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Theory of Everything: The Generation Model

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Abstract: The main purpose of this paper is to present the long history of the quest to understand both the composition and the structure of the Universe in terms of the nature of the building blocks of the constituent ordinary matter and the nature of the forces acting between these elementary particles. This quest is essentially to find a 'Theory of Everything', i.e. a single framework, which describes all the forces of the cosmos and their interactions between the elementary particles constituting the ordinary matter of the Universe. The long history of the above quest for a 'Theory of Everything' is discussed critically with regard to the merit of the essential contributions made towards the 'Final Theory'. In particular, the negative aspects of each contribution, especially the dubious assumptions that caused the quest to fail to achieve an appropriate 'Theory of Everything' in terms of the Standard Model (SM) of particle physics and the Standard Model of Cosmology (SMC) will be discussed in detail. Furthermore, it will be demonstrated that the development of an alternative model of particle physics, termed the Generation Model (GM), primarily to overcome many deficiencies of the SM, leads to a successful 'Theory of Everything'.

1. INTRODUCTION

According to historical records, the quest to understand both the composition and the structure of the Universe has so far lasted for over 2500 years. The nature of the Universe is dependent primarily upon two properties: (1) the nature of the building blocks, i.e. the elementary particles, of the constituent ordinary matter; and (2) the nature of the forces acting between these elementary particles. This quest is referred to, in several different ways, as a quest to find a 'Theory of Everything', or a 'Final Theory', i.e. a single framework that would describe all the forces of the cosmos and their interactions between the elementary particles of the constituent ordinary matter of the Universes [1-6].

In this paper, the long history of the above quest for a 'Theory of Everything' will be discussed critically with regard to the merit of each of the essential contributions made towards the 'Final Theory'. Both the positive and negative aspects of each contribution will be considered. In particular, the negative aspects of each contribution, especially the dubious assumptions that caused the quest to fail to achieve an appropriate 'Theory of Everything' in terms of the Standard Model (SM) of particle physics and the Standard Model of Cosmology (SMC) will be discussed in detail. Furthermore, it will be demonstrated that the development of an alternative model of particle physics, termed the Generation Model (GM), primarily to overcome many deficiencies of the SM, leads to a successful 'Theory of Everything'.

As discussed in Reference 6, progress in the understanding of the nature of the Universe will be divided into three eras: (i) the era of classical physics, which is assumed to run from antiquity (ca.600BC) until about 1895 and is associated with the macroscopic world in which only the gravitational and electromagnetic forces are evident from direct experience because of their long-range nature, and ordinary matter was considered to be composed of atoms; (ii) the era of transitional physics, 1895-1932, in which several discoveries were made, which could not be reconciled with classical physics and indicated the need for new physics; and (iii) the era of modern physics, 1932 to the present day, which is associated mainly with the microscopic (subatomic) world in which both the weak nuclear and the strong nuclear short-range forces operate.

In 2000, the understanding of the nature of the Universe was based primarily upon two important theoretical models: (1) the Standard Model (SM) of particle physics, and (2) the Standard Model of Cosmology (SMC)[7]. Both these models, based primarily upon observations, were essentially completed during the 20th century and were developed employing two new theories, *relativity theory* and *quantum mechanics* that originated in the earlier years of the 20th century.

2. HISTORY OF THE QUEST FOR A THEORY OF EVERYTHING

2.1 Era of Classical Physics

Newton's Laws of Motion and His Universal Theory of Gravity

It is generally agreed that the first major step in the quest for a 'Theory of Everything' begins with Isaac Newton (1642-1727), who formulated laws of motion, that were not improved upon for over 200 years. In particular, in 1687, he announced his three laws of motion and his universal theory of gravity in his book, "The Mathematical Principles of Natural Philosophy", generally known as the *Principia*, considered by many physicists to be the most influential physics book ever written. The essence of Newton's ideas was to propose a unified theory that encompassed both motion in the heavens and motion on the Earth. Newton's laws of motion have been generally confirmed.

Newton showed that according to his universal law of gravitation, the gravitational force of attraction between any two spherical bodies of matter acts in direct proportion to the product of their masses and decreases in inverse proportion to the square of their distance apart: indeed, he showed that the planets, which are approximately spherical bodies, move on elliptical orbits around the spherical Sun, in agreement with the three laws of Johannes Kepler (1571-1630). In the 19th century, Newton's laws of motion were employed by astronomers to discover the planet Neptune in 1846. In addition, Newton's laws not only unlocked the motion of the planets and comets, but also laid the foundation of the laws of mechanics, which today are used on the Earth to design buildings, planes, trains, rockets, etc.

Unfortunately, Newton declared in his *Principia* that he could not understand the *cause* of the gravitational force. I have called this the *enigma* associated with the gravitational force [6].

Newton had explained the mathematics rather than the physics of the phenomena described by the universal law of gravitation, i.e. *how* the gravitational force of attraction acts between any two spherical bodies but it does not explain *why* the universal law of gravitation provides a good description of many natural phenomena [6]. This is the main failure of Newtonian mechanics concerning the quest, and is responsible for the failure of Newtonian mechanics for distances large compared with the Solar System.

Atomic Matter

In 1808 [8] John Dalton (1766-1844) established the atomic theory of ordinary matter based upon the ideas of ancient Greek philosophers Leucippus (ca.480-420BC) and his pupil Democritus (ca.460-370BC), who considered that ordinary matter is composed of discrete units, which they named *atoms* from the Greek word *ατομοσ* meaning *indivisible*.

Dalton's atomic theory assumed: (1) all matter is made of atoms that are indestructible and indivisible; (2) all atoms of a particular element have the same mass and chemical properties; (3) atoms of different elements have different masses and different chemical properties; (4) chemical compounds consist of two or more different kinds of atoms and (5) a chemical reaction is a rearrangement of atoms.

Furthermore, Dalton found that each atom of an element was characterized by its measured relative atomic weight and he fixed that the hydrogen atom had a notional relative atomic weight of 1, so that all other elemental atoms could be calculated relative to this figure. By 1810 Dalton had managed to establish the relative atomic weights of 20 elemental atoms.

By 1818 Jöns Berzelius (1779-1848), one of the earliest to accept Dalton's atomic theory, had determined the relative atomic weights for 45 of the 49 accepted elements. In addition, Berzelius had noticed that elements appeared to have different electrical affinities and also that there appeared to be groups of different kinds of elements with *similar* properties, if the elements were tabulated in order of their relative atomic weights.

Eventually these observations led Dmitri Mendeleev (1834-1907) to realize in 1869 that if the elements were listed in order of their relative atomic weights, their properties (e.g. valency) repeated in a series of periodic intervals, e.g. fluorine, chlorine, bromine and iodine. Mendeleev named his discovery the Periodic Table of the Elements. This implies that an appropriate 'Theory of Everything' predicts a "periodic table" of its "elements". Indeed Dalton's atomic theory predicts that its elemental atoms exhibit a periodic table such that groups of different kinds of elemental atoms have *similar* properties, if the elemental atoms are tabulated in order of their relative atomic weights. Consequently, Mendeleev's Periodic Table of the Elements corresponds essentially to a 'Theory of Everything' in the 19th century.

Dalton's atomic theory remains essentially valid today for chemical reactions so that Dalton's theory provides the theoretical foundation of chemistry. However, today it is known that there exist atoms of a given element that have different masses, known as *isotopes*, although they do have the same chemical properties.

Electromagnetic Force

The electromagnetic force has also been known from the time of ancient Greece. Indeed, the word *electromagnetism* is derived from combining two Greek terms: *electron* for amber and *magnetis lithos* for magnesian stone. Thales (ca.624-546BC) was aware of magnetic materials (lodestones) and also that electric charge could be generated by rubbing fur on amber.

Two kinds of electric charge were discovered in 1733 by Charles-Francois de Cisternay du Fay (1698-1739), which he named *vitreous* and *resinous* (later known as positive and negative) electric charge, respectively. He also found that like-charged objects repel each other, while unlike-charged objects attract one another.

The electrostatic force between two static electrically charged particles with charges q_1 and q_2 was discovered in 1785 by Charles Augustin de Coulomb (1736-1806). This electrostatic force is given by Coulomb's law: $\mathbf{F} = k_e q_1 q_2 \mathbf{r}/r^3$, where $\mathbf{r}$ is the radial vector pointing away from charge q_1 and towards charge q_2 and k_e is Coulomb's constant. The force $\mathbf{F}$ acting on q_1 by q_2 is attractive (repulsive) if q_1q_2 is negative (positive) for unlike (like) charges, respectively. Without knowledge of the internal structure of atoms, Coulomb forces were the only interatomic forces well understood in the 19th century. However, further progress was made with the nature of the electromagnetic force: if the two electric charges are not static but are *moving*, additional forces were found to come into place, these are called magnetic forces.

In 1831 Michael Faraday (1791-1867) found that if a magnet is moved through a loop of wire that an electric current flowed in the wire. He then employed this technique to construct the electric dynamo: the first electric power generator. In 1858 he proposed that electromagnetic forces extended into empty space around a conductor of electricity. His concept of *lines of force* emanating from charged bodies and magnets led to the idea of electric **E** and magnetic **B** fields. This constituted a paradigm shift in the concept of a force: it should be noted that an essential property of a *field* is that it contains *energy*.

In 1865 James Clerk Maxwell (1831-1879) expressed Faraday's ideas in terms of differential equations to describe how the electric and magnetic fields vary in space due to sources, electric charges, electric currents or magnets, respectively. In addition, Maxwell calculated that an electromagnetic field could propagate through space as a wave moving with the speed of light. i.e. light was an electromagnetic wave.

In 1884 Oliver Heaviside (1850-1925), employing vector calculus, reduced twelve of Maxwell's original twenty differentiable equations in twenty unknowns down to four differential equations in four unknowns that are now known as *Maxwell's equations*. These equations describe more simply the nature of electric fields, magnetic fields and the relationship between the two electromagnetic fields. In 1889, Heaviside derived the magnetic force on a moving charged particle.

