One Two Three . . . Infinity: Facts and Speculations of Science Study Guide

One Two Three . . . Infinity: Facts and Speculations of Science by George Gamow

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Plot Summary

"One, Two, Three. . . Infinity - Facts and Speculations of Science" by George Gamow is a work that is jam-packed with facts and information that cover in great detail the advancements man has made and the knowledge he has gained about himself, his world and his universe through the sciences of mathematics and physics.

The book opens with everyone's favorite subject: mathematics. The book contains a history of numbers that begins with how numbers came to be and how they were used in different societies. To the Hottentots in South Africa, numbers were almost meaningless - in fact they only related to and need three numbers. If someone asked a Hottentot tribesman with four or more children how many children he had, his response would be "many." But, of course, in most other cultures, the need arose for a workable numeric system. Roman numerals filled the bill for a time, however, the numerals were too cumbersome and a more proficient numeric system was adapted, the one that is still used today. From that innovation, math took off into many advanced disciplines including: the theory of abstract groups, non-commutable algebra, imaginary numbers, and non-Euclidian geometry.

The book explores the unusual properties of space and how it relates to man and earth. Advancements in math and geometry allowed man to begin the exploration of space without leaving earth. Man was able to devise ways to measure the distances between the earth and moon and the earth and the sun. The reader learns that our three-dimensional world could really be considered a four-dimensional world if the element of time is added to the mix. Discoveries by early physicists and astronomers gave modern scientists and astrophysicists the ability and tools to make major strides in the understanding of deep space and how relatively miniscule our planet really was.

The author does not limit his focus to the vastness and enigmatic nature of outer space. He delves into another unknown world that was much closer to home. Man became curious about the elements and chemicals that make up matter. Science looked deep into the unknown worlds of the atomic and subatomic and discovered the smallest particles in the universe and become to understand that everything, even the largest objects, were comprised of these tiny powerhouses. Man began to look inward and discovered what the differences were between inorganic and organic substances and what made something alive.

Finally, the author looks at the challenges that await man in deep space. Scientists have confirmed the existence of the billions of galaxies and stars in the skies and the planets, some like earth, that in all probability orbit around these distant planets where life as we know it is possible and even probable. The evolution of the sun and stars and ultimately the universe is discussed in great detail. The book appropriately ends on a note of mystery: Is the universe finite or infinite?

Chapter I: Big Numbers

Chapter I: Big Numbers Summary and Analysis

How High Can You Count?

The Hottentot tribes did not have a name for numbers over three. If asked how many children they had and if the answer was more than three, they would answer "many." In advanced civilizations, all we have to do is add zeroes to our heart's content to arrive at the biggest number ever - a number larger than the total number of atoms in the universe or 3 x 1074 . Of course, modern math was not known in ancient times and was only developed some 2,000 years ago by an unknown Indian mathematician. Prior to that, time numbers were represented in Egypt by symbols and in Rome by Roman numerals. For these human ancestors, the grains of sand on a beach or the number of stars in the sky were considered "incalculable." In ancient Greece, Archimedes devised a way to write large numbers that is similar to the system used today. Other historic figures grappled with accounting for large numbers including King Shirham of India who was tricked into supplying infinite bags of wheat by his grand vizer who was a skilled mathematician.

How to Count Infinities

There are some numbers larger than any that can be written no matter how much time and energy is invested. The number of all numbers is infinite. It is difficult for humans who live in a finite world to grasp the concept of infinity. Famous mathematician Georg Cantor is the founder of the mathematics of infinity. It is a feckless undertaking to attempt to compare larger and smaller infinities. Doing so, one can relate back to the thinking of the Hottentots who were happy to say that anything over three was merely "lots."

Cantor theorized that if the number of items in one infinite set of items equals the number of items in another set of items and there are no unmatched numbers, then the two infinite numbers must be considered equal. If there are unpaired numbers that remain, we may assert that one infinite collection of items is larger than the other. In the world of infinity, "a part may be equal to the whole" (p. 17) The famous German mathematician David Hilbert demonstrated that different properties are encountered when working with infinite numbers than when calculating finite amounts. Infinite numbers are denoted by the Hebrew letter aleph. The aleph represents the number of all integers; the aleph with a subscript of "1" represents the number of all geometrical points and the aleph with the subscript of "2" represents the number of all curves.

Chapter II: Natural and Artificial Numbers

Chapter II: Natural and Artificial Numbers Summary and Analysis

The Purest Mathematics

Among scientific disciplines, mathematics is considered the Queen of all Sciences and stands alone when compared to other branches of knowledge. However, other sciences, like physics, try to establish a fraternity with the "Queen." Math is certainly used to explain the elements of the physical universe. These mathematical disciplines include "the theory of abstract groups, non-commutable algebra and non-Euclidian geometry" (p. 24)

The purest form of mathematics, one that remains useless to any discipline outside of itself, is the theory of numbers which is one of the oldest and most complex results of pure mathematics. Within the discipline itself, some of its propositions are considered experimental and unproven. On the subject of prime numbers, the discipline took on the question as to whether or not the number of prime numbers was unlimited. Prime numbers are those than cannot be represented as the product of two or more smaller numbers. Euclid asserted that there was no such thing as the largest prime. However, modern mathematics demonstrated through reduction to a contradiction (or proving that something cannot be false) that the number of primes is infinite. A method of listing such infinite primes was first addressed by Greek philosopher and mathematician Eratosthenes and is referred to as "the sieve." However, finding a general formula to produce only primes still eludes mathematicians.

Another theorem of the theory of numbers that has never been proved or disproved is the Goldbach conjecture which was proposed in 1742. This theory states that each even number is represented by two prime numbers. The Russian mathematician Schnirelman took a step toward providing proof. He was able to provide proof that each even number is the sum of "not more than 300,000 primes." Another Russian mathematical genius, Vinogradoff, was able to reduce the conclusion to the sum of four prime numbers. But no further progress has been made yet and may never be.

Another question addressed under the discipline of the theory of numbers is whether the percentage of primes remains constant no matter the size of the number. The laws governing the median distribution of primes represents a remarkable discovery in the science of mathematics: "The percentage of primes with an interval from 1 to any larger number N, is approximately stated by the natural logarithm of N1." (29) The theory was proven in the 19th century by French mathematician Hadamard.

The roots of the Great Theorem of Fermat extend back to ancient Egypt. The theory is not necessarily connected to prime numbers. The theory stated that in any equation like xn + yn = zn, where n is larger than 2, there is no solution. No one has been able to prove the theory despite reward money being offered to do so. The theory could be wrong and obviously is not easy to prove or disprove.

The Mysterious Square Root of Negative One

Is there a square root of a negative number? Twelfth century mathematician Brahmin Bhaskara responded to the question by asserting that there is no square root of a negative number because a "negative number is not a square" (p. 32) But through the years, the issue of a square of negative numbers kept emerging. Sixteenth century Italian mathematician Cardan was the first to include the square root of a negative number in a formula. He used the negative square to produce a result of 40 by splitting the number ten into two parts. After Cardan dared to use the square root of negative numbers, or imaginary numbers as they came to be known as, other mathematicians began to use them. The family of imaginary numbers represents a mirror image of real numbers starting with the basic unit of the square root of negative one which is indicated by the symbol "i." There are practical applications of imaginary numbers. By using the square root of -1, it was discovered that space and time could be united into a four-dimensional image, which ultimately played a role in Einstein's theory of relativity.

