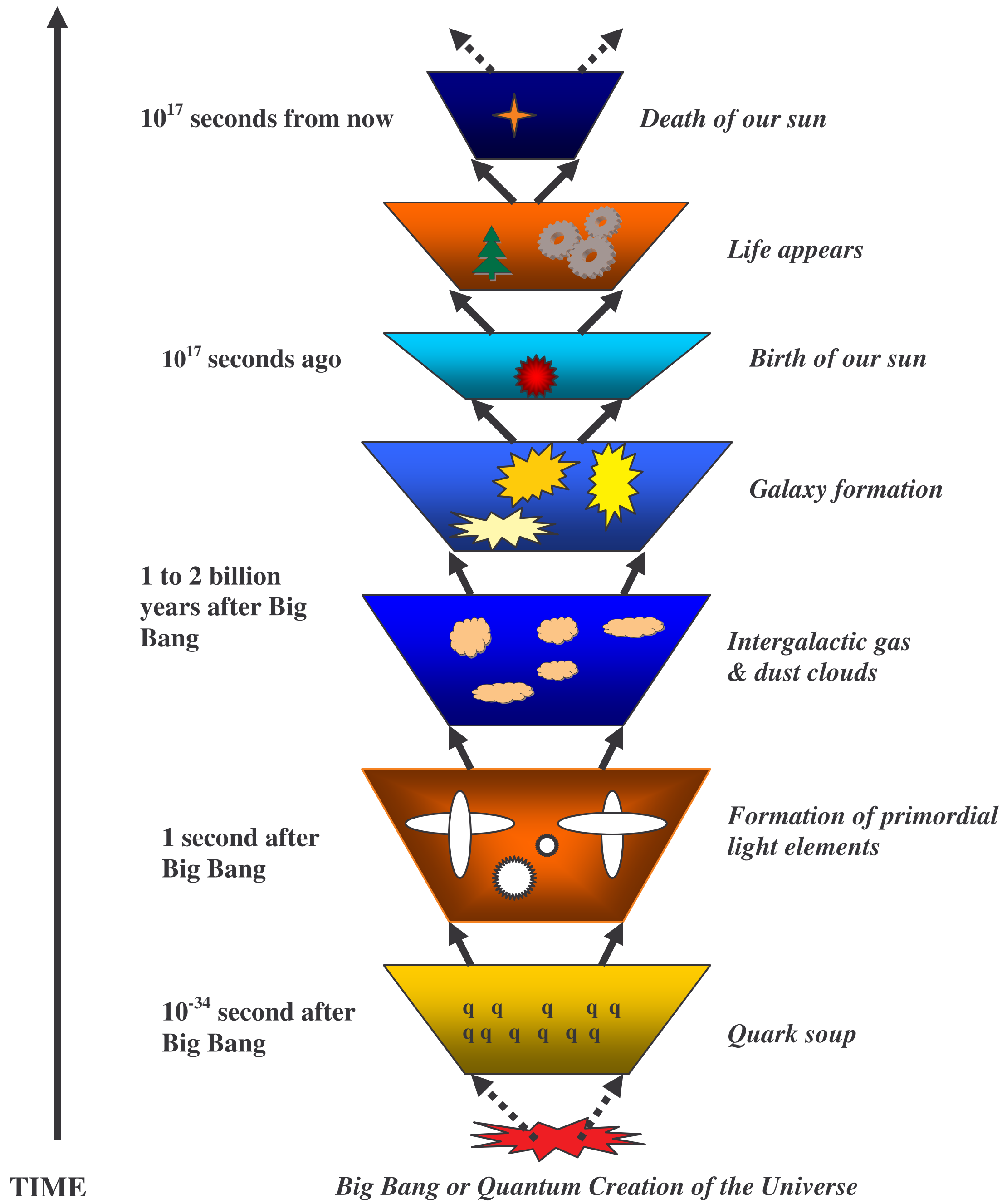


Figure 5. A pictorial representation of the expanding universe and its history[56]

Since the present evolution of the universe is described by general relativity, what does this theory tell us concerning the ultimate fate of the universe? We go back to the FLRW model of an expanding universe which gives us three possibilities: (a) a closed universe; (b) an open universe; and (c) a flat universe. Using a two-dimensional analogy, one could think of a closed universe as something like a ball, or a sphere, which closes in on itself. The open universe, on the other hand, is shaped like the saddle of a horse where part of its contour opens upwards, and perpendicular to it, a curve which goes downwards. One could think of the flat universe as something like a flat sheet of paper.