Finally, in 1892, Hendrik Lorentz (1853-1928) derived the modern form of the electromagnetic force, which includes contributions from both the electric and magnetic fields. This force is known as the Lorentz force: $\mathbf{F} = q(\mathbf{E} + \mathbf{v} \times \mathbf{B})$, where **E** and **B** are the electric and magnetic fields, respectively, acting upon a particle with charge q and velocity **v**.

Summary: Era of Classical Physics

During the 2500 years from the ancient Greeks until 1895, the era of classical physics, the understanding of the composition and the structure of the Universe proceeded very slowly from the Greek basis that matter consisted of a mixture of four fundamental ingredients: earth, air, fire and water. In the 17th century, however, it became apparent that this simple scheme was not correct, since the number of basic, i.e. elementary substances, termed elements, which could not be broken down into simpler components, found on the surface of the Earth, was much greater than four.

In the 19th century, Dalton developed his atomic theory, based upon the ideas of the ancient Greek philosophers, Leucippus and Democritus, that each element was composed of discrete units, called atoms that were considered to be indivisible. This was a major step in the right direction for the quest of a 'Theory of Everything', although atoms were soon found to possess an inner structure. Indeed, Mendeleev constructed his Periodic Table of the Elements, which essentially corresponded as the 'Theory of Everything' in the 19th century, if the elements were tabulated in order of their atomic weights.

The other important concepts developed in the era of classical physics, was a *partial* understanding of the nature of each of the two long-ranged forces acting between the elementary atoms: the gravitational force introduced by Newton in 1687 and the electromagnetic force introduced by Coulomb in 1785. Both these forces were evident to the ancient Greeks from direct everyday experience because of their long-range nature. For many centuries, these two forces were regarded as *fundamental*: in fact only the electromagnetic force is still regarded as a fundamental force [6]. Indeed, it is interesting to note that both Faraday and Albert Einstein (1879-1955), independently, attempted to *unify* gravity with electromagnetism, as an important step towards a 'Theory of Everything'. However, both failed completely, since they lacked a full understanding of all the forces of nature.

2.2 Era of Transitional Physics

Introduction

Prior to 1895 atoms were still considered to be the basic units of matter. However, several discoveries: X-rays, radioactivity and the electron, were made during the years 1895-1900, that could not be reconciled with classical physics and indicated the need for new physics [6]. In the era of transitional physics, 1895-1932, the development of this new physics and its important contributions to the quest for a 'Theory of Everything' will be discussed critically.

X-rays were discovered in 1895 by Wilhelm Roentgen (1845-1923) while investigating cathode rays in a high vacuum Crookes tube. Roentgen found that some invisible rays emanating from the tube could pass through books and papers on his desk. Later he discovered their medical use by making a photograph of his wife's hand.

In 1896 Henri Becquerel (1852-1908) discovered accidently the phenomenon of radioactivity. Becquerel had wrapped a photographic plate in black paper, had placed a uranium salt upon it and had stored the combination within a drawer for several days. He found that the uranium salt emitted a mysterious radiation, which had caused a blackening of the photographic plate during the few days that it had been within the drawer. This discovery of the phenomenon of radioactivity provided a major contribution to the quest for a 'Theory of Everything'.

In 1897 John J. Thomson (1856-1940) discovered the first *subatomic* particle, later named the *electron*. Thomson estimated that the mass of this subatomic particle was about 2000 times smaller than a hydrogen atom.

X-Rays

The discovery of X-rays by Roentgen in 1895 did not contribute significantly to the quest for a 'Theory of Everything', although it did provide a very important contribution for the medical treatment of patients with broken bones or wounded soldiers in later wars.

Radioactivity

The mysterious radiation found accidently by Becquerel in 1896 emitted from a uranium salt was named *radioactivity* in 1898 by Pierre (1859-1906) and Marie (1867-1934) Curie, who were the first to investigate the nature of the radioactive radiation emanating from the uranium element.

In 1898 the Curies obtained samples of pure uranium by extracting microscopic quantities from the so-called *pitchblende* from the Joachimsthal, then extinct, silver mines. They discovered that the crude pitchblende seemed more radioactive than the refined uranium, and realized that there must be other kinds of radioactive elements awaiting discovery inside the pitchblende ore. In due course they found two radioactive elements that they named polonium and radium. These substances only existed in traces in pitchblende, but the degree of radioactivity of both these new elements was estimated to be of magnitude about two million times greater than uranium.

In 1898 Ernest Rutherford (1871-1937) made an important discovery concerning the radioactive emanations from uranium. By wrapping a sample of uranium in successive layers of aluminium foil, Rutherford showed that the uranium radiation is complex and that there are present at least two distinct kinds of radiation: one that is readily absorbed and the other of a more penetrative character. These different radiations were later named alpha (α) and beta (β) rays, respectively. Subsequently, it was determined that the α-radiation consisted of helium nuclei particles, called α-particles, while the β-radiation consisted of electrons. This discovery of Rutherford played an important role in the quest for a 'Theory of Everything'.

Subatomic Physics

In 1904 Thomson, based upon his discovery of the electron in 1897, asserted that 'the atom consists of a number of electrons moving about in a sphere of uniform positive charge matter'. This came to be known as the 'Plum Pudding' model.

In 1909 Hans Geiger (1882-1945) and Ernest Marsden (1889-1970) investigated the scattering of α-particles from a metal plate, following a suggestion by Rutherford. They found that about 1 in 8000 α-particles were reflected, i.e. were scattered by more than 90^0. Subsequently, Rutherford carried out a series of calculations based upon the results of the α-particle scattering experiments and concluded that most of the mass of an atom resided within a minute *nucleus* that had a positive charge equal in magnitude (+*Ze*) to the total electric charge (−*Ze*) of all the electrons in the neutral atom, and a diameter only 1/100000 of that of the atom as a whole. The integer *Z* is known as the *atomic number* of the element. Consequently, he determined that most of the atom is empty space. This caused Thomson's 'Plum Pudding' model to be abandoned. A new model (termed Rutherford's model) of the atom was born in 1911: one in which the positive charge of an atom, and almost all of its mass, are concentrated in a *nucleus* surrounded by a cloud of electrons.

The mathematical expression derived in 1911 by Rutherford for the scattering of *α*-particles allowed the value of *Z* of the scattering atom to be determined. It was found that if the elements are arranged in the order of the *periodic table*, initiated by Mendeleev, that their values of *Z* increase in consecutive numbers so that hydrogen has $Z = 1$, helium has $Z = 2$, lithium has $Z = 3$, etc. In addition, elements in the same vertical column in the periodic table have similar chemical properties. This observation is important for the development of particle models of matter, e.g. the Standard Model of Particle Physics (SM), which will be discussed later.

In 1919 Rutherford employed sufficiently high energy *α*-particles, probably from polonium, to bombard N^{14} forming O^{17} with the emission of a hydrogen nucleus. Similar experiments with a variety of light nuclei also caused a hydrogen nucleus to be emitted. Consequently, it was concluded that the hydrogen nucleus was one of the building blocks of all other nuclei and it was accorded a special name: the *proton* from the Greek word *πρoτoσ*, meaning first, only the second subatomic particle to be discovered.

The atomic masses of various elements, *A*, had been measured during the 19th century employing chemical reactions. Atomic masses are measured in atomic mass units (amu) and one amu is defined to be 1/12 of the mass of the common carbon atom (C^{12}). In 1913 Thomson found that there were two kinds of neon atoms with $A = 20$ (Ne^{20}) and $A = 22$ (Ne^{22}). Thus, it was found that atoms could have identical nuclear charge *Z* but different atomic masses *A*. Such atoms were termed *isotopes* by Frederick Soddy (1877-1956) of the same element from the Greek words *ισo* meaning equal and *τoπoσ* meaning place. Measurements showed that the atomic mass of each isotope, when expressed in amu is always quite close to an integer. This implied that the nuclei of all the elements are composed of a small number of building blocks.

It was clear that the nuclei of all the other elements, other than H^1, are not composed of protons only, otherwise *Z* would be always equal to *A*. It was eventually suggested by Rutherford that there may be an electrically neutral particle with a mass close to that of the proton, This hypothesis was confirmed in 1932 when the *neutron* was discovered by James Chadwick (1891-1974). The neutral neutron was the third subatomic particle to be discovered.

In the 1930s the conventional atom was thus considered to consist of a minute nucleus, composed of *Z* protons and $A - Z$ neutrons, surrounded by a cloud of *Z* electrons, so that the *proton, neutron and electron* were now regarded as the elementary particles of matter. The discovery of these three subatomic particles was a very important contribution to the quest for a 'Theory of Everything'.

Indeed, Dalton's atomic theory in the 1930s may be considered to be the 'Theory of Everything', since the three subatomic particles, the proton, neutron and the electron were regarded as the elementary particles of matter and the electromagnetic force was the only significant force involved in the structure of atoms.

Relativity Theory

In the early years of the 20th century, two theories, relativity theory and quantum mechanics, were initiated that ultimately led to further significant progress in the understanding of the nature of both matter and forces. First, the progress in relativity theory will be discussed.

In 1905 Einstein introduced his *special theory of relativity*. which is based upon two assumptions: (1) the speed of light in a vacuum is the *same* for all inertial observers, i.e. those moving with uniform velocity, and is independent of the motion of the light source; (2) the laws of physics are the *same* in all inertial frames of reference.

Einstein's special theory of relativity implies the replacement of the earlier Galilean relativity of Newtonian mechanics, based upon an absolute time and a stationary initial frame of reference, and defined by the Galilean transformations: $x' = x - vt$, $y' = y$, $z' = z$, $t' = t$, by transformations (later termed *Lorentz transformations*): $x' = \beta(x - vt)$, $y' = y$, $z' = z$, $t' = \beta(t - vx/c^2)$, where $\beta = (1 - v^2/c^2)^{-1/2}$ and v is the relative uniform velocity along the x- axis.

The special theory of relativity implies several additional consequences associated with the nature of forces, including the variation of mass with velocity and the equivalence of mass and energy. These have been experimentally verified.

Newtonian mechanics assumes that the mass of a particle is *constant* under all conditions of velocity. Special relativity implies that the mass m of a particle in an inertial frame of reference moving with relative uniform velocity v is given by: $E = mc^2 = \beta m_0 c^2$, where E is the energy and m_0 is the *rest mass* of the particle.