Chapter III: Unusual Properties of Space

Chapter III: Unusual Properties of Space Summary and Analysis

Dimensions and Co-ordinates

Everyone can conjure up an image of space but what does the word actually mean. It could be termed as that which surrounds us. It could be further defined by referring to the three directions it contains. In a three-dimensional world, we can move forward or back, up and or down and right or left. Coordinates can pinpoint a destination within a space. It is difficult for man to conceptualize superspaces in which there are more than three dimensions. It is easier for man to think in terms of subspaces in which there are less than three dimensions, i.e., two dimensional surfaces and one-dimensional lines.

Geometry without Measure

Ordinary geometry involves the numerical relationship between distances and angles. However, the fundamental property of space does not require the measurement of lengths or angles. The branch of geometry that is used to understand and define space is known as analysis situs or topology. It is one of the most difficult mathematical disciplines to grasp. Put simply, it is the relationship expression of a closed geometrical surface and does not require a measurement of lengths and areas; rather, it focuses on the number of geometrical units involved. Geometrical units include vertices, edges and faces.

The relationship between the number of geometrical units was first noted by seventeenth century French mathematician Rene Descartes. Later, mathematician Leonard Euler provided definitive proof Descartes' relationship theory. Another typical topological problem that is closely associated with Euler's theorem is the "problem of the four colors." (51) This problem involves dividing a sphere into separate regions and coloring these regions so that no two adjacent regions that have common borders have the same color. Thorough experimentation it has been proven that as few as four different colors are required to accomplish this task no matter how large the sphere and how many separate areas it contains. Since numbers and areas are involved, it would follow that a calculation or formula could be devised to state this fact mathematically. However, mathematics can only prove that five colors suffice although the four color concept can be proved manually.

Turning Space Inside Out

What happens if the "four colors" concept is taken to a three-dimensional level? In order to address this question, one has to think outside the box, to imagine three-dimensional spaces that are different than those found in straight Euclidian geometry. A spherical surface has no boundaries but is a finite area. Imagine that two apples are forced together and joined only at their skins. The result would be an apple within an apple. As a way of determining the material needed to apply the "four colors" concept to a three-dimensional object, apple-eating sets of worms, one black and one white, would eat through both apples, creating channels that started from an area on the surface to an area on the other side of the apple. The sets of worms would create independent channels without interfering with each other.

These channels would be unhindered and could be traveled from where they started to their final destination without obstruction. All available areas of the sphere would be turned into channels. The result wold be a labyrinth of channels inside the two apples that had been forged together. If the worms chewed a whole in the middle of the joined apples, a doughnut-shaped sphere would result. In either case, the skins could be removed from the apples and laid out flat allowing for the number of different materials needed to be determined. Such an experiment has never been done, of course. It is just a mental exercise in imaginative geometry that can prepare the mind to understand exotic elements such as curved space and space closed on itself.

Another element that is part of the general properties of space are right and left-handed bodies. A pair of gloves are completely identical except that they are mirror images of each other. However, a left-handed glove will not fit properly on a right-hand and vice versa. Other objects with similar restrictions include shoes and golf clubs. Objects such as tennis rackets and tea cups are not bound by left or right requirements and can be used unencumbered by a left-handed or right-handed person. Objects like the tea cup possess a plane of symmetry that can be cut into two identical parts. Objects like gloves do not have such a symmetry and cannot be cut into identical halves. Asymmetrical items such as the glove is bound into a left- and right-handed modification. Asymmetrical objects appear in both man-made objects and in nature. A right-handed object can be turned into a left-handed object by taking it out of known space into the fourth dimension (using one's imagination) rotating it and putting it back as a left-handed object. On a two-dimensional plane, the "surface of Mobius" could be used to turn right to left. The Mobius theory states that on a twisted surface a right-handed object can be turned into a left-handed one by carrying it around and through the twist.

Chapter IV: The World of Four Dimensions

Chapter IV: The World of Four Dimensions Summary and Analysis

Time is a Fourth Dimension

The concept of a fourth dimension is difficult if not impossible for humans to understand. How can a four-dimensional object become part of our world? We are able to place a three-dimensional object into a two-dimensional plane by drawing a picture of it on a piece of paper. This process is is referred to as geometrical projection. By using geometrical projection, we can squeeze a four-dimensional object into our three-dimensional world without part of it sticking out. We can project a three-dimensional cube onto a plane and find that it assumes a form with two squares, one inside the other. The projection of a four-dimensional supercube would produce a form consisting of a cube within a cube connected by the vertices.

The plane projection of an ordinary sphere is formed by placing two flat discs together. To imagine a supersphere, one must envision one sphere within another and joined at the outer surface - just like the apples in the previous chapter. Although this imagery allows us to conceptualize the properties of a fourth dimension, we cannot really imagine a fourth independent direction in our physical space.

But an element that can be referred to as a fourth dimension already exists in our world - time. Space and time are used to describe most things in our world. Dates and times and when or where are integral parts of our lives. Therefore, everything that exists has three dimensions in space and one in time. If a cube is built and exists for one month and then is disassembled, each line that was used to form the cube existed for one month and still exists in time. In the language of four-dimensional space-time geometry, the line that represents the history of each individual particle is called its "world-line" (p. 72)

Time-Space Equivalent

A problem arises when considering time as the fourth dimension and as equal to the three spatial dimensions. The units to measure space and time are different. All the physical dimensions of a form can be measured in the same units such as in inches or miles. Since time is measured in minutes and seconds, how can space and time be compared in order to establish a commonality? Length and time could be compared by measuring the distance from point A to B in miles and then learning the time it takes to travel from point A to B at a certain rate of speed. This rate of speed, or standard velocity, is what is used to compare space and time. The only reliable velocity known in physics is the speed of light also known as the "propagation velocity of physical interactions" (p. 75)

The first attempt to measure the speed of light was made by Galileo Galilei in the seventeenth century. He was unsuccessful in arriving at a solid provable theory; however, his discoveries of the moons of Jupiter provided the basis for measuring the speed of light. In 1675, Danish astronomer Roemer noticed differences in time intervals in the eclipses of Jupiter's moons. He ultimately concluded that these differences were based on the relative distances between earth and Jupiter at the time of the eclipses. From his work, it was established that the speed of light is about one hundred and eighty-five thousand miles per second. The French physicist Fizeau created a device to measure the speed of light at small distances. Through the work of these early scientists, modern astronomers can measure the distances between celestial objects. Using the speed of light, one light mile is equal to .0000054 seconds and one light foot is equal to .0000000011 seconds. Therefore, the supercube discussed earlier with an area of 1 ft x 1 ft x 1ft has a time dimension of 00000000.1 second.

Four-Dimensional Distance

The Pythagorean theorem states that the distance between two points is the square root of the sum of the squares of the individual distances. Using this theory and adding time as a fourth coordinate can determine the four-dimensional distance between two objects or events. But in order to do so, unconventional ways must be devised to preserve some of their natural differences. Einstein weighed in on this issue and concluded that the difference between space and time can be determined by using the general Pythagorean theorem but adding the negative sign in front of the square of the time element. Four-dimensional distance can be defined as the square root of the sum of the squares of all four coordinate distances.

Chapter V: Relativity of Space and Time

Chapter V: Relativity of Space and Time Summary and Analysis

Turning Space into Time and Vice Versa

Space distances and time intervals between two separate events must be imagined as projections on the space-time axis. The rotation of the four-dimensional axis-cross may result in at least the partial transformation of distances into durations and vice versa. The separations in space and time can be reflected when two fixed events are projected on the space-time axis. Common sense or conventional wisdom says that in order to plot the space and time of an event observed from a moving object, the time axis must be adjusted according to the object's speed but the space axis must remain untouched. However, that theory is contradicted by newer theories that demands that the time axis remains perpendicular to the three spaces axes no matter what the perspective.