These three possibilities describe different ways in which the universe may evolve. Note that, because gravity will always attract all matter and energy, the gravitational force will slow down the expansion of the universe. Let us label the matter-energy density of the universe as ρ. If there is enough matter-energy density acted upon by gravity, i.e., $\rho > \rho_c$ (where ρ_c is the critical value[57]), the expansion of the universe would slowly come to a halt, and the gravitational pull will make the universe start to contract. Gravity will dominate until the universe collapses into a single point called the *Big Crunch*. This is how a closed universe would evolve (see Figure 6). On the other hand, if there is not enough matter-energy density in the universe, i.e., $\rho < \rho_c$, then gravity cannot stop the expansion, and the universe will continue to expand forever. This is referred to as an open universe. If the universe contains just the right amount of matter-energy density, i.e., $\rho = \rho_c$, then we have a flat universe. For an open or flat universe, the continuous expansion cools down the universe leading to the *Big Chill* many trillions of years from now where temperatures are near absolute zero. If we plot the increasing size of the universe as time increases, we obtain the graphs in Figure 6.

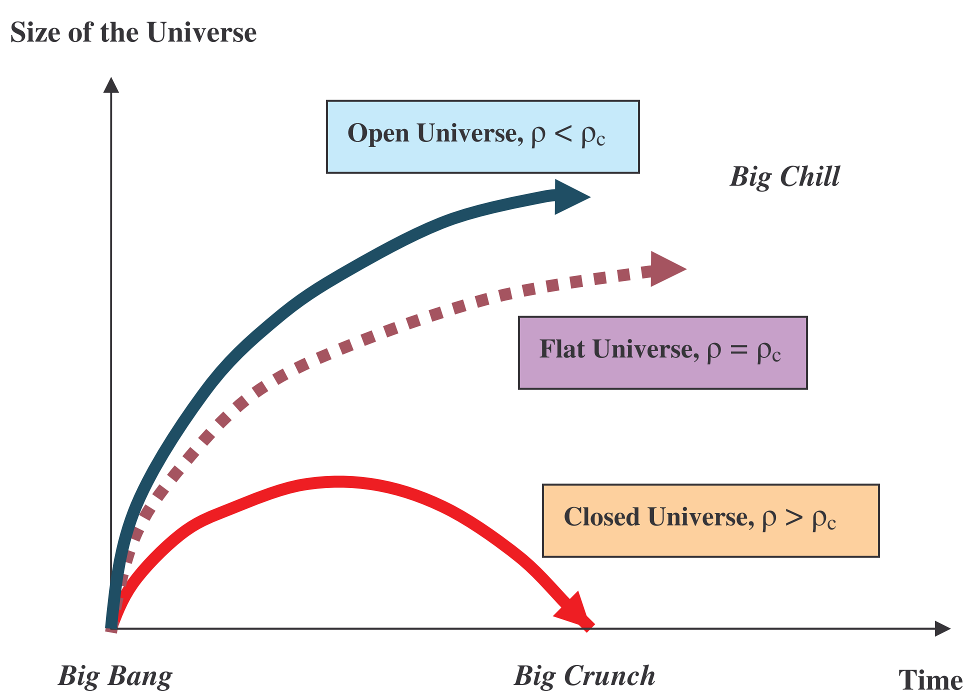


Figure 6. The evolution of the universe may be described by the three types of expansion allowed by the FLRW model.