This relativistic variation of mass leads to an advance of the perihelion of an elliptical orbit associated with an inverse square force law, such as assumed in both Newton's universal law of gravity and Coulomb's law of the electrostatic force. The former provides a contribution to the advance of the perihelion of the planet Mercury, while the latter describes a contribution to the *fine structure* of the hydrogen atom.

The Lorentz transformations of the special theory of relativity also imply that the speed of light represents an upper limit for the speed at which any physical interaction may be transmitted. This led Einstein to note that the special theory of relativity therefore *conflicted* with Newton's universal law of gravitation, since Newton's law implied that the gravitational interaction acted *instantaneously* for cosmological distances.

Consequently, Einstein searched for a theory that possessed all the successful features of Newton's universal law of gravitation but did *not* conflict with the special theory of relativity. After considerable contemplation between 1905 and 1915, Einstein developed a new theory of gravity named the *General Theory of Relativity* (GTR) [9].

This new theory of gravity proposed by Einstein in 1915 was his generalization of the special theory of relativity to include accelerating frames of reference in addition to inertial frames of reference. In this theory, gravity is *not* regarded as a force but rather as a consequence of massive objects warping spacetime, which describes the three dimensions of space together with one dimension of time. Essentially, Einstein substituted the concept of curved spacetime (i.e. not Euclidean geometry) based upon the Karl Schwarzschild (1873-1916) solution of the equations of general relativity, for the mysterious Newtonian action at a distance.

The GTR rapidly became generally accepted for many years following 1915. In particular, Einstein using the Schwarzschild solution of his GTR, described the anomalous precession of 43 arc-seconds per century of Mercury's orbit around the Sun, as estimated by Urbain Le Verrier (1811-1877) in 1859 to be about 40 arc-seconds per century larger than the total perturbation caused by all the known other planets. This early success of Einstein's GTR inspired confidence in his new theory of gravity.

However, it was the observation of the deflection of light rays near the Sun during a total solar eclipse that established the viability of Einstein's gravitational theory.

According to the Schwarzschild solution, the deflection of light rays near the Sun was calculated to be about 1.76 arc-seconds, which is exactly *twice* the value predicted by Newton's theory of gravity, if photons, i.e. quanta of energy, are subject to Newtonian gravitation in the same manner as massive particles.

In 1919 Arthur Eddington (1882-1944), the leader of an expedition to test Einstein's theory of gravity by observing the deflection of light rays from stars passing near the Sun during a total solar eclipse, concluded that the expeditions observations favoured Einstein's theory rather than Newton's, although the observations were not sufficiently accurate to be conclusive. However, later measurements using microwaves rather than visible light have confirmed Eddington's conclusion.

Einstein's and Newton's theories of gravity predict very similar results for the solar system, although the two theories are based upon very different assumptions. In the two examples in the solar system: (1) the precession of the orbit of Mercury and (2) the deflection of light rays by the Sun, the differences in the predictions are small. In hindsight this, close agreement appears to arise because Einstein based his gravity theory upon the assumption that Newton's theory was accurate for *weak* gravitational fields. As will be indicated later, this assumption will be shown to be invalid, leading to an understanding of why the GTR is unable to describe observations on cosmological scales.

In 1917 Einstein applied his GTR to constructing a *static* model of the Universe. Initially, Einstein based his model on assumptions corresponding to those of Newton's much earlier attempt: the Universe was infinite and the distribution of matter was homogeneous and isotropic on sufficiently large scales. However, in 1929 Edwin Hubble (1889-1953) discovered that light from remote galaxies was redshifted and that the fainter the galaxy the larger was its redshift. Hubble, reluctantly, assumed that the redshift of a galaxy was due to a Doppler effect, implying that the galaxy was moving away from the Earth with a speed that increases with distance. This implied, for the first time, that the Universe was *not* static, as originally assumed, but was *expanding*. Making the same assumptions, Alexander Friedmann (1888-1925) had predicted in 1922 what Hubble discovered later.

In 1927 Georges Lemaitre (1894-1966) noted that expanding Universes could be extrapolated backwards in time to an originating very small singular point, which he called the 'primordial atom', that the present Universe arose from as a result of the observed expansion. This model of the origin of the Universe was termed the Big Bang model by Fred Hoyle (1915-2001) in 1950.

The GTR describes spacetime by a metric that determines the distances separating nearby points (stars, galaxies, etc). The assumption that the metric should be homogeneous and isotropic on large scales uniquely requires that the metric be the Friedmann-Lemaitre-Robertson-Walker metric (FLRW metric). During 1935-1937 Howard Robertson (1908-1961)[10] and Arthur Walker (1909-2001)[11] proved that the FLRW metric is the only one that is spatially homogeneous and isotropic on large scales.

The prevailing model of the Big Bang is based upon the GTR. According to this theory, extrapolation of the expansion of the Universe backwards in time yields an *infinite* mass-energy density and temperature at a finite time, approximately 13.8 billion years ago. This was demonstrated by Roger Penrose (1931-) and Stephen Hawking (1942-2018) in 1970 [12].

Thus the ‘birth’ of the Universe appears to be associated with a *singularity*, which describes not only a breakdown of the GTR, but all the laws of physics. This suggests that the GTR with the FLRW metric is *not valid* for extremely small regions of space. Consequently, it is necessary to consider the appropriate theory that describes the extraordinarily tiny: quantum mechanics, based upon quantum theory.

Today, scientists still describe the Universe mainly in terms of two theories: (i) Einstein’s GTR, which describes the force of gravity and the large-scale structure of the Universe; and (ii) quantum mechanics, which describes the physics of the very small. Unfortunately, however, as emphasized by Hawking and others, these two theories are known to be *inconsistent* with each other, so that one needs to accommodate the gravitational force within the domain of quantum mechanics by developing a *quantum theory of gravity* that will apply for both the large and small scales of the Universe. This became a very important requirement for a ‘Theory of Everything’, and its solution will be discussed later [6].

Quantum Theory Hypothesis

In the mid-1890s Max Planck (1858-1947) began to look at the problem of radiant heat. The classical view was that the wavelengths of radiant heat given off by a hot body must consist of *all* possible frequencies. According to the laws known at that time, a hot object would give off energy at all possible frequencies, up to a certain maximum, depending on how hot it was. Furthermore, it was known from experiment that shorter wavelengths of electromagnetic energy were hotter than the longer wavelengths. This implied that as a body became hotter that it would emit an increasing amount of radiant energy: this became known as the *ultraviolet catastrophe problem*, since it disagreed with experiments at that time.

The data obtained in these experiments looked deceptively simple: at a fixed temperature, the data fell on a smooth curve when displayed in a graph of intensity versus frequency. The points representing the intensity started near zero at low frequencies then climbed steeply upward to reach at a peak at an intermediate, predominent frequency, and finally descended on a gentle slope toward zero intensity for high frequencies. The intensity curves for higher temperatures were high, but qualitatively, they still had the same shape.

Thus, the ultraviolet catastrophe was found to disagree with theoretical calculations based upon Newtonian physics carried out by the experimenters.

In 1900 Planck succeeded in solving the ultraviolet catastrophe problem by introducing a *quantum hypothesis*: the absorption and emission of radiation takes place by the transfer of *energy quanta*, i.e. finite elements of energy according to $\Delta E = hv$, where $h = 6.626 \times 10^{-34}$ Joule.sec is Planck's constant and v is the frequency of the radiation. This quantum hypothesis, which was in direct conflict with the well-established principals of classical physics, initiated the development of a quantum theory that provided a basis for understanding the subatomic world, later termed quantum mechanics.

Photoelectric Effect

In 1905 Einstein accepted the quantum hypothesis of Planck for the processes of emission and absorption of electromagnetic radiation but also proposed that the radiation itself consists of energy quanta, later called *photons*. Thus, Einstein's proposal provided not only an explanation of Planck's quantum hypothesis required to solve the ultraviolet catastrophe problem but also provided an explanation of the *photoelectric effect*.

The photoelectric effect was discovered in 1887 by Heinrich Hertz (1857-1894), when he noticed during his experiments with radio waves that electric sparks between adjacent metallic terminals were triggered more readily when the terminals were illuminated with ultraviolet light: evidently, the electrons absorbed energy from the light, and this caused their emission from the terminals. This effect was investigated in greater detail by Philipp Lenard (1862-1947), who found that the energy absorbed by the electrons from the ultraviolet light increased with the frequency of the light. This behaviour of the electrons was at variance with Maxwell's equations but agreed with Einstein's proposal that light itself consisted of energy quanta.

Since quantum mechanics considers that electromagnetic waves consist of photons, it implies that the electromagnetic field suggested by Faraday is replaced by photons. Thus, in quantum mechanics, the original concept of a force makes little sense. Instead one has *interactions* with charged electrons emitting or absorbing photons, and the concept of a force has become the exchange of a particle. This was a major step in the understanding of the subatomic world. In addition, quantum mechanics indicated that light has both *wave* and *particle* properties.

Bohr Quantum Theory and Quantum Numbers

In 1913 Niels Bohr (1885-1962) applied the quantum hypothesis to the structure of the atom: he inferred that the atom can only exist in *definite stationary states* with energies $E_0, E_1, E_2, \ldots$, so that only those radiation spectral lines can be absorbed for which hv has the exact value to raise the atom from one stationary state to a higher one. Bohr assumed for the hydrogen atom, that the orbits of the electron about the proton corresponded to those predicted classically but which fulfilled certain quantum conditions involving integral *quantum numbers*, corresponding to the stationary states of the atom. In this way, Bohr was able to describe the formula found in 1885 by Johann Balmer (1825-1898) for the discrete hydrogen spectrum: $v = R(1/n^2 - 1/m^2)$, where $n = 1,2,3,...$ and $m > n$ is an integer. $R = 109678\ cm^{-1}$ is the Rydberg constant.

This treatment of the hydrogen spectrum by Bohr introduced *quantum numbers* into the model describing the structure of matter in order to represent the values of quantized quantities in the dynamics of a quantum system. For example, in the hydrogen atom, four quantum numbers describe completely the quantized dynamics of the electron [6].