Science is at a crossroads as to whether to accept the conventional wisdom or follow newer theories that says the space axis must be turned with the time axis so that the two are always both perpendicular. If the latter is adhered to, it means that the space separation of two events has different values when observed from a moving object. Adjusting the space axis would mean that the time separation when observed from a moving object would differ from that observed from a stationary point.

Since speed is a variable, two events occurring at the same place but at two different times will be observed as appearing at two different places if the observers are in a different state of motion or non-motion. The opposite is also true: two events occurring at the same time but at two different places will be observed as appearing at two different times if the observers are in a different state of motion or non-motion.

Ether Wind, and Sirius Trip

If modern science persists in using the language of four-dimensional geometry, the entire system of classical physics as developed by Sir Isaac Newton will be challenged. Newton's theory is: "Absolute space, in its own nature, without relation to anything external, remains always similar and immovable." (88) This principal held for centuries until contradictory facts repeatedly emerged through experiments and research. The first monumental strike against classical physics came about from the work of American physicist, A. A. Michelson in 1887. Michelson found that light represents a wave motion traveling through the ether which is the interstellar space and intervals between atoms. But what the properties of "light ether" is has not yet been defined. One false assumption in the experimentation in the nineteenth century was that the light ether was comprised of the same properties as those we are familiar with. These early scientists assumed that light ether reacted as a solid during the propagation of light but behaved as a liquid when pushing through the light of faraway stars and planets. Science knows today that the mechanical properties of ordinary substances are based on the atomic structure. Today, the light ether is simply called space.

It would seem logical that a man standing on earth should feel the "ether wind" because the earth is spinning and orbiting but he does not because this "ether wind" slips unnoticed in between atoms. Michelson worked to develop a device that could record the differences in velocity of light moving in different directions. His apparatus used the zero-point method for measuring the speed of light in directions perpendicular to one another. After much work and research, he was surprised to learn that the ether wind had absolutely no impact on the speed of light.

Classical physics tells us to expect some contraction of material bodies that move through a resisting medium. A boat racing through water is slightly squeezed bow to stern. Of course the strength of the material that the boat is made of will influence the size of the contraction. Variations in contraction due to the material that his apparatus was made of were apparently responsible for the failure of Michelson's experiments. Einstein explained this phenomenon in 1904 as follows: "We deal here with the contraction of space itself, and all material bodies moving with the same speed contract in the same way simply because they are imbedded in the same contracted space" (p. 97)

The ether wind and the effect of space shrinking that man experiences is so miniscule that it goes unnoticed. The contraction, or shortening of length, is based on the movement of two systems with respect to one another. This shrinkage is only substantial as the speed of a moving object approaches the speed of light. Likewise, the expansion of time is only perceptible at a velocity near the speed of light. If an object moves so fast that the contraction causes its length to be reduced to one-half, that means that time intervals become twice as long. This is what the theory that space travelers won't age as fast as those on earth is based on. There is nothing faster in the universe than the speed of light - no object can travel at a speed that equals or exceeds the speed of light.

Curved Space, and the Riddle of Gravity

The curvature of a three-dimensional object can be calculated by a scientist by measuring the angles between the straight lines connecting three points in that space. If the sum of the three angels equals 180 degrees, the space is flat. If the sum does not equal 180 degrees then the space is curved. A straight line, or geodesic, is the shortest distance between two lines. Einstein's general theory of curved space assumes that larger physical spaces become curved and the bigger the mass the bigger the curve. Einstein's theory also addressed the relationship between curved space and universal gravity. Since our three-dimensional world is really a four-dimensional world of space and time, Einstein came to the conclusion that "the phenomenon of gravity is merely the effect of the curvature of the four-dimensional space-time world." (109) Thus, the traditional concept of gravity can be replaced by the geometry of space.

Chapter VI: Descending Staircase

Chapter VI: Descending Staircase Summary and Analysis

The Greek Idea

In studying the structure of matter, the properties of heterogeneous materials is the first step toward understanding. In the cases of substances like copper or glass, a probing microscope will not find any varying properties. But strong magnification reveals a micro-crystalline structure in copper and most other substances. Ancient Greek philosopher Democritus believed that no matter how homogenous matter looked it was probably formed from small separate particles which he dubbed "atoms" or "indivisibles." He called them indivisibles because he theorized that nothing could be smaller. Democritus thought all atoms were the same. His colleague, Empedocles, differed and thought there were different atoms which configured in different combinations and amounts to create different substances. Empedocles listed the four basic elements as fire, water, air and rocks. As we know today, there are 92 different chemical elements - 92 different atoms. The combining of the different atoms in different amounts is what creates all of nature's substances.

How Large Are the Atoms?

Chemists think of atoms in terms of their complex relationships with other atoms. Physicists think of them in terms of size and weight. Determining the size and weight of atoms is a simple process in which a substance is expanded and stretched until a chain of single atoms is exposed.

Molecular Beams

The molecular structure of a substance can be discovered by studying the outflow of vapors and gases through small apertures into its surrounding space. The stream of matter of low vapor density is known as the "molecular beam" and is formed by separate molecules. Such a beam can be used to measure the velocity of heat. A device that captured the velocity of molecular beams was built by Ottto Stern who was able to prove that the velocity of molecular motion increases with the temperature of gas. This proves the kinetic theory of heat which states that the increase of heat in a body is really the increase of molecular motion.

Atomic Photography

British physicist W. L. Bragg developed a method of photographing single atoms and molecules contains in crystalline bodies. Photographing atoms and molecules seemed impossible until Bragg created a way to capture their images by mimicking the functioning of the microscope. Several prints are taken and then layered to form the final composite photo. Using Bragg's method, pictures can be taken of crystals in which molecules remain still. Molecules cannot be photographed in liquids or gases because of their natural movement in those elements.

Dissecting the Atom

Democritus gave the atom its name which meant "indivisible" because he thought he had discovered the smallest particle, one which could not be reduced to a smaller size. Many centuries later, the concept that the atom was indivisible was rejected. Modern science also discovered that atoms had different shapes. The atoms of hydrogen are spherical while the atoms of sodium are elongated ellipsoids. The variations of optical spectra of elements was attributed to the difference of the vibration frequencies of the different shaped atoms.

The attempts to explain the properties of atoms hit a brick wall until it was realized that atoms were not not simple structures. There were things going on inside of the atoms. British physicist J. J. Thomson discovered that the chemical elements of atoms consisted of positively and negatively charged parts. The atom maintained its structure by electrical attraction. The atom was electrically neutral because the negative charge equaled the positive charge. Negative particles were called electrons. An imbalance between positive and negative charged particles, it results in either extra electrons or negative ions or extra positive particles referred to as positive ions. Thomson learned the nature of individual particles by extracting them from atoms and studying beams of freed electrons at high speeds. Through this process Thomson was able to estimate their mass.

In 1911, Rutherford demonstrated, through his renowned experiments on the scattering of alpha particles, that the positive charge of the atom and most of its mass was located in an extremely small nucleus in the center of the atom. He disproved Thomson's theory that a tiny atomic nucleus was in the center of the atom and negative electrons were on the outside. He envisioned the structure of the atom to resemble a tiny solar system with the atomic nucleus at the center and the electrons orbiting it. The differences between atoms were their internal structures specifically the number of electrons rotating around the nucleus. The heavier the atom the more electrons it has. The numerical designation of an atom is known as the atomic number. The electric attraction between two charged ions combine to form more complex elements. For example, a charged ion of sodium with cling to a charged ion of chlorine to form sodium chloride or table salt.