As to which scenario the universe may be in, physics tells us that the present universe has been finely tuned that it appears very flat. In particular, if ρ is slightly greater than ρ_c , say $\rho \approx \rho_c\ (1+10^{-55})$, then the universe would have collapsed millions of years ago. As can be extrapolated from Table 1, the number 10^{-55} is extremely small. On the other hand, if ρ is slightly lesser than ρ_c , i.e., $\rho \approx \rho_c\ (1-10^{-55})$, then ρ today would be very small and it would have been hard to form our solar system. Life would not have developed, and no one would be discussing about the universe today. Although the universe seems to have the right amount of matter-energy to be flat, a huge portion of ρ still needs to be determined. A very active research area today is the identification of this unknown part of the universe which is non-luminous, and has consequently been called the dark matter[58].

In sum, to explore and understand the origins of life and the universe, the approach of science has been somewhat analogous to that of archaeology. As defined, archaeology means[59] "*the study of ancient cultures, peoples and periods of history by scientific analysis of physical remains….*" The universe today is one big laboratory which exhibits the physical remains of how the universe began. Our surroundings contain the clues of what has happened in the past. Just like detectives investigating a crime, physicists reconstruct and investigate the origin of the universe by using the present observable universe as a constraint in arriving at a correct theory. With the help of quantum mechanics and general relativity, for instance, a proposed theory of the origin of the universe, and its subsequent evolution, should lead to a scenario which does not contradict the present-day structure of galaxies, the cluster of galaxies, the observed abundance of light elements, the 3 Kelvin microwave background radiation, and other physical constraints. A similar approach holds true for investigations on the origin of life. Scientists simulate the conditions of the young earth, and perform experiments which could shed light on how life could have begun. There are still many gaps that remain in our understanding, and many holes to be filled in our never-ending quest for the truth. Counter proposals to what were presented here have also been given.

For the religious, how may one view these dialogues between science and religion? Perhaps the words of St. Paul, as quoted by St. Augustine may help when he remarked on what sort of man a bishop should be: "That he should be strong on sound doctrine, and capable of refuting those who contradict it (Ti 1:9)."[60]

It is often said that, one man's speculation is as good as the other, in the absence of evidence. Hence, the scientific tradition has always been to provide concrete evidence. It is the nature of scientists to leave no stone unturned as long as well-posed questions remain unanswered. Man, it seems, has been programmed to seek for the truth. One can, of course, invoke religion on areas that cannot yet be explained by science. Faith may begin at the point where science ends.[61]

Whatever new laws and designs of nature that science may continue to unravel, one may opt to recall what St. Thomas Aquinas once wrote: (a) There must be a Law-maker; (b) There must be a Designer, and (c) there must be a Creator. There are, however, many ways in which the Creator is perceived by man. For some, God does not interfere with life, but is necessary only to start everything off at the beginning of time. God is the first cause and the universe, as programmed by God, will just evolve on its own. Man, as designed by God, would be the instrument for God's continuing creation (cloning, good or bad, is now a reality). On the other hand, others look at the Creator as a personal God who can interact with man in the universe from time to time. This is especially true in Christianity, which began about 2,005 years ago, when the Word of God became flesh, and the prayer taught by this Son of Man is a rather personal one starting with, "Our Father, who art in Heaven."

The encounters between science and religion, however, have taken their toll on the latter. In advanced countries, for instance, where science and technology are deeply rooted in everyday life, one observes a convent turned into a hotel, a renovated church transformed into a restaurant, and church services attended mainly by the old people. Does progress in science and technology relegate religion into the sidelines? We see how achievements in science may affect an individual in two ways: one concludes that he can do without religion, or one is humbled by the power and beauty of God's creation. In the end, much depends on how man reconciles within himself the dizzying progress of science and the tempering wisdom of the church. Here, the words of St. Bonaventure may serve as a guide … the created universe itself is a ladder leading towards God. Some created things are His traces; others, His image; some of them are material, others spiritual; some temporal, others everlasting: thus some are outside us, and some within.[62]

ENDNOTES

*

Invited talk delivered at the Immaculate Heart of Mary Seminary, Tagbilaran City, Philippines, 14 September 2005.