The *principal* quantum number n (or m) in the Balmer formula describes quantized energy levels of the electron. The *azimuthal* quantum number l describes the magnitude of the quantized orbital angular momentum of the electron: the values of l range from 0 to n-1. The *magnetic* quantum number m_l describes the quantized orbit that yields a projection of the quantized orbital angular momentum along a specified axis: the values of m_l range from $-l$ to $+l$ with integer intervals. The *spin projection* quantum number m_s describes the quantized *intrinsic* spin angular momentum of the electron within a quantized orbital and gives the projection of the quantized spin angular momentum along a specified axis: the only values of m_s are -1/2 and + 1/2, since the electron has intrinsic spin $s = 1/2$.

Exclusion Principle

In 1925, in order to account for the total number of electron orbitals in an atom, Wolfgang Pauli (1900-1958) introduced the *exclusion principle*, which states that no two electrons can exist in the same quantum state defined by the above four quantum numbers, n,l,m_l, and m_s.

In 1926 both Enrico Fermi (1901-1954) and Paul Dirac (1902-1984) independently showed that the Pauli exclusion principle applied to identical particles with *half-integer* spin in a system with thermodynamic equilibrium. Such particles are known as *fermions* because Fermi published first. Dirac also pointed out that the exclusion principle did *not* apply to identical particles with *integer* spin. Such particles are known as *bosons*, named after Satyendra Bose (1894-1974), who investigated them.

The difference between fermions and bosons arises since fermions obey Fermi-Dirac quantum statistics, which describes a system of identical *half-integer spin* particles, e.g. electrons in thermal equilibrium, by *antisymmetric* many particle wave functions, while bosons obey Bose-Einstein quantum statistics, which describe a system of identical *integer spin* particles, e.g. photons in thermal equilibrium, by *symmetric* many-particle wave functions.

Quantum Mechanics

In 1925 Werner Heisenberg (1901-1976) stated that the basic reason for the partial failure of the Bohr quantum theory is that it deals with quantities, which are *unobservable*. Heisenberg said that to develop a consistent system of atomic physics, later termed *quantum mechanics*, only observable entities, e.g. the frequencies and intensities of light emitted by an atom rather than the orbits of electrons, should be introduced into the theory. In 1925 such a system called *matrix mechanics* was developed by Heisenberg in collaboration with Max Born (1882-1970) and Pascual Jordan (1902-1980).

In 1926 Erwin Schrodinger (1887-1961) developed a second version of quantum mechanics based upon the wave nature of particles, called *wave mechanics*. This alternative system is based upon the hypothesis of Louis de Broglie (1892-1987) that to every particle there corresponds a wave, the wave length λ of which is connected to the momentum p of the particle by the relation $\lambda = h/p$, involving Planck's constant h. In 1927 Dirac showed that matrix mechanics and wave mechanics were essentially equivalent.

The development of quantum mechanics, which describes the behaviour of all subatomic particles, was one of the most important contributions to the quest for a 'Theory of Everything'.

Uncertainty Principles

In 1927 Heisenberg introduced his so-called 'uncertainty principle' asserting that pairs of physical properties of a particle, e.g. *position* and *momentum* cannot both be determined precisely at the same time. Another pair are *energy* and *time*, which implies that a particle may have an energy that does not correspond to its actual momentum, provided that this occurs only for a short time in agreement with the uncertainty relation relating energy and time.

Heisenberg's 'uncertainty principle' is essentially a consequence of the dualistic nature of particles, arising from the two versions of quantum mechanics: in wave mechanics, particles have 'wave properties' such as a wavelength λ that is related to its 'particle property' momentum p by the relation $\lambda = h/p$. This relation leads to Heisenberg's uncertainty relationship, which states that the product of the uncertainties in determining position Δx and momentum Δp is approximately h, i.e. $\Delta x.\Delta p \approx h$. Similarly, the wave property, frequency v is related to the particle property, energy, by the relation $E = hv$. This leads to Heisenberg's second uncertainty relationship, which states that the ratio of the uncertainties in determining energy ΔE and frequency Δv is approximately equal to h: i.e. $\Delta E/\Delta v \equiv \Delta E.\Delta t \approx h$. Heisenberg's uncertainty relations completely overthrew the determinism of classical Newtonian mechanics.

Dirac Equation

Unfortunately, Schrodinger's quantum mechanics did not include the special theory of relativity, so that it was not guaranteed to work at speeds close to the speed of light. However, the unification of quantum mechanics and special relativity was accomplished in 1928 by Dirac, who derived a relativistic wave equation called the *Dirac equation*.

Dirac found that his four-component equation [6] approximately predicted all the electron properties resulting from its spin: spin angular momentum and its magnetic moment, although the physical meaning of *four* components rather than two components was not immediately obvious. In 1931, following considerable contemplation, Dirac concluded that his four component equation not only described the spin properties of the electron but also described the existence of an associated particle with the same mass but with the opposite (positive) charge of the electron that Dirac called the *antielectron*.

In 1932 Carl Anderson (1905-1991) discovered accidently a positively charged particle with the same mass as the electron while using a cloud chamber to study cosmic ray particles. This particle, which he called the positron, was the first *antiparticle* to be discovered.

Dirac's equation predicts that for every charged fermion there exists an antiparticle with the same mass but with the opposite charge. Indeed, every fermion including neutral fermions such as the neutron have corresponding antiparticles having the same mass as the particle but *opposite* values of their *intrinsic additive quantum numbers* including charge.

It has become conventional to represent an antiparticle by a 'bar' above the symbol representing the particle.

The discovery of antiparticles, which had the same mass as the corresponding particle but the opposite values of their *intrinsic additive quantum numbers* including charge, e.g. the positron and electron, was an important step in the quest for a 'Theory of Everything'.

Although during the era of transitional physics, quantum mechanics involving the Dirac equation proved to be extremely successful in solving many problems in both physics and chemistry, phenomena were discovered in 1947 that defied it. First, Willis Lamb (1913-2008) and Robert Retherford (1912-1981) measured a small but finite energy gap between the 2s and 2p eigenstates of the hydrogen atom, contrary to the prediction of the Dirac equation that these two energy levels should have the same energy. Second, Polykarp Kusch (1911-1993) measured that the electron magnetic moment was slightly larger than the value predicted by the Dirac equation. This led to the development of a relativistic quantum field theory of the interaction of photons with electrons [6].

This initial field theory consisted of a relativistic quantum field of photons, a relativistic quantum field of electrons that acts as the source of electromagnetism, and the interaction between these two fields. Although this theory led to agreement with the experimental result of Kusch for the electron magnetic moment, it unfortunately yielded an *infinite* result for the finite energy gap between the 2s and 2p eigenstates of the hydrogen atom, termed the Lamb shift.

This infinity problem was overcome by three physicists: Shin'Itiro Tomonaga (1906-1979), Julian Schwinger (1918-1994) and Richard Feynman (1918-1988), who independently, using different mathematical methods, managed to *renormalize* the theory to remove the infinities arising in the calculations.

The *renormalization process* employed to remove the unwanted infinities was initiated by Hendrick Kramers (1894-1952) in 1947. Kramers considered that the mass of an electron resulted partly from the electric field energy surrounding the electron so that one must clearly separate the 'bare' mass, i.e. the mass not including the field contribution, and the 'physical' mass that one observes experimentally. Kramers suggested that since the bare mass is not observable, one should choose it so that after inclusion of the field contribution, one obtains the observed value of the mass.

This *renormalized* quantum field theory is called Quantum ElectroDynamics (QED). It was the first such theory to be discovered and it became an integral part of the SM. Indeed, QED was considered to be by far the most accurate theory in all of science, since it provided a calculation of the Lamb shift that agreed with the measured value to 12 significant figures.

QED

The development of a quantum theory of light and electrons, called quantum electrodynamics or QED, was a major step forward for the quest for a 'Theory of Everything', although there were indications at the time that the resultant QED had serious problems associated with it.

In 1930 Robert Oppenheimer (1904-1967) realized a disturbing problem: when one attempted to describe the quantum theory of an electron interacting with a photon, he discovered that the quantum corrections yielded *infinite* results. He concluded that there was an essential flaw in simply combining the Dirac equation of electrons with Maxwell's theory of photons.

Consequently, little progress was made for nearly two decades in understanding the above failure of the quantum theory until Tomonaga, Schwinger and Feynman managed to remove the unwanted infinities, employing their so-called renormalization techniques. Unfortunately, these techniques involved two *different* infinities that appeared to cancel each other, leaving a finite result that agreed with experiment: (i) the bare mass and charge of the electron and (ii) the quantum corrections. Cancellation requires *infinity minus infinity equals zero!*, which was considered mathematically very dubious. Indeed, even Dirac, who helped to create QED in the first place, did not like the techniques of renormalization. which indicated a serious problem with the physics of QED. This will be discussed in more detail later.

Summary: Era of Transitional Physics

In the era of transitional physics (1895-1932), significant progress was made in the quest for a 'Theory of Everything' by the development of two new theories: special relativity and quantum theory.

The discovery by Rutherford concerning the radioactive emanations from uranium led to the conclusion that most of the mass of an atom resided within a minute nucleus that had a positive charge equal in magnitude ($+Ze$) to the total electric charge ($-Ze$) of all the electrons in the neutral atom, and a diameter only 1/100000 of that of the atom as a whole, so that most of the atom is empty space. This model of the atom was termed Rutherford's model in 1911.

The introduction of Einstein's special theory of relativity led to further progress in the understanding of the nature of both matter and forces. In particular it implied the replacement of the earlier Galilean relativity of Newtonian mechanics by a new relativity defined by Lorentz transformations [6], which implied the variation of mass with velocity and the equivalence of mass and energy. In particular special relativity implied that the mass of a particle in an inertial reference frame of reference moving with relative uniform velocity v is given by: $E = mc^2 = \beta m_0 c^2$, where E is the energy, $\beta = (1 - v^2/c^2)^{-1/2}$ and m_0 is the (rest mass) of the particle.

The Lorentz transformations also implied that the speed of light represents an upper limit for the speed at which any physical interaction may be transmitted. This led Einstein to develop a new theory of gravity named the *General Theory of Relativity* (GTR). The GTR predicted both an anomalous precession of Mercury's planetary orbit and also the deflection of light rays near the Sun that differed from Newtownian mechanics but agreed with observation.