Micromechanics and the Uncertainty Principle

There was concern that energy within an atomic structure could eventually be depleted. Once kinetic energy was exhausted, it was theorized that the atom would collapse. However, experiments showed that the atomic systems were stable and that electrons continued orbiting without a loss of energy. Science was looked to explain why there was not a natural loss of energy within the atomic structure. But scientists were incorrect when they first tried to apply the laws of classical mechanics to the orbiting electrons in the atomic system. It was concluded that the application of classical mechanics could not be applied in a structure as small as the atom. The new science of micromechanics considers the motion of particles in the same way that modern optics considers the propagation of light waves through observation of the waves of electromagnetic energy.

Chapter VII: Modern Alchemy

Chapter VII: Modern Alchemy Summary and Analysis

Elementary Particles

Is the atomic nuclei the ultimate in simple structures or can it be divided further? English chemist, William Prout, hypothesized that the "atoms of all different chemical elements have a common nature representing only various degrees of concentration of hydrogen atoms" (p. 149). Since oxygen is 16 times heavier than hydrogen, it must contain 16 hydrogen atoms. Iodine has an atomic weight of 127 and therefore must be formed from 127 hydrogen atoms. Many scientists at the time disregarded his theory. Prout did not live long enough to learn that he was right. British physicist F. W. Aston proved that chlorine was comprised of two kinds of chlorine atoms with identical chemical properties but with different atomic weights.

Elements with identical chemical components but different weights are referred to as isotopes. Translating Prout's theory into today's scientific language results in this theory: "The nuclei of different atomic species are composed of various numbers of elementary hydrogen nuclei, which, because of their role in the structure of matter, were given the special name of 'protons' (p. 150). Protons without charge are called neutrons. Protons and neutrons should not be considered as different particles; rather, they are the same basic particle in different electrical states. Collectively, they are called nucleons. Protons can turn into neutrons by losing their positive charge and neutrons can turn into protons by taking on that positive charge. A century after Prout conceptualized his theory, modern science has tweaked it to state that all known substances are the result of different combinations of two kinds of fundamental particles: nucleons and electrons. The neutron represents the basic unit of matter. Positive electrons actually do exist in nature. Negative protons may exist as well but it has not been proven. If a negative proton does exist in nature, it could be formed by a neutron that acquired a negative charge or lost a positive one.

The reason that positive and negative particles are rare outside the atom is that their positive and negative states cancel each other out and do not leave too many rogue particles behind. The energy is not destroyed, however, only changed. That energy cannot be created or destroyed is the most fundamental law of physics.

If negative protons exist, the assumption can be made that the atoms and molecules are on the inverted scheme. Inverted atoms have identical properties as that of other atoms but their nuclei having been constructed from neutrons and negative protons and have positive electrons surrounding them. However, they would have the same chemical make-up as other like atoms and could not be distinguished from them. Once two such opposite substances are brought together mutual annihilation will immediately occur as in the atomic bomb.

Neutrinos were discovered when something was missing from an atomic structure. And that missing thing was energy. And since energy can't be destroyed it was concluded that it was stolen and the thieves were called neutrinos. These particles are too small and fast-moving to capture. However, the secondary effect of these neutrinos can be observed.

Can the elements of an atom - nucleons, electrons, neutrinos and electromagnetic waves - be subdivided? At this point, the consensus is that these are the smallest particles in the universe and that they cannot be subdivided. However, scientific theories have been proven to be wrong before.

The Heart of the Atom

The heart of every atom is the nucleus. In the atomic nucleus there are cohesive forces interacting between separate nucleons that prevent the nucleus from breaking up from the action of electric repulsion between protons. In contrast to the outer body of the atom where electrons have space to move about, the nucleus is comprised of a large number of nucleons packed tightly creating a dense liquid. The nuclei of different elements, therefore, can be considered to be various sized droplets of "nuclear fluid" that are electrically charged. If surface-tension forces dominate, two nuclei coming in contact with one another have a tendency to fuse. If the electric forces of repulsion prevail, the nucleus will break apart in two or more parts at a high rate of speed. This breaking up process is called fission.

Bohr and Wheeler in 1939 made the important conclusion that the surface tension forces are dominant in the first half of the periodic table up to silver while the electric repulsive forces prevail for the heavier nuclei. Therefore, the lower half of the periodic table contains unstable elements that are prone to break apart and release a substantial amount of internal nuclear energy. Two nuclei of the lighter elements have a tendency to fuse. Neither nuclear fission or fusion can take place without human action. Both these processes are considered to be in a state of metastability, meaning that without an initial excitation neither process could get underway. Although the threat of nuclear explosion is an ever present one in our world, some comfort can be found in the fact that a nuclear reaction is a very difficult process to begin.

Atom Smashing

A true understanding of the complexity of the atom could not be attained without breaking it into two or more parts. In 1896, Becquerel discovered radioactivity. It was found that the release of radiation from the atoms of elements such as uranium and thorium occurs due to the slow decay of the atoms. This decay resulted in the atoms breaking into two unequal parts: an alpha particle, a small remnant of the atomic nucleus of helium; and the large portion representing the remainder of the nucleus. In uranium two free charges of electricity were emitted. The original nucleus of the lead atom was stable and showed no signs of decay. Only the heaviest elements that have a tendency to break up spontaneously result in the emission of radioactivity. The discovery of the break-up of nuclei and the resultant radioactive release was proof of the complexity of the atomic structure. Rutherford went a step further and and created an apparatus to bombard the atoms and produced the same result as the natural decay of the nuclei.

After Rutherford's experiment, the science of the artificial transformation of elements became an important branch of physics. Wilson invented the cloud chamber that allowed scientists to see what happened when a nuclear projectile hit a nucleus. Other devices such as the electrostatic generator, a cyclotron and a linear accelerator were all developed by scientists to study the atomic structure.

Nucleonics

Nucleonics is the science of practical applications for nuclear energy that has been liberated on a large scale. A major goal of nucleonics was to discover an effective way to sustain a nuclear reaction by the production of consecutive generations of neutrons. Experimentation led to the conclusion that the light isotope of uranium, U-235, was the only brand of nuclei to which progressive branching chain reactions was possible. In order to be able to use the energy of U-235, it had to be separated from the heavier nuclei of U-238 or a way had to be devised of neutralizing the action of the heaver nuclei without removing them.

Chapter VIII: The Law of Disorder

Chapter VIII: The Law of Disorder Summary and Analysis

When water is magnified a few million times, a granular structure formed by separate molecules is revealed and the molecules are see to be in a state of violent agitation. This movement in water or any substance is called heat (or thermal) motion. The motion of molecules in the nervous fibers is what causes us to feel heat. The English botanist Robert Brown noticed he could study plant spores in liquid or smoke or dust floating in the air. The Brownian motion was discovered by the scientist when he applied heat to the tiny particles and caused them to move even more violently. It was discovered that at -273 centigrade, or absolute zero, all molecules come to rest. Molecules reach their melting point at varying degrees depending on the cohesive forces acting upon them. To take a clear photo of molecules, cooler temperatures are needed to keep them inactive.

Molecules stay in tact after solid material melts. But as temperatures increase, the molecules fly apart in all directions. The higher the melting point of a substance, the higher its boiling point is as well. When a crystalline structure of solid material breaks up, the molecules first crawl around like worms but ultimately fly apart. No molecules are left when the temperature reaches several thousand degrees. The matter becomes gas. Collisions of molecules at high temperatures causes the breaking up of the molecules and damage to the atoms. Thermal ionization occurs when the temperature rises into tens and hundreds of thousand degrees of temperature. Thermal agitation causes the sequential destruction of the architecture of matter based on quantum law. It results in the chaotic collision of molecules that apparently follows no order or law of physics.

How Can One Describe Disorderly Motion?