[1] S. W. Hawking, in *Astrophysical Cosmology*, Pontificia Academiae Scientarium Scripta Varia, 48 (Pontificia Academiae Scientarium, Vatican City, 1982).

[2] S. W. Hawking, "*A Brief History of Time*" (Bantam Books, New York, 1988) p. 122.

[3] Space-time is characterized by its curvature. Singularity means that at a point in space-time the curvature becomes infinite, making it impossible to do further calculations or measurements.

[4] This is equal to – 270.15 degrees Celsius. Note that the temperature in Kelvin is equal to the temperature in the Celsius scale plus 273.15. Hence, 0^{o} C is equal to 273.15 Kelvin.

[5] See, e.g., M. S. Turner and J. A. Tyson, "Cosmology at the Millennium," in *More Things in Heaven and Earth* (The American Physical Society, New York, 1999) p. 245.

[6] See, e.g., J. A. Wheeler, in *Battelle Rencontres*, edited by C. DeWitt and J. A. Wheeler (Benjamin, New York, 1968); B. S. DeWitt, "Quantum theory of gravity,I," *Physical Review* **160** (1967) 1113.

[7] For an exactly solvable model using the path integral formulation, see for example, C. C. Bernido, "Summation-over-histories for the Friedmann universe," *Physical Review* D**54** (1996) 7902.

[8]. E. P. Tryon, *Nature (London)* **246** (1973) 396. See, also, M. G. Albrow, *Nature (London)* **241** (1973) 56.

[9] The total energy for a closed universe is zero, whereas for an open universe it is infinite (ref. 17, p. 388).

[10] J. B. Hartle and S. W. Hawking, "The wave function of the universe," *Physical Review* D**28** (1983) 2960.

[11] Ref. 9 used the transformation from real time t to imaginary time τ (symbolically, $t \rightarrow i\tau$), a technique commonly used in the path integral formulation of quantum mechanics. The imaginary number i is defined as the square root of -1.

[12] A. Vilenkin, *Physics Letters* **B117** (1982) 25; "Birth of inflationary universes," *Physical Review* D**27** (1983) 2848; "Quantum creation of universes," *Physical Review* D**30** (1984) 509.

[13] Hermann Weyl, *Space Time Matter*, (Dover Publications, Inc., New york, (1952).

[14] The antiparticle of the electron, for example, is the positron. The positron (symbolized by e^+) has the same mass and lifetime as the electron (symbolized by e^-). The electric charge of the positron is opposite to that of an electron.

[15] See, e.g., M. S. Turner and J. A. Tyson, "Cosmology at the Millennium," in *More Things in Heaven and Earth* (The American Physical Society, New York, 1999) p. 251.

[16] The deuterium D is an isotope of hydrogen. Hydrogen has a nucleus which contains only a proton. The D, however, has a nucleus which has a proton and a neutron.

[17] M. Kaku, *Visions* (Oxford University Press, 1998), p.323.

[18] Martin Harwit, *Astrophysical Concepts*, 3rd edition (Springer-Verlag, New York, 1998), p.18.

[19] Ibid., p. 12.

[20] Ibid., p. 20.

[21] Ibid., p. 290.

[22] Ibid., p. 293.

[23] Ibid., p. 564.

[24] Ibid., p.290.

[25] Ibid., p. 564.

[26] Philip Ball, *Designing the Molecular World*, (Princeton University Press, New Jersey, 1994), p. 178.

[27] Martin Harwit, *Astrophysical Concepts*, 3rd edition (Springer-Verlag, New York, 1998), p. 290.

[28] Joseph Silk, *The Big Bang* (W. H. Freeman & Co., San Francisco,1980), p. 295.

[29] Martin Harwit, *Astrophysical Concepts*, 3rd edition (Springer-Verlag, New York, 1998), p. 290.

[30] Philip Ball, *Designing the Molecular World*, (Princeton University Press, New Jersey, 1994), p. 261.