The main impact of quantum mechanics upon the concepts of ordinary matter and forces that were important for the quest of a 'Theory of Everything' is three-fold. First, the unification of the special theory of relativity and quantum mechanics by Dirac indicated that matter consists of *both* particles and antiparticles. Second, quantum mechanics led to Faraday's original concept of the electromagnetic force as arising from the existence of an electromagnetic *field* within the space between interacting charged bodies, to the notion of photons being exchanged between the charged bodies. Third, the observation of phenomena that disagreed with the predictions of the Dirac equation led to the development of QED, which describes the interaction of photons with electrons and positrons in terms of a *renormalizable* relativistic quantum field theory. Unfortunately, this renormalization process actually indicated a serious problem with the physics of QED, and although it did serve to reduce the many infinities in electrodynamics, it did not contribute directly to the quest for a 'Theory of Everything'.

Furthermore, in 1970, Hawking and others [12] realized that quantum mechanics and the GTR were *inconsistent* with each other, so that it was considered an essential requirement that one needed to develop a *quantum theory of gravity* that will apply for both the large and small scales of the Universe to achieve an appropriate 'Theory of Everything'.

2.3 Era of Modern Physics

Introduction

The era of modern physics is considered to begin in the important year 1932 in which several significant discoveries and advances were made in the understanding of the nature of both ordinary matter and forces.

Anderson had discovered a positively charged particle with the same mass as the electron, the positron, which is the antielectron contemplated by Dirac to exist according to his four component relativistic equation.

The first proton accelerator was constructed by John Cockcroft (1897-1967) and Ernest Walton (1903-1995), who using the nuclear reaction: $p + Li^7 \rightarrow a + a + 17.2$ MeV, found that the decrease in mass in the disintegration process was consistent with the observed energy release, according to $E = mc^2$, as concluded by Einstein in 1905.

In particular, Chadwick had discovered the neutron as a constituent of atomic nuclei, employing energetic *a*-particles from polonium nuclei to accomplish the nuclear reaction: $a + Be^9 \rightarrow C^{12} + n$. This raised two important questions.

First, what holds the neutrons and protons together within the minute atomic nuclei? This involves the concept of a *strong nuclear force*: the stability of an atomic nucleus, composed of many neutrons and protons, requires the existence of a new type of force that is stronger than the electromagnetic repulsion between the constituent protons.

Second, the discovery of the neutron also implied that there are no electrons within atomic nuclei, so that any theory of *β*-decay is required to account for the process whereby a neutron is converted into a proton, an electron and an electron antineutrino, as proposed by Pauli in 1930.

This necessitated the existence of a second nuclear force (later termed the *charge-changing (CC) weak nuclear force*).

In the years following 1932, many new particles were discovered thereafter either in cosmic rays, with accelerators or reactors. In 1936, just four years after the discovery of the positron, Anderson and Seth Neddermeyer (1907-1988), while studying cosmic rays, discovered another new particle that has a mass intermediate between the mass of an electron and the mass of a proton. It became known as the *muon (μ)*. Consequently, by 1936 the number of known particles was only six, if the electron antineutrino predicted by Pauli existed. Unfortunately, as the years passed, the number of known particles increased rapidly. Indeed, by the early 1970s, the number of new particles that had been observed by experimenters was in the hundreds. Scientists realized that, if they were to make progress toward gaining any real understanding of the nature of matter, it would be necessary to bring some order to all this chaos. In the era of modern physics, 1932-present, the development of this order will be discussed critically, concerning the quest for a 'Theory of Everything'.

In elementary particle physics, symmetry and gauge invariance play a major role in the understanding of the elementary particles and the forces between them.

Symmetry and Gauge Invariance

The concept of gauge invariance as a physical principle governing the fundamental interactions between elementary particles was first proposed in 1919 by Hermann Weyl (1885-1955) in an attempt to extend ideas employed by Einstein's GTR, involving the gravitational force, to the case of the electromagnetic interaction.

This attempt by Einstein to unify the gravitational and electromagnetic forces, which have similar inverse square ($1/r^2$) fields, failed completely as stated in Section 2.1, since he lacked a full understanding of all the forces of nature.

Furthermore, the above attempt by Weyl, involving a 'scale invariance' of spacetime, also failed. However, with the development of quantum mechanics, it was realized in 1927 by Vladimir Fock (1898-1974) and Fritz London (1900-1954) that Weyl's original gauge theory could be given a new interpretation: a gauge transformation corresponds to a change in the *phase* of the wavefunction describing a particle, rather than a change of scale.

There are two kinds of symmetry arising from gauge invariance [13], depending whether the invariance is 'global' or 'local'.

Global gauge invariance leads to a symmetry involving different particles that behave similarly with respect to a particular force. Such a symmetry is called a *flavor* symmetry because the different particles involved are distinguished by some attribute called flavor, which is conserved by the particular force.

Local gauge invariance leads not only to the conservation of some attribute of a set of particles involved in the symmetry but also to a *fundamental* force acting between the particles. This force is normally mediated by *massless* particles.

Strong Isospin

In 1932 Heisenberg, assuming that atomic nuclei are composed of neutrons and protons, commenced developing quantum models to describe their structures in terms of the various nuclear forces acting between the atomic constituents. In particular he introduced the notion of *strong isospin*.

Heisenberg suggested that the proton and neutron, which had very similar masses and appeared to be subject to the same nuclear force, could be regarded as two quantum states of the same particle that he called the *nucleon*. By analogy with ordinary spin, Heisenberg considered the nucleon to have *strong isospin*, $I = 1/2$, with the two values of its strong isospin projection quantum numbers, $I_3 = \pm 1/2$, corresponding to the proton and neutron, respectively.

Heisenberg realized that the approximate equality between the number of protons and neutrons, especially for light nuclei, e.g. C^{12}, implied that the strong nuclear force was *short-ranged* and also that the strong nuclear force between any two nucleons, i.e. $n - n$, $n - p$ and $p - p$ strong nuclear forces were very similar, essentially charge independent.

This nuclear symmetry, described by the concept of strong isospin, provided an understanding of isobaric nuclei, i.e. nuclei having the same atomic masses *A*. Thus, if electromagnetic forces were neglected, nuclei such as Li^7 and Be^7 would be identical.

These considerations led to the notion of *mass multiplets*, i.e. systems having the same mass but different charges, with a relation between the charge *Q* and the strong isospin projection quantum number I_3. Thus, for a general isobaric nucleus, assuming $I_3 = +1/2$ for each proton and $I_3 = -1/2$ for each neutron, one has $Q = I_3 + A/2$, where I_3 is the sum of the strong isospin projection quantum numbers of the *A* constituent nucleons.

This equation relates the charge *Q* to the strong isospin projection quantum number I_3 and the atomic mass *A* of each isobaric nucleus. All these three quantum numbers are known as *additive quantum numbers* since each represents the sum of the corresponding additive quantum numbers of all the nucleons comprising the composite isobaric nucleus.

The atomic mass *A* corresponds to the *baryon number*, introduced by Ernest Stuckelberg (1905-1984) in 1938 to account for the stability of ordinary matter. Stuckelberg proposed that if each nucleon is assigned baryon number $A = +1$, while the photon, electron, positron, electron antineutrino and electron neutrino have $A = 0$, conservation of baryon number forbids the decay of the proton into a positron and other neutral particles. In addition, conservation of baryon number forbids the decay of a neutron into an electron and a positron, although it does allow the decay of a neutron into a proton, an electron and an electron antineutrino as in *β*-radiation radioactivity.

Both the charge Q and the baryon number A additive quantum numbers have been found to be conserved in all interactions occurring in nature. This means that in an equation describing an interaction between particles that the sums of both charges and baryon numbers on the left hand side of an equation are identical with the corresponding sums on the right hand side.

This development of charge Q and baryon number A as additive quantum numbers was a very positive first step for the continuing quest for a 'Theory of Everything', since it involved the development of a classification system based upon *conserved* additive quantum numbers for the very many new particles discovered later in the 1950s and 1960s.

Strong Nuclear Force

In 1935 Hideki Yukawa (1907-1981) published his theory concerning the nature of the strong nuclear force that binds the nucleons within the nucleus to one another. Following Heisenberg's early notions of the strong nuclear force, Yukawa assumed that the strong forces between any two nucleons were both *short-ranged* and *very similar*. With these assumptions, Yukawa estimated that the mediating particles (later called *pions*) should exist in the three charge states, Q = +1, 0 and -1, and should have masses intermediate between the electron and the proton.

In 1947 Donald Perkins (1925-2022) found an event in cosmic rays in which a particle interacted strongly with a nucleus, indicating that the particle was one of Yukawa's predicted mediating pions of the strong nuclear force. Later in 1947, Cecil Powell (1908-1969) and collaborators, using photographic emulsion techniques to study cosmic rays, found two events demonstrating the decay of a pion into a muon plus a neutral particle, later determined to be a neutrino-like particle.

The discovery of a strongly interacting meson of the type predicted by Yukawa led to an extension of the strong isospin concept to pions. Since Yukawa's theory of the strong nuclear force required three charge states of the pion, it was allotted strong isospin I = 1 and since it was also assigned baryon number A = 0, the three values of I_3 are +1, 0 and -1, corresponding to the three charge states Q = +1, 0 and -1, respectively.

To summarize: the concept of strong isospin is very useful for understanding phenomenologically strongly interacting processes involving nucleons, pions and antinucleons.

Weak Nuclear Force

The first weak nuclear interaction process, nuclear *β*-decay, was discussed in 1896. In 1930 Pauli proposed that the continuous energy spectra of the electrons emitted in the radioactive decays of certain nuclei could be understood if a neutron decayed to a proton with the emission of both an electron and another particle, later termed an electron antineutrino; $n^0 \rightarrow p^+ + e^- + \bar{\nu}_e$. This raised the question: What is the nature of the force that causes this radioactive decay?