The radical behavior of agitated molecules, or thermal motion, led to the establishment of the Law of Disorder or the Law of Statistical Behavior. Calculations to predict thermal motion provide the most probable results which are based in part on statistical data and the process of diffusion which is one of the most important processes in molecular physics. The process of diffusion is a slow one as seen in the example of light coming from the center of the sun. It takes 50 years for light to travel from the center of the sun to its surface because of all its many collisions with neutrons and electrons in the material of the sun. Once it reaches the surface, the same light travels unencumbered from the sun's surface to earth in eight minutes.

Counting Probabilities

Diffusion represents only one example of the application of the law of statistical probability on the issue of molecular motion. In the law of probability, it is a 50-50 proposition that you'll get heads or tails in a coin toss. If you increase the number of coins or toss the coins more often, there are more possibilities. The laws of probability become more exact the larger the number of trials that take place. Probability calculus can also be used to predict the potential of getting the poker hand you want. The smaller the number involved in the sampling, the less reliable the results.

The "Mysterious" Entropy

The laws of probability are most applicable in the world of molecules just by the sheer number of the particles that exist. The Law of Entropy rules the thermal behavior of every entity in the universe. The Law declares: "Any spontaneous changes in a physical system occur in the direction of increasing entropy and the final state of equilibrium corresponds to the maximum possible value of the entropy" (p. 226). It is the second law of thermodynamics; the first being the Law of Conservation of Energy. The Law of Entropy could also be called the Law of Increasing Disorder. The entropy reaches its "maximum when the position and velocities of molecules are distributed completely at random so that any attempt to introduce some order in their motion would lead to the decrease of the entropy" (p. 226).

Entropy can be increased in one part of a body by decreasing it in another part even though it may cause the motion in the other part more disorderly.

Chapter IX: The Riddle of Life

Chapter IX: The Riddle of Life Summary and Analysis

We Are Made of Cells

What constitutes the differences between living and nonliving matter? Understanding an automobile, we must take it apart to learn about its functioning. Like the car, to understand a complex living organism like the human body, its parts and their functioning must first be understood before a conclusion can be drawn about the entire body. Various types of tissues are the building blocks of complex living organisms. A knowledge of the atoms which the tissue is comprised of is essential. The elementary structural units of every tissue of the body are cells which could also be called biological atoms. The average-sized human body is comprised of several hundred thousand billion separate cells. A fly or an ant has a few hundred million cells. There is also a large class of mono-cellular organisms - one-celled organisms - such as amoebae and fungi and various types of bacteria.

The living cell has three basic functions: it assimilates necessary materials for its structure; turns these materials into substances used for growth; and, divides into two similar cells when it becomes too large. Some inorganic substances have some of these functions. A small salt crystal dropped into a salt solution in water will grow by taking on salt molecules extracted from the water. An increase of weight will cause the crystal to break into two pieces. Baby crystals will continue to grow. But life is a more complicated example of ordinary physical and chemical phenomena. There are stark differences in the example. The crystal has a mechanical accretion of material not a biochemical assimilation. The crystal breaks apart from external forces while the living cells split into half by internal forces.

The living cell is the simplest living organism. Through an atomic microscope, one can observe that a cell is made of a transparent jelly-like material. It looks simple but it has a complex chemical make-up known as protoplasm. Each cell has a nucleus formed by a network of chromatin. All the cells in the body contain exactly the same number of chromosomes. More highly developed species have more chromosomes. The number of chromosomes is always even. Each body has identical sets of chromosomes, one from the father and one from the mother both of which contain hereditary coding. Chromosomes initiate cell division. Newly produced "baby" cells will grow to the size of their "mother" then begin further division. The forces behind this process are basically unknown. The rapid growth and development of a new born being is due to cell division. Once a body is fully developed, the cells are at rest other than for occasional cell replacement and upkeep.

A special type of cell leads to the formation of "gametes" or "marrying cells" which are the basic cells required for reproduction. At its very earliest stage, cells are "set aside" for reproduction and are stored in reproductive organs. These cells go through very little division staying fresh and new for the reproductive process. The chromosomes in these cells do not split but are pulled apart so that each side receives only one-half of the original chromosome. This process is known as "meiosis" while the normal cell division process is called "mitosis." The cells that result form meiosis are sperm cells and egg cells or male and female gametes.

Hereditary and Genes

The union of a pair of gametes from two parents grows and develops into a similar, not exact, replica of its parents. The science of genetics is the study of characteristics transferred from parents to children. The laws of heredity have mathematical simplicity. Color blindness, like other conditions, results from a defect in the X chromosome. The female cells possess two X-chromosomes and the male cells possess one X and one Y chromosome. Hereditary properties such as color blindness can be carried by recessive genes from grandparents to grandchildren. Dominant characteristics become noticeable when only one chromosome of the pair is affected.

Genes as "Living Molecules"

The fundamentals of life reside in a set of genes hidden in the deep interior of its cells. An average chromosome is about a thousandth of a millimeter thick. One chromosome is thought to be responsible for as many as several thousand different hereditary properties. Each gene is constructed from about one million atoms. The gene is the smallest unit of a living organism and cannot be subdivided further but are linked to complex molecules that fall under the laws of basic chemistry. It could be said that the gene is the missing link between organic and inorganic matter. In the case of a gene molecule, the structure is so complex that there are many unknowns about it.

In 1902 Dutch biologist de Vries discovered that "spontaneous hereditary changes in living organisms always take place in the form of discontinuous jumps known as mutations" (p. 260). For example, the average fruit fly has a gray body and long wings. However, once in a while a mutated fly with a black body and short wings will occur. Characteristics in a living organism will either show no change or a big change or mutation. Changes in characteristics along with the struggle for existence as sited by Charles Darwin lead to evolution.

The biological units known as viruses are free genes without a cell surrounding them. Viruses are collections of large numbers of individual particles, all the same size and smaller than bacteria. The reproductive process of viruses seems to mimic that of the doubling of chromosomes in cell division. Viruses are vulnerable to mutation which are passed along to offspring. Such mutated viruses can cause epidemics of influenza because humans have not built up immunity to the new mutation. Experimental work has been done in synthesizing living organisms by using viruses.

Chapter X: Expanding Horizons

Chapter X: Expanding Horizons Summary and Analysis

The Earth and Its Neighborhood

In ancient times, the earth was believed to be a flat disc and the universe relatively small - just big enough to surround earth. Aristotle was the first to assert that the earth was a sphere made up of land and water and surrounded by air. There was harsh rejection of his theory. In books published late into the fifteenth century, some 2,000 years after Aristotle, still scoffed at the idea of a round earth. When Magellan sailed around the world, the round-earth theory began to see growing support. Greek scientist Eratosthenes estimated the size of the earth by using the position of the sun and the shadows it cast. His estimates proved to be surprisingly accurate. Parallactic displacement was used to measure the distance of the earth to the moon and from the earth to the sun. Astronomers have concluded that the distance to the sun is 92,870,000 miles. Using the same method, astronomers are able to estimate the distance to other planets and stars.

The Galaxy of Stars

In 1838, German astronomer Bessel noticed via parallactic displacement that the star 61 Cygni was very small and was 690,000 times farther away than the sun. Light from the sun takes eight minutes to arrive at earth's surface while the light from 69 Cygni takes eleven years. Knowing the distance of the star, an estimate of its size was made as being slightly smaller than the sun. The closest star to earth other than the sun is alpha-Centauri which is 4.3 light years away. Stars have been found to vary greatly in size and luminosity. Betelgeuse is 300 light-years away and about 400 times larger and 3600 times brighter than our sun. A faint dwarf called Van Maanene's star is 13 light-years away and is smaller than earth and about 20,000 times fainter than the sun.