[31] Ibid., p. 262.

[32] See also, Joseph Silk, *The Big Bang* (W. H. Freeman & Co., San Francisco,1980), p. 293.

[33] Philip Ball, *Designing the Molecular World*, (Princeton University Press, New Jersey, 1994), p. 184.

[34] Ibid., p. 264.

[35] Ibid., p. 226.

[36] Ibid., p. 233.

[37] See, e.g., http://people.howstuffworks.com/evolution11.htm (Aug. 2005).

[38] Philip Ball, *Designing the Molecular World*, (Princeton University Press, New Jersey, 1994), p. 326.

[39] http://stemcells.nih.gov/info/basics (Aug. 2005)

[40] *Philippine Daily Inquirer*, Feb. 20, 2005, p. H1.

[41] M. Kaku, *Visions* (Oxford University Press, 1998), p. 366.

[42] http://www.lbl.gov/Science-Articles/Archive/JGI-Osolin-Pufferfish-DNA.html (July 2002).

[43] This Table is an augmented version of the one found in M. Kaku, *Visions* (Oxford University Press, 1998), p.153.

[44] http://www.grg.org/FruitFlyDNA2.htm (Aug. 2005)

[45] See, e.g., S. Jones, R. Martin, D. Pilbeam, and S. Bunney, eds., *The Cambridge Encyclopedia of Human Evolution*, (Cambridge University Press, Cambridge, 1992) p. 310.

[46] This was also emphasized by P. Sullivan, *Philippine Daily Inquirer*, Feb. 20, 2005, p. H1.

[47] See, e.g., http://en.wikipedia.org/wiki/Deep_Blue (July 2005).

[48] See, e.g., http://www.top500.org/list/1997/06/

[49] http://computer.howstuffworks.com/dna-computer1.htm (Aug. 2005).

[50] See, e.g., http://en.wikipedia.org/wiki/Deep_Blue (July 2005).

[51] See, e.g., http://en.wikipedia.org/wiki/Deep_Blue (July 2005)

[52] See, e.g., D. Fearnley-Sander, "Hermann Grassmann and the creation of linear algebra," *American Mathematical Monthly*, **86** (1979) pp. 809-817.

[53] The information contained in the linear structure of polymers may be modeled. See, e.g., C. C. Bernido, M. V. Carpio-Bernido, and J. Bornales, "On chirality and length-dependent potentials in polymer entanglements," *Physics Letters* A**339** (2005) 232-236. Also, C. C. Bernido and M. V. Carpio-Bernido, "Entanglement probabilities of

polymers: a white noise functional approach," *Journal of Physics A: Math. Gen.* **36** (2003) 4247-4257.

[54] See, e.g., H. Frauenfelder, P. G. Wolynes, and R. H. Austin, "Biological Physics," in *More Things in Heaven and Earth* (The American Physical Society, New York, 1999) p.713.

[55] See, e.g., M. Kaku, *Visions* (Oxford University Press, 1998), p. 73.

[56] A more technical time-line may be seen in, A. D. Linde, *Rep. Prog. Physics*, **47** (1984) p. 925.

[57] The critical value is $\rho_c \approx 8.4 \times 10^{-30}$ g/cm^3 , or roughly 5 protons per cubic meter (e.g., ref. 5, p.254).

[58] See, e.g., B. Sadoulet, "Deciphering the Nature of Dark Matter," in *More Things in Heaven and Earth* (The American Physical Society, New York, 1999), p.329.

[59] Oxford Advanced Learner's Dictionary, 5th Edition (Oxford University Press, 1995).

[60] St. Augustine, *Teaching Christianity* (Augustinian Heritage Institute, New York, 1996) p. 239.

[61] C. C. Bernido, "Science, God, and Society: Comments" in *Church and Society: Challenges for Tomorrow*, ed. V. R. Gorospe (Quezon City, 1985), p. 48.

[62] "*Itinerarium Mentis*," in *The Works of Bonaventure* (St. Anthony Guild Press, Paterson, N. J.).