In 1938 Oskar Klein (1894-1977) proposed [14] that the weak nuclear force could be mediated by massive charged bosons, now called W^+ and W^- bosons, which had properties similar to those of photons. He termed them ‘electrically charged photons’ but unlike photons, they were *massive* in order to satisfy the very short-range nature of the weak nuclear force. Thus, *β*-decay could be considered to be a two-step process: $n^0 \rightarrow p^+ + W^-$, $W^- \rightarrow e^- + \bar{\nu}_e$, provided the large mass of the W^- boson and its short lifetime are compatible with Heisenberg’s uncertainty principle. Such weak nuclear interactions, involving either W^+ or W^- mediating bosons, are known as charge-changing (CC) weak nuclear interactions.

This proposal by Klein was a very important step in the development of a Particle Physics Model, e.g. the SM in the present case for the quest for a ‘Theory of Everything’.

Strangeness Additive Quantum Number

Following the discovery of the neutron in 1932, many new particles were found either in cosmic rays studies or were produced employing accelerators to study nuclear interactions.

These accelerator experiments demonstrated that in general the new particles were produced in pairs (termed associated production), a typical reaction being $\pi^- + p^+ \rightarrow \Lambda^0 + K^0$, but decayed individually in about 10^{-10}s. Such a mean lifetime is about 10^{12} times longer than expected if the production and decay mechanism are governed by the same interaction, i.e. production time $\sim 10^{-22}$s. For this reason, both the hyperon Λ^0 and the K^0 meson were called *strange* particles.

Unfortunately, this so-called ‘paradox’ of strange particles was claimed in 1953 by Murray Gell-Mann (1929-2019) and Kazuhiko Nishijima (1926-2009) independently, to be resolved by the introduction of a new additive quantum number called *strangeness (S)*. Strangeness was assumed to be conserved in strong nuclear interactions but not necessarily so in weak nuclear interactions. Thus, strange particles were produced copiously in pairs via a strong nuclear interaction but decayed individually very slowly via a CC weak nuclear interaction, that did *not* conserve *S*.

However, the introduction of a ‘partially conserved’ additive quantum number such as *S* during the development of the SM was a very *dubious* assumption [6]. Indeed, in quantum mechanics, quantum numbers are usually conserved quantities and furthermore the nature of the CC weak nuclear interaction is ‘weak’ because it is mediated by massive *W* bosons not because the strangeness quantum number is not conserved.

The strangeness assumption, which was *not* required to explain the ‘weak’ nature of the weak nuclear force, unfortunately led to several major problems for the development of the SM of particle physics, associated with both the classification of the elementary particles and the nature of the universality of the CC weak nuclear force. Essentially, the strangeness assumption led to an incorrect SM and to its failure as a ‘Theory of Everything’. Later the SM was considered to be *incomplete*, since it failed to account for many empirical observations: the existence of three generations of leptons and quarks, the origin of mass, the nature of the gravitational force, the matter-antimatter asymmetry problem, the origin of *CP* violation, the origin of parity violation in weak nuclear interactions, the existence of strange quarks in the proton, etc [6].

Although the strangeness assumption led to an incorrect SM, subsequent studies of the many new particles discovered during the 1950s and 1960s developed several important contributions to the quest for a ‘Theory of Everything’.

Parity

The physical quantity *parity* is a purely quantum mechanical concept, since it is related to the properties of wave functions, if: $\psi(-x,-y,-z) = +\psi(x,y,z)$ or $-\psi(x,y,z)$, where x,y,z are the spatial coordinates and ψ is the value of the wave function at a given point, so that ψ is *symmetric* and is assigned a positive parity $P = +1$ or ψ is *antisymmetric* and is assigned a negative parity $P = -1$.

The above notion of parity was introduced into quantum mechanics by Eugene Wigner (1902-1995) in 1927 in order to explain that two subsets of energy levels of iron atoms did not intercombine [6].

It should be noted that parity is *not* an additive quantum number but is a *multiplicative* quantum number, i.e, one for which the corresponding 'product' rather than the 'sum' of the quantum numbers of a system of particles tends to be conserved.

Between 1947 and 1953 several new particles were discovered in cosmic rays. In particular, two of these particles then known as the tau particle, which decayed into three pions, and the theta particle, which decayed into two pions, presented a problem. Both particles decayed via a CC weak nuclear force and were *indistinguishable* apart from their decay mode, since their masses and lifetimes were found to be about the same.

The essential problem was that the tau particle would have parity $P = -1$, while the theta particle would have parity $P = +1$, if the pions had parity $P = -1$, as was generally believed at that time. Hence, if conservation of parity holds, the theta and the tau particles could not be the same particle.

In 1956 Tsung-Dao Lee (1926-2023) and Chen-Ning Yang (1922-2025), in order to resolve this theta-tau puzzle, proposed that parity conservation might be violated in weak nuclear interactions. This was rapidly confirmed in 1956-57 by several groups, including Chien-Shiung Wu (1912-1997) and collaborators, who studied the β-decay of polarized Co^{60} nuclei in late 1956, and noted the direction of the electrons with respect to the spin of the Ni^{60} nuclei. The final result of this experiment was that many more electrons were emitted in the antiparallel direction than in the parallel direction, so that parity was almost 100% violated,[15].

Consequently, it was found that the electron was left-handed, i.e. $P = -1$, and that the antielectron neutrino was right-handed, i.e. $P = +1$. In 1958, the helicity of the electron neutrino participating in a CC weak nuclear interaction was measured by Maurice Goldhaber (1911-2011) and collaborators and was found to be negative, i.e. $P = -1$, thereby confirming the earlier experiment of Wu.

Lepton Conservation

In 1936 the muon was discovered by Anderson and Neddermeyer and in 1947 the pion was found independently by both Perkins and Powell and his group. Both these particles decay via CC weak nuclear interaction processes, such as: $\pi^- \rightarrow \mu^- + \bar{\nu}_\mu$ and $\mu^- \rightarrow e^- + \bar{\nu}_e + \nu_\mu$. On the other hand, certain decay modes were *not* observed. In particular, the muon decay modes: $\mu^- \rightarrow e^- + \gamma$ and $\mu^- \rightarrow e^- + e^+ + e^-$.

In order to explain the absence of such decay modes, Emil Konopinski (1911-1990) and Hermoz Mahmoud (1918-2010) in 1953 introduced the idea of *lepton conservation* analogous to baryon conservation. By assigning lepton number $L = +1$ to e^-, μ^+ and ν (the different kinds of neutrinos were not yet established), $L = -1$ to e^+, μ^- and $\bar{\nu}$ and $L = 0$ to all other particles, the above unobserved processes were forbidden. Furthermore, the reaction describing β-decay: $n^0 \rightarrow p^+ + e^- + \bar{\nu}_e$ conserved the proposed lepton numbers.

In 1962 Leon Lederman (1922-2018), Melvin Schwartz (1932-2006) and Jack Steinberger (1921-2020) demonstrated that the muon neutrino ν_μ was *different* from the electron neutrino ν_e, so that the classification system of Konopinski and Mahmoud was not quite correct.

The experimental evidence for the existence of two neutrinos led to the acceptance of an alternative scheme, involving separate lepton numbers $L_e = +1$ and $L_\mu = 0$ for the lepton pair (ν_e, e^-) and $L_e = 0$ and $L_\mu = +1$ for the lepton pair (ν_μ, μ^-), respectively. If these additive quantum numbers are assumed to be separately conserved in all interactions, then all the unobserved decay modes are forbidden. This latter scheme was readily extended to the lepton pair (ν_τ, τ^-), involving a third charge lepton, the tau particle τ^- discovered by Martin Perl (1927-2014) and collaborators in 1975, and an associated neutrino, the tau neutrino ν_τ discovered by the same group in 2000.

To summarize: the introduction of lepton numbers, which are strictly conserved in both electromagnetic and CC weak nuclear interactions, provided a useful description of the allowed decay modes and the possible reactions involving leptons. Furthermore, the introduction of the concept of lepton conservation also served a very useful development for the concept of *weak isospin* associated with an $SU(2)$ symmetry, although it also led to a very complicated classification of the six leptons that eventually were considered to be elementary particles of the SM.

Weak Isospin

Another property of the weak nuclear forces discovered in the late 1940s was their ‘universality’. Analysis of experiments revealed that the coupling constants, i.e. the strengths of the forces, for μ-decay and μ-capture were of the same order of magnitude as that for β-decay. This led to the hypothesis of a *universal weak nuclear force*, mediated by the W bosons [6].

The occurrence of the three doublets (ν_e, e^-), (ν_μ, μ^-) and (ν_τ, τ^-) with separate lepton numbers and their similar behaviour with respect to the ‘universal’ CC weak nuclear force mediated by the W particles led naturally to the notion of a *weak isospin*, associated with an $SU(2)$ symmetry.

In 1958 Sidney Bludman (1927-) proposed that many aspects of the weak nuclear force could be described by an $SU(2)$ global gauge theory, assuming a triplet of three vector bosons, W^+, W^0 and W^-, in a ‘weak isospin space’ [6]. Moreover, it did indicate the possibility of a *neutral* weak nuclear force, mediated by the W^0 boson, which is distinct from the usual electromagnetic force.

Bludman also noted that, if the lepton doublets (ν_e, e^-) and (ν_μ, μ^-) were considered as weak isospin doublets ($i = 1/2$) with ν_e and ν_μ having $i_3 = +1/2$ and e^- and μ^- having $i_3 =$ -

1/2, the charge of each lepton satisfied a relation analogous to that for strong isospin: $Q = i_3 - L/2$, where $L = +1$ is the lepton number for each lepton, analogous to $A = +1$ for each baryon.

Bludman's proposal was very useful for the development of the accepted classification of the six known leptons within the framework of the SM.

Quark Model

The introduction of the strangeness quantum number, *S*, which was conserved in both strong and electromagnetic interactions led to a search for a higher symmetry that was an extension of the strong isospin concept, based upon an *SU*(2) symmetry.

In 1961 Gell-Mann and Yuval Ne'eman (1925-2006) independently proposed a new model (later termed the *eightfold way* [16]) for classifying *hadrons*, i.e. particles influenced by the strong nuclear force, based upon an *SU*(3) symmetry. The name hadron is based upon the Greek word for strong: *αδροσ*. This model considered the division of the hadrons into 'families' comprising several multiplets, i.e. those having both the same baryon number and strong isospin number, satisfying the relation $Q = I_3 + (A + S)/2$, into a larger set called a *supermultiplet*.