There are about 2,000 stars that are visible to the naked eye each night. With a pair of field binoculars, another 50,000 stars can be observed. A 2.5 inch telescope would reveal a million more. Using the 100-inch Mt. Wilson telescope about a half-billion stars would come into focus. British astronomer William Herschel discovered the Milky Way which was thought to be merely space gas before he discerned it was actually a band of stars so far away that they appeared to be gas. It was ultimately estimated that our stellar system contains about 40 billion stars. The billions of stars forming the Milky Way Galaxy move around the dark, cloudy galactic center.

Copernicus was the first to conclude that earth and the other planets were orbiting the sun. Dutch astronomer Oort discovered the orbiting of the stars around the galactic center of the Milky Way. From the measurements of the Oort effect, it was determined that it takes the sun 200 million years to orbit the galactic center.

Toward the Limits of the Unknown

There are many other galaxies in addition to the Milky Way. The closest of these galaxies is the Andromeda Nebula. For many years, distant galaxies were confused with large masses of stellar dust. They were too far away for a parallactic measurement to be taken. A new way to measure these distances was devised by Harvard astronomer Harlow Shapley by focusing on the pulsating stars or Cepheids. He was able to devise a way to measure the distance to these pulsating stars by observing the time between pulsation periods. The vast distances that he was able to calculate demonstrated that the galaxies were much larger and father away than first imagined.

Closer scrutiny revealed that there were a great variety of galaxies. There are spherical galaxies, elliptical with different degrees of elongation, spirals with tight and loose bodies. There seemed to be an evolution of galaxies from the spherical to the opened spiral. American astronomer Edwin Hubble proved that galaxies are scattered uniformly throughout space. However, there are instances when as many as 1,000 galaxies are clustered like stars similar to how stars cluster in some galaxies. The average space between two galaxies is 5 million light years.

Is the universe finite or infinite? Dr. Hubble discovered that the number of galaxies increase more slowly in the distance which could indicate a curvature and the finiteness of space. The curvature is very small. The luminosity of stars grows fainter at greater distances indicating the possible aging of the galaxies billions of light years away. Much work still has to be done to determine whether the universe is infinite.

Chapter XI: The Days of Creation

Chapter XI: The Days of Creation Summary and Analysis

The Birth of Planets

Although there is solid ground on earth, it is just a relatively thin layer over a molten earth - the way the planet began. The temperature of the earth must reach the melting point of rocks (between 1200 and 1800 degrees Celsius) at a depth of only 50 km beneath the earth's surface. It is estimated that 97 percent of the earth's body must be in a molten state. The earth is still in a cooling state which it is estimated began several billion years ago.

In 1749 the French naturalist George-Louis Leclerc, opined that the planetary system resulted from a collision of a comet with the sun. A short time later, German philosopher Immanuel Kant disagreed feeling that the planetary system developed without any intervention by another celestial body; that the sun's cooling created gaseous rings that surrounded it forming the blueprint for the planetary system. Over the centuries, there have been many theories and much debate about how the planetary system was created.

But in 1943, German physicist C. Weizsacker developed the modern concept based on information collected through astrophysical research. New knowledge about the chemical make-up of matter in the universe led to the theory that when the sun condensed, a mass of material existed outside of it creating a large rotating structure that surrounded it. This material eventually settled into separate rings that contained dust and debris. The dust and debris eventually formed into the planets. Since the forming planets were under constant attack from cosmic matter, their bodies remained hot.

When the supply of dust and debris was finally depleted, the earth and other planets began to cool. Mathematical calculations revealed that each planetary orbit is approximately twice as large as that of the orbit nearest to it and toward the system's solar center. The moon and the satellites of other planets underwent a similar process during their formations. It was also Weizsacker's theory that the development of our solar system was not a unique event; rather, it was a process that must have taken place in the formation of all the stars. It appears that all stars possess planetary systems leading to the logical conclusion that there must be literally millions of planets just within our galaxy alone. Since all the complicated molecules and chemicals that create life existed on the cooling planets all over the galaxy and universe, it follows that life, as we know it, undoubtedly developed in other worlds and galaxies.

The Private Life of the Stars

What is the life cycle of the sun and other stars? The sun is a rather old star and a typical star of the Milky Way. The sun is 6000 degrees C at the surface and in the neighborhood of 20 million degrees at its center. Two nuclear physicists, H. Bethe and C. Weizsacker, discovered the nuclear process known as the carbon-cycle which is responsible for the energy production that takes place in the sun. This thermonuclear process is not a single event. It is a sequence of reactions in a closed circular stage that loops back to its starting point every six steps. The elements involved in this process are the nuclei of carbon and nitrogen. These nuclei are forever being regenerated and act as catalysts for the thermonuclear process. Bethe was able to demonstrate that the energy liberation of the reaction chain at 20 million degrees matched the volume of energy radiated by the sun. M. Schwartzschild discovered that over half of the solar matter is formed by pure hydrogen, less than half of the other half by pure helium and the relatively small amount of remaining matter by all other elements.

What astrophysicists have learned about the sun can, of course, be applied to many other stars. However, there are different types of stars. The "red giant" developed its large dimensions due to internal forces that are not completely known. Although they are large, red giants aren't as dense as other smaller stars. "White dwarfs" are much smaller than our sun but much denser and represent the late stages of stellar evolution. Once the star has depleted its hydrogen supply, the body of the star begins to contract and go through a series of phases in which density is ever increasing. The last stage of the life of such a star is its transformation to a "black dwarf" which is fundamentally a dead star. The end of life for some stars, generally larger stars, can be in a supernova explosion. Remnants of such explosions that took place millions and billions of years ago can still be seen in our skies. An astronomer who spots a star that is brighter than normal, could indicate that the star is beginning the process toward explosion.

The first supernova explosion that was recorded outside our galaxy was in 1885 in the Great Andromeda Nebula galaxy. A supernova explosion begins with a rapid expanding of its gaseous outer shell. The famous Crab Nebula is the remnant of a supernova explosion in 1054. The nebula was formed by the gas that was expelled with the star exploded. The process is begun when a star's hydrogen is depleted, the star expands and then begins to collapse on itself.

Primordial Chaos and the Expanding Universe

Can we assume that the universe always existed and always will? Is there an evolutionary process at work in the universe as a whole? The definitive answer is that the universe is and has been undergoing change. We can see the evolution process of the stars and in the supernova explosions that have left their permanent marks in our sky. Even though astrophysicists toss around terms in the millions and billions of years when speaking of the formation of the stars and sun, the fact that these celestial bodies have ages indicate that they had a beginning and from the dead stars that they have an end. From the supernova explosions and black dwarfs we know that celestial bodies have endings as well. Elements found in outer space such as thorium and uranium are known to be in various stages of decay. We can assume that the heavy nuclei was all formed in some past epoch.

For many years, the universe was thought to be several billion years old. There have been many changes and an evolutionary process of some order has been taking place since then. Relying on the Doppler effect, which captures the movement of distant celestial bodies, scientists confirm that the stars seem to be moving away from us. In other words, the universe is still expanding. The more likely age of the universe has be adjusted from several billion years old to five or more billion years old. The kinetic energy of the receding galaxies is greater than their gravitational energy. It would follow that our universe is expanding into infinity and has no chance of contracting back to a former stage.

Characters

Albert Einstein

Albert Einstein played a huge role in the advancement of the sciences of physics and mathematics. Einstein developed many theories but his theory of relativity and his general theory of relativity are the best known to the general public. He included the concept of curved space in his general theory of relativity. The theory made the assumption that the "physical space becomes curved in the neighborhood of large masses." Einstein had come to the conclusion that "the phenomenon of gravity is merely the effect of the curvature of the four-dimensional space-time world." A big problem that faced Einstein in reconciling his general theory of relativity was the dilemma of whether the universe was finite and infinite.

Contraction is a physical phenomenon that Einstein dealt with in developing some of his theories. Some contraction of a material body moving through a resisting medium is an expected result. A boat racing through water will contract slightly in length depending on the rate speed and the material of the boat. Albert Einstein weighed in on this subject in 1904 when he was a university professor. Einstein is quoted as saying, "We deal here with the contraction of space itself, and all material bodies moving with the same speed contract in the same way simply because they are imbedded in the same contracted space."

H. Bethe and C. Weizsacke

H. Bethe and C. Weizsacker were two German nuclear scientists who simultaneously discovered the carbon-cycle. The carbon-cycle is the nuclear process which is responsible for the energy production that takes place in the sun and the stars. This thermonuclear process is not limited to a single event. Rather; the process is a sequence of reactions, or reaction chain, that take place in a closed circular stage that loops around continuously to maintain the flow of energy.

Bethe was able to demonstrate that the energy liberation of the reaction chain at 20 million degrees matched the volume of energy radiated by the sun.

It was Weizsacker's theory that the development of our solar system was not a unique event. The physicist felt the solar system was created during the cooling stage of our sun. In the fall of 1943, Weizsacker cut through the Gordian Knot of the planetary theory. He used new information that had been gathered by other astrophysicists and that a detailed theory of the origins of the planets could be developed.

Edwin Hubble

American astronomer Edwin Hubble proved that galaxies were scattered uniformly throughout space. The Hubble Telescope was named after him.

Aristotle

Aristotle was among the first to offer the theory that the earth was a sphere and that there was a vastness that was far beyond just a nice covering for us.

Democritus

Ancient Greek philosopher Democritus believed that no matter how homogenous matter looked it was probably formed from small separate particles which he dubbed "atoms" or "indivisibles."

Ernest Rutherford

Physicist Ernest Rutherford is known as the father of nuclear physics. He demonstrated that the positive charge of the atom and most of its mass was located in an extremely small nucleus in the center of the atom.

Isaac Newton

Sir Isaac Newton theory on space and time: "Absolute space, in its own nature, without relation to anything external, remains always similar and immovable," has been challenged by modern advancements.

Galileo Galilei

In the seventeenth century, Galileo Galilei made the first attempt to measure the speed of light but was unsuccessful in developing a provable theory. However, Galileo's discoveries of the moons of Jupiter provided the basis for measuring the speed of light.

Archimedes

Archimedes invented a numerical system that would accommodate the writing of large numbers that is similar to the modern one used today.

Georg Cantor

Georg Cantor is the founder of the mathematics of infinity. Cantor theorized that if the number of items in one infinite set of items equals the number of items in another set of items and there are no unmatched numbers, then the two infinite numbers must be considered equal.

Objects/Places

The Theory of Numbers

The purest form of mathematics, one that remains useless to any discipline outside of itself, is the theory of numbers which is one of the oldest and most complex results of pure mathematics.

Analysis Situs or Topology

The branch of geometry that is used to understand and define space is known as analysis situs or topology. It is one of the most difficult mathematical disciplines to grasp.

Geometrical Projection

A three-dimensional object can be placed into a two-dimensional plane by drawing a picture of it on a piece of paper. This process is is referred to as geometrical projection and facilities the concept of the fourth dimension.

Contraction

Contraction occurs when a material body moves through a medium of resistance.

Molecular Beam

The stream of matter of low vapor density is known as the "molecular beam" and is formed by separate molecules.

Micromechanics

The new science of micromechanics considers the motion of particles by observation of the waves of electromagnetic energy.

Neutrinos

Neutrinos were discovered when energy was missing from an atomic structure. And since energy can't be destroyed it was concluded that it was stolen and the thieves were called neutrinos. These particles are too small and fast-moving to capture. However, the secondary effect of these neutrinos is observable.

The Law of Entropy

The Law of Entropy rules the thermal behavior of every entity in the universe. The Law declares: "Any spontaneous changes in a physical system occur in the direction of increasing entropy and the final state of equilibrium corresponds to the maximum possible value of the entropy."

Genes

The fundamentals of life reside in a set of genes hidden in the deep interior of its cells.

Milky Way

The solar system is located in the spiral galaxy known as the Milky Way. It is one of billions of galaxies in the universe.

Themes

The Basics

After craning their necks for decades and taking in the stars and sun and moon and wondering about them, early scientists began to look closer to home. They became curious about much smaller things than the glorious celestial objects. Ancient Greek philosopher Democritus was ahead of his time when he theorized that despite how homogenous matter appeared to be it was probably formed from small separate particles which he dubbed "atoms." Democritus named the small particles "atoms" which translated to "indivisibles" because he believed that these tiny atoms could not be further reduced. On that part, he was wrong but he was right that those small particles that he dubbed atoms were everywhere and that they were the basic building blocks of the entire universe.

Democritus was wrong about something else. He thought all atoms were the same. His colleague, Empedocles, differed and thought there were different atoms which configured in different combinations and amounts to create different substances. Empedocles listed the four basic elements as fire, water, air and rocks. As we know today, there are 92 different chemical elements - 92 different atoms. The combining of the different atoms in different amounts is what creates all of nature's substances.

The curiosity of these early scientists led to the discovery of the elements. The periodic table contains all the elements that are found throughout the universe. These elements are the foundation for all matter and were essential for the the development of the earth, stars and galaxies and for life itself.

Evolution

A thread that runs through this book of facts and speculation is change, even evolution. Charles Darwin, author of "Origin of the Species" is mentioned only briefly in this account. Darwin focused on biological evolution but this book contains the story of the evolution of the planets, stars and even galaxies. If one looks closely enough, there are connections between many things in the universe. For example, the electrons in an atom orbit the nucleus just as the planets orbit the sun. Is that a coincidence or part of a plan? Since animals go through evolution and change through the ages, it follows that inorganic matter could as well. After all, everything in the universe is composed of atoms.

There are vivid descriptions of the earth being born and evolving. The different evolutionary stages of the sun and stars from birth to death are described in this work. Physicists have devised ways to measure the size and distance of stars as well as the ages of some of the celestial objects. Red giants are aging stars that expand into a less dense sphere before they begin to collapse upon themselves. Although the process takes thousands of years, the star will eventually contract to a black dwarf, or dead star, when it loses all its nuclear energy. A larger star like a blue giant might meet its evolutionary end in a blaze of glory known as a supernova explosion.

Galaxies, like the Milky Way, go through an evolutionary process as well. Different stages of galaxy life is seen in the types of these vast celestial bodies. Some galaxies are tight spheres, others are elliptical and some are open spirals. Scientists theorize that all galaxies started out as tight spheres and through the eons of their existence began to "unwind." The transformation of galaxies is another sign of evolutionary change.

The universe is ever-expanding. Scientists verify that stars and galaxies are receding from the earth which indicates the universe's expansion. Since signs of evolution seems to be everywhere, the question begs if the universe is also in a stage of its own evolution.

Man's Challenges

Reading "One, Two, Three. . . Infinity - Facts and Speculations of Science" by George Gamow gives the reader a great understanding of what man has learned about himself and his place in the universe. There is also a theme of the challenges that have faced man throughout time. While it is true that we have gained much knowledge thanks to our mathematicians and scientists, it is also true that there is so much that we don't know. There's an old adage that says: The more we know the less we understand. No saying could be more apt for the challenges that man has faced and faces to understand the vast universe in which we are but a tiny dot.

Early man was challenged with a way to account for his possessions and valuables. Roman numerals were created and satisfied this need for a time. However, as life and society became more complex, a more efficient system was needed and man met the challenge and created the numeric system we have today. From basic numbers, man was challenged to develop more and more complex disciplines of mathematics in order to advance our culture and learn more about the earth and the space around it. Once again, man responded to the call.