Gell-Mann and Ne'eman proposed that the Λ, Σ and Ξ hyperons, discovered during the 1950s with accelerators, together with the nucleons form an octet of an *SU*(3) symmetry. Similarly, the strange kaons, also discovered in the 1950s, together with the three pions and another meson, η^0, discovered in 1961, were proposed to form another octet with *SU*(3) symmetry.

The observed *SU*(3) symmetry led to a search for an understanding in terms of its *fundamental* representation, corresponding to a triplet of particles. Following several attempts, the *quark model* was proposed independently in 1964 by Gell-Mann and George Zweig (1937). The members of the fundamental *SU*(3) triplet were assumed to be three kinds of spin-1/2 particles called up (*u*), down (*d*) and strange (*s*) *quarks* by Gell-Mann, consisting of a strong isospin doublet (*u*, *d*) and a strong isospin singlet (*s*). Each quark is assumed to have $A = 1/3$, since three quarks comprise a baryon. The *u*-quark and the *d*-quark, where *u* and *d* stand for the 'up' and 'down' direction of the strong isospin projection number, have $Q = +2/3$, $I_3 = +1/2$ and $Q = -1/3$, $I_3 = -1/2$, respectively and $S = 0$, while the s-quark stands for the strange quark and has $Q = -1/3$, $I_3 = 0$ and $S = -1$.

The 1964 quark model considered that all the hadrons known in the 1960s were composed of the three basic quarks and their three basic antiquarks. Each meson was composed of a quark-antiquark pair, e.g. the π^+ meson was a (u, $\bar{d}$) pair, while each baryon was composed of three quarks, e.g. the proton was a (*u*, *u*, *d*) triplet, and each antibaryon was composed of three antiquarks, e.g. the antiproton was a ($\bar{u}$, $\bar{u}$, $\bar{d}$) triplet, Thus mesons have integral spins, 0 or 1, while baryons and antibaryons have half-integral spins 1/2 or 3/2.

To summarize: the 1964 three quark model provided an excellent description of all the various known hadrons at that time, in terms of their *SU*(3) properties. However, the quark model raised new concerns.

The main problem arose because the quark model indicated that several particles were predicted to have *three identical quarks* in the same quantum state, thereby violating the Pauli exclusion principle [6].

The above problem was resolved in 1965 by Yoichiro Nambu (1921-2015) and Moo-Young Han (1934-2016), who introduced a new degree of freedom for each quark. The quarks were allotted an additional quantum number called *color*, which can take three values so that in effect there are three kinds of each quark, *u*, *d* and *s*. Nowadays, the quarks are considered to carry a *single color charge*: red, green or blue, and the corresponding antiquarks are considered to carry a *single anticolor charge*, antired, antigreen or antiblue, Color charge is somewhat analogous to electric charge, although it is associated with an $SU(3)$ symmetry rather than a $U(1)$ symmetry.

Han and Nambu also introduced the notion that the color degree of freedom was associated with a new 'color' symmetry, $SU(3)_C$, and that the quarks interacted via eight vector bosons (later called *gluons*), which acted as an octet in $SU(3)_C$ but as singlets in $SU(3)_f$: the original $SU(3)$ symmetry became known as 'flavor' $SU(3)_f$ symmetry. In addition, they proposed that the lowest mass hadrons were $SU(3)_f$ *singlets*: the baryons being composites of three quarks, each having a different color, while the mesons were composites of a quark and an antiquark of opposite colors.

The nature of the gluon fields is such that they lead to a 'runaway growth' of the fields surrounding an isolated color charge [6,17]. In fact, all this structure implies that an isolated quark would have an infinite energy associated with it, This is the reason why *isolated* quarks are not observed. Nature requires these infinities to be essentially cancelled or at least made finite.

It does this for hadrons in two ways: either by bringing an antiquark close to a quark, i.e. forming a meson or by bringing three quarks, one of each color together forming a baryon, so that in each case the composite hadron is *colorless*. It should be noted that in the color charge theory of Han and Nambu, that the combination of the three different colors, red + green + blue, is equivalent to the combination of two opposite colors, red + antired, i.e. 'zero' color charge. However, quantum mechanics prevents the quark and antiquark of opposite colors or the three quarks of different colors from being placed *exactly* at the same place. This means that the color fields are *not* exactly cancelled, although sufficiently it seems to remove the infinities associated with isolated quarks.

Currently, the strong nuclear force is considered to arise between quarks carrying a color charge, red, green or blue, and consequently is different in character from the force between colorless hadrons. The force between hadrons is a *residual interaction* acting between all the colored quarks of one hadron and all the colored quarks of the other hadron. This residual interaction is still sufficiently strong so that the neutrons and protons are bound together within atomic nuclei. The mediating particles between the colorless hadrons are colorless mesons such as the pions.

In 1973 the force between particles carrying a color charge, which has been termed the *chromodynamic force*, was developed into a more complete theory called *Quantum ChromoDynamics* (QCD), after the Greek word *χρομα* for color by Harald Fritzsch (1943-2022), Gell-Mann and Heinrich Leutwyler (1938-) [18]. The theory assumes that the chromodynamic force is mediated by eight electrically neutral massless particles having spin-1, called gluons. Each gluon carries both a single color charge and a single anticolor charge, and consequently gluons exert chromodynamic forces upon each other. These so-called 'self-interactions' of the gluons lead to two important consequencies: (1) *antiscreening effects* leading to an increase in the strong nuclear force field as the separation between the quarks increases and (2) *color confinement* leading to a finite range of the strong nuclear force [4].

Summary: Era of Modern Physics

The discovery of the neutron in 1932 raised questions concerning the existence of both the strong nuclear force and the CC weak nuclear force, which were very important developments for a 'Theory of Everything'.

Furthermore, it was recognized that the strong nuclear force binding the neutrons and protons together within atomic nuclei was short-ranged and also essentially charge independent for the *n* - *n*, *n* - *p* and *p* - *p* interactions, mediated by pions.

The proposal by Klein that the weak nuclear force could be mediated by massive charged bosons, W^+ and W^-, was a very important step in the development of the SM for the quest for a 'Theory of Everything'.

Furthermore, the experiments of Wu and others, who discovered that parity conservation was violated in weak nuclear interactions, was also an important contribution to the development of the SM in the quest for a 'Theory of Everything'.

The assumption of the strangeness additive quantum number *S* in 1953, which was *not* conserved in weak nuclear interactions, was a very *dubious* assumption, which was not necessary to describe the very slow decay of the so-called 'strange particles', since the decay process was mediated by massive *W* bosons. This led to several problems in the development of the SM that later was considered to be *incomplete*.

However, the introduction of the strangeness quantum number, which was conserved in both the strong nuclear and electromagnetic interactions did lead to a search for an extension of the strong isospin concept, based upon an *SU*(2) symmetry, to the classification of *hadrons*, based upon an *SU*(3) symmetry. This considered the division of the hadrons into 'families' comprising several multiplets into a larger set called a *supermultiplet*. Ultimately, this led to the *quark model*, which considered the particle members to be built out of three kinds of spin-1/2 quarks.

In the era of modern physics, many new particles, which were subject to the strong nuclear force, called *hadrons*, were created. Following the discovery of so many hadrons, considerable effort was made to understand and classify the various kinds of new particles, resulting in new models. In particular, the *quark model* proposed independently by Gell-Mann and Zweig in 1964 was important for the quest for a 'Theory of Everything'.

The quark model considered all the hadrons known at that time were composed of three elementary particles, called quarks by Gell-Mann: the up *u*, down *d* and strange *s* quarks, together with their corresponding antiparticles: $\bar{u}$, $\bar{d}$ and $\bar{s}$. Each meson was composed of a quark-antiquark pair, while each baryon was composed of three quarks and each antibaryon was composed of three antiquarks.

The quark model was based upon what became known as an $SU(3)_f$ flavor symmetry. Following the discovery of evidence for the existence of three more quarks, the charmed quark *c* in 1974, the bottom quark *b* in 1977 and the top quark *t* in 1995, the model was extended to an $SU(6)_f$ symmetry, and the whole set of six quarks formed six elementary particles of the SM.

The introduction of lepton conservation, analogous to baryon conservation, led to a very complicated classification of the six leptons, which eventually were considered to be elementary particles of the SM.

Consequently, in the SM the elementary particles that are the constituents of ordinary matter were assumed to be the six leptons: electron neutrino (ν_e), electron (e^-), muon neutrino (ν_μ), muon (μ^-), tau (ν_τ), tau (τ^-) and the six quarks: up (*u*), down (*d*), charmed (*c*), strange (*s*), top (*t*) and bottom (*b*), together with their antiparticles.

The incorrect assumption of the above twelve particles as *elementary* led to major problems for the SM and together with the strangeness problem discussed in Section 2.3, essentially led to the need for an alternative model of particle physics in the quest for a 'Theory of Everything'. This alternative model was termed the Generation Model (GM) of particle physics, which was developed from 2002-2019 [5] in order to overcome the fact that the quest for a 'Theory of Everything' had essentially come to a standstill in the late 20th century.

2.4 Models of Particle Physics

Introduction

The Standard Model of Particle Physics (SM) [6] and the Standard Model of Cosmology (SMC) [7] were developed as part of the quest for a 'Theory of Everything' during the 20th century. However, during the latter part of the 20th century, most scientists considered that both the SM and the SMC were *incomplete* in the sense that they provided little understanding of many empirical observations [3,6]: the existence of three generations of leptons and quarks, the origin of mass, the nature of the gravitational force, the matter-antimatter asymmetry problem, the origin of both *CP* violation and parity violation in weak nuclear interactions, the existence of strange quarks in the proton, etc.

As discussed in Reference 6, the incompleteness of the SM arose from several *dubious* assumptions made during the long-term development of the SM in the 20th century. This led to the necessary development of an alternative particle physics model, the GM [5,19], that removed several dubious assumptions inherent in the SM. The GM, including its development, has been described in some detail in Reference 6.