Scientists understood that our world was a three-dimensional one but also knew that to understand space and the vast universe, that they had to take on the challenge of a fourth dimension. After much research and experimentation, physicists decided that by the inclusion of time as another dimension to our spatial three-dimensional world, allowing us to advance our understanding of space and time and relativity. To learn more about matter and humankind, science was challenged to look into the atomic and subatomic world. Scientists made great inroads and discoveries and unleashed unimagined energy by discovering the unseen universe of the smallest particles in existence.

Deep space presented and still presents the biggest challenge to man. Astrophysicists and scientists learned about space and gained more knowledge for the edification and benefit of mankind. The largest challenge yet to face man is the question about the nature of the universe. Is the universe infinite or finite? Man developed a mathematical discipline of infinite numbers - will that advancement allow us to embrace the infinite on a larger scale? Scientists have grappled with the question of infinity and theories and speculation are emerging but there is no definitive answer yet by judging from the past, mankind is up to that challenge.

Style

Perspective

"One, Two, Three. . . Infinity - Facts and Speculations of Science" by George Gamow is written from the third-person perspective. George Gamow is a nuclear physicist and is more than qualified to present the theories and information that are contained in this book. Gamow was one of the world's foremost physicists. Among other advancements, Gamow discovered the theory of radioactive decay. Gamow is touted by the Saturday Review of Literature for his "remarkable ability to combine technical accuracy, choice of material, dignity of expression and readability," in the writing of this book.

Gamow also served as the illustrator for the book. It is obvious that the book was prepared with much care and respect. His hand drawn illustrations are not those of a professional artist but the charm with which they were sketched more than makes up for it.

This book was written in 1960. Since that time, there have been many advancements in science and physics that of course are not included in this book. Gamow has a wealth of information and facts in this book and it should be looked to as a valuable historical work. However, since it was written over fifty years ago, the reader needs to recognize that for the latest update on the advancements made in nuclear and astrophysics, newer material needs to be obtained and studied.

Tone

"One, Two, Three. . . Infinity - Facts and Speculations of Science" by George Gamow presents a history of mathematics and science with detailed descriptions, examples and illustrations to help the reader with subjects that are very complex and unfamiliar to the majority of the population. Since Gamow is a physicist himself, he of course has the necessary background and understanding to grasp the subject matter and explain it in a through manner.

There is a professorial tone to the work which is understandable since Gamow has such an intimate knowledge of the subject matter. Anyone who opts to read this book should expect to read and re-read certain sections because of the depth of detail and lengthy explanations and descriptions. The book is more text book than it is a straight read. Gamow provided the illustrations for the book himself. They are very helpful in gaining more understanding of the subject matters and there is a generous amount of illustrations found throughout the book.

Gamow has amassed a wealth of information in one work. It is obvious that he has great respect for the scientists who came before him and for the pioneering work and advancements that have been made in the most challenging and important aspects of mankind's existence.

Structure

"One, Two, Three. . . Infinity - Facts and Speculations of Science" by George Gamow is separated into four major parts. Part I. "Playing with Numbers" is focused on the history of the science of mathematics, its advancements and applications in the modern world. Part I has two chapters: Big Numbers and Natural and Artificial Numbers. Part II. "Space, Time & Einstein" concentrates on the role of physics and mathematics in the exploration and understanding of space. This part has three chapters: Unusual Properties of Space, The World of Four Dimensions and Relativity of Space and Time.

Part III "Microcosmos" delves into the atomic world and into the elements and chemicals and how organic and inorganic substances are created. This section has four chapters: Descending Staircase, Modern Alchemy, The Law of Disorder and The Riddle of Life. Part IV. "Macrocosmos" explores the universe, the life of stars and infinity. It has two chapters: Expanding Horizons and The Days of Creation.

The book is laid out in basically a chronological order in that material covered in one chapter builds on the information covered in previous chapters. Throughout the entire work there are many plates and illustrations. The illustrations are the handiwork of author Gamow. There is a preface written by the author and a detailed index that follows the last section.

Quotes

"There are some who, without regarding the number as infinite, yet think that no number can be named which is great enough to exceed that which would designate the number of the Earth's grains of sand" (Chapter I, p. 6).

"Mathematics is usually considered, especially by mathematicians, the Queen of all Sciences and, being a queen, it naturally tries t avoid morganatic relations with other branches of knowledge" (Chapter II, p. 24).

"We all know what space is, although we should find ourselves in a rather awkward position if we weer asked to define exactly what we mean by the word. We should probably say that space is that which surrounds us, and through which we can move forward or backward, right or left, up or down" (Chapter III, p. 41).

"The concept of the fourth dimension is usually surrounded by mystery and suspicion. How dare we, creatures of length, height, and width, speak of four dimensional space" (Chapter IV, p. 64).

"We see that from the point of view of four-dimensional space-time geometry the topography and the history of the universe fuse into one harmonious picture, and all we have to consider is a tangled bunch of world lines representing the motion of individual atoms, animals or stars" (Chapter IV, p. 73).

"Einstein came to the remarkable conclusion that the phenomenon of gravity is merely the effect of the curvature of the four-dimensional space-time world." (Chapter V, p. 109).

"The existence of neutrinos was discovered by a method that a mathematician would call 'reductio ad absurdum.' the exciting discovery began, not with the fact that something was there, but rather that something was missing" (Chapter VII, p. 158).

"Although molecular motion as well as molecules themselves are not directly discernible to the human eye, it is molecular motion that produces a certain irritation in the nervous fibers of the human organism and produces the sensation that we call heat" (Chapter VIII, p. 192).

"The average distance between two neighboring galaxies is about 5,000,000 light-years and the visible horizons of the universe contain about several billion individual stellar worlds" (Chapter IX, p. 294).

"From the star 61 Cygni, which is one of our nearest cosmic neighbors, the light travels to the Earth for about 11 years. If, because of some cosmic catastrophe the light form 61 Cygni were extinguished, or it were to explode in a sudden flash of fire, we should have to wait for 11 long years until the flash of the explosion, speeding the the interstellar space, and its last expiring ray finally brought to earth the latest cosmic news that a star had ceased to exist" (Chapter X, p. 279).

"Shall we consider the universe as extending into infinity and conclude that bigger and better telescopes will always reveal to the inquiring eye of an astronomer new and hitherto unexplored regions of space, or must we believe, on the contrary, that the universe occupies some very big but nevertheless finite volume, and is, at least in principle, explorable down to the last star" (Chapter IX, p. 294).

"If, as it appears now, each star possesses a system of planets, there must be millions of planets within our galaxy alone...and it would be at least strange if life - even in its highest forms - ha d failed to develop in these 'inhabitable' worlds" (Chapter XI, p. 313).

Topics for Discussion

Explain the life of a star? What is a "black dwarf?" What is a supernova explosion? How do each of these stages evolve?

What is infinity? Why is it a difficult for humans to grasp? Is the universe infinite?

Name items that have one dimension, two dimensions and three dimensions? How many dimensions exist on planet earth?

What is the fourth dimension? How is the fourth dimension measured accurately against the other three dimensions?

What is an atom? What is contained in the atomic structure? What are the smallest particles known to man on earth or in the universe? Can they subdivided?

What are the differences between inorganic and organic substances? What occurs during the process of cell splitting? What is a gene? What role does the gene play in living beings? Why doesn't an elephant mother have a zebra baby?

What is the Law of Disorder? What is the Law of Entropy? Describe the natural motion of molecules? What is the motion of molecules when heat is introduced into their space?

What is nuclear fission? What is nuclear fusion?