In April 2001, I was fortunate to attend a public lecture presented in Canberra, Australia by a then recent Nobel laureate, Martinus Veltman (1931-2021) concerning the "Facts and Mysteries in Elementary Particle Physics", prior to the publication in 2003 of his book with the same title [3]. Veltman stated that the *greatest puzzle of elementary particles was the occurrence of three families of elementary particles that have the same properties except for mass* in the SM.

It occurred to me that this three generation problem was analogous to the occurrence of similar patterns of the elements in Mendeleev's Periodic Table, in which groups of elements in columns of this table shared chemical properties and only differed in their atomic weights. All the atoms of these elements are not elementary but are *composites* of electrons, neutrons and protons.

This suggested to me, as it did to several other physicists much earlier [19], that the so-called elementary particles of the SM, the six leptons and the six quarks, as well as their antiparticles, were all actually *composite particles*. Furthermore, the equivalence in magnitude of the electric charges of the electron and proton, indicated that the electric charges of the quarks, comprising a proton, are intimately related to that of the electron, suggesting that the leptons and quarks are composed of the same kinds of building blocks. This in turn indicated that both leptons and quarks should be classified in terms of the same kinds of additive quantum numbers.

Consequently, the *nonunified* classification scheme of the SM, involving nine additive quantum numbers, charge (Q), lepton number (L), muon lepton number (L_μ), tau lepton number (L_τ), baryon number (A), strangeness (S), charm(C), bottomness (B) and topness (T), (see [6]), represented a major stumbling block for an alternative model to the SM.

The next two Sections will discuss the Failure of the SM and the Success of the GM as a 'Theory of Everything', respectively.

Failure of the SM as a Theory of Everything

First, the SM assumes that the fourteen particles, the six leptons, the six quarks and the *W* and *Z* bosons are all elementary particles and hence *massless*, since according to Einstein's theory of special relativity, the mass of a particle is related to its energy content *E* by the equation $m = E/c^2$, where *c* is the speed of light in a vacuum, and elementary particles have no energy content. This very dubious assumption led to a major problem for the development of the SM: "How did these fourteen particles acquire their observed masses?"

In the SM, the masses of the elementary leptons and quarks and the *W* and *Z* bosons are considered to arise from the existence of a 'condensate', analogous to the Cooper pairs in a superconducting material. This condensate, called the Higgs field was introduced by Robert Brout (1928-2011), Francois Englert (1932-) and Peter Higgs (1929-2024) in 1964 [20,21] in order to spontaneously break the $U(1) \times SU(2)_L$ local gauge symmetry of the electroweak interaction in the SM (see [6] for details) to generate the masses of the *W* and *Z* bosons. The Higgs field was also able to provide the finite masses of the leptons and quarks. Unfortunately, the introduction of the Higgs field within the framework of the SM leads to the introduction of fourteen new parameters. Indeed, as pointed out by Holger Lyre [22], the introduction of the Higgs field in the SM to spontaneously break the local gauge symmetry of the electroweak interaction, simply corresponds mathematically to putting in 'by hand' the masses of the fourteen elementary particles of the SM: the Higgs mechanism does *not* provide any physical explanation for the origin of the masses of the leptons, quarks and the *W* and *Z* bosons.

Unfortunately, the development of the Higgs mechanism in order to provide masses to the leptons, quarks and the *W* and *Z* bosons does not contribute anything towards prescribing any appropriate elementary particles as the building blocks of matter, so that the SM fails completely as a 'Theory of Everything'.

Success of the GM as a Theory of Everything

The development of a successful alternative model of particle physics to the SM commenced in 2002 [23]. This paper entitled "A Generation Model of the Fundamental Particles", was the first publication to mention the alternative model as the Generation Model (GM).

The paper describes a new *simpler and unified* classification of the elementary leptons and quarks of the SM in terms of only *three* additive quantum numbers: charge Q, particle number p and generation number g, rather than the more complicated and nonunified scheme of the SM involving the *nine* additive quantum numbers: charge Q, lepton number L, muon lepton number L_μ, tau lepton number L_τ, baryon number A, strangeness S, charm C, bottomness B and topness T, (see [6] for details).

The charge quantum number Q was introduced into the SM to describe the conservation of electric charge: in this 2002 GM, the charge quantum number serves the same purpose. The particle quantum number p replaces both the baryon quantum number A of quarks and the lepton quantum number L of leptons in the SM, so that $p = 1/3$ for quarks and $p = -1$ for leptons, essentially in agreement with the corresponding quantum numbers of the SM. The generation quantum number g replaces the remaining six additive quantum numbers of the SM: L_μ, L_τ, S, C, B and T. In this way, it distinguishes the different generations and lends its name to the model itself. The choice of $g = 0$ for the first generation of two leptons and two quarks, (ν_e, e^-, u, d), is natural since these are the constituents of ordinary matter for which the remaining additive quantum numbers are all zero.

The second major step in the development of an alternative model to the SM took place during the period 2003-2011 and resulted in the 2011 GM [5], which is a composite model of the leptons and quarks of the SM. Indeed, during the late 20th century , numerous such models had been proposed [24]. The underlying reason for this was that twelve elementary particles of the SM, the six leptons and the six quarks, was considered to be too many basic particles. In addition, there was considerable indirect evidence that the leptons and quarks were probably *composite* particles [6].

In the SM the six leptons and the six quarks can be grouped into three *generations* : (i) (e^-, ν_e, u, d), (ii) (μ^-, ν_μ, c, s) and (iii) (τ^-, ν_τ, t, b), and each generation contains particles that have similar properties. During 2001 I had concluded that a basic problem with the SM was its *nonunified* classification of its elementary leptons and quarks that presented a major stumbling block for the development of a composite model of these particles. Fortunately, in 2002 I had developed the 2002 GM, which did not suffer from the same stumbling block, since this model possessed a *unified* classification scheme of the leptons and quarks, Consequently, in 2003 I set out to develop a composite version of the 2002 GM. After considerable contemplation, this led to the 2011 GM, which was capable of describing the three families of the SM, in terms of a composite model of the leptons and quarks [6].

The 2011 GM is based partly upon the two elementary particle models of Haim Harari (1940-) and Michael Shupe (1946-2022) [25,26]. The elementary particles of the GM are two kinds of massless spin-1/2 particles, introduced independently in 1979 by Harari and Shupe to describe the electric charge states of the four particles, which constitute the first generation of the elementary particles and their antiparticles of the SM. In the GM, the two massless elementary particles are (i) a *T*-rishon with electric charge *Q* = +1/3 and (ii) a V-rishon with *Q* = 0. Their antiparticles are a *T*-antirishon with *Q* = -1/3 and a *V*-antirishon with *Q* = 0. In the GM, each lepton and quark is a composite particle of the elementary *T*-rishons, *V* -rishons and/or their antiparticles the *T*-antirishons and the *V*-antirishons. The elementary particles were named 'rishons' from the Hebrew word for primary by Harari.

The GM recognizes only two fundamental forces in nature: (1) the usual electromagnetic force, mediated by massless neutral spin-1 photons between electrically charged particles, and described by a *U*(1) local gauge theory, called Quantum ElectroDynamics (QED) [27], and (2) the strong nuclear force, mediated by massless neutral spin-1 hypergluons between rishons and/or antirishons carrying a color and/or anticolor charge, respectively, and described by an *SU*(3) local gauge theory, called Quantum ChromoDynamics (QCD) [18]. There are eight independent kinds of hypergluons, each of which carries a combination of a color charge and an anticolor charge, e.g. red-antigreen.

The strong nuclear force between the color (anticolor) charges carried by the quarks (antiquarks) is such that in nature the quarks and antiquarks are grouped into composites of either three quarks of different colors or three antiquarks of different anticolors, called baryons and antibaryons, respectively, or as a composite of a single quark and a single antiquark, called a meson, in which the quark and antiquark carry opposite colors, e.g. red and antired. In this QCD formulation, each baryon, antibaryon or meson is *colorless*, analogous to the case in the SM. Thus, the two fundamental forces of the GM are essentially equivalent to the corresponding fundamental forces of the SM: the only essential difference is that in the GM, the color charges are carried by the elementary rishons, rather than the elementary quarks of the SM. The same is also true for the residual strong nuclear forces acting between the quark constituents of colorless hadrons, mediated by colorless mesons, which are sufficiently strong so that neutrons and protons are held together within atomic nuclei.

In the following Sections it will be indicated how the GM successfully provides an understanding of many problems and puzzles associated with the SM and the SMC,

Three Generations of Leptons and Quarks:

In the GM, the six leptons and the six quarks, of the SM, are not elementary particles but are composite particles, consisting of three, five or seven, *T*-rishons, *V* -rishons, *T*-antirishons and/or *V*-antirishons, for the first, second and third generations, respectively [6,19].

In the case of the first generation, each lepton exists in an antisymmetrical three-particle colorless state, which physically assumes a quantum mechanical triangular distribution of three differently colored identical rishons (or antirishons), since each of the three-color interactions between pairs of rishons (or antirishons) is expected to be strongly attractive [28]: the elementary rishons or antirishons are held together by the appropriate massless hypergluons. Each quark of the first generation, is a composite of a colored rishon and a colorless rishon-antirishon pair, so that the quarks carry a color charge. Similarly, the antiquarks are a composite of an anticolored antirishon and a colorless rishon-antirishon pair so that the antiquarks carry an anticolor charge. All the rishons and antirishons of the first generation are assumed to be in the lowest 1s quantum state. The rishon structures of the second-generation particles are the same as the corresponding particles of the first generation plus the addition of a colorless rishon-antirishon pair, which is a combination of a $\overline{V}^{*}V$ and a $\overline{V}V^{*}$ pair, that have $Q = p = 0$ but $g = \pm 1$, respectively, [6,18]. The rishon structures of the third generation are the same as the corresponding particles of the first generation plus the addition of two such rishon-antirishon pairs. The excited V-rishon and its antiparticle are assumed to be in a 2s quantum state. In this way, the pattern for the first generation is repeated for both the second and the third generations of leptons and quarks.

Origin of Mass:

In the SM (see Section 2.4), most of the mass of ordinary matter (protons and neutrons) is attributed to the energy of their constituents, while the mass of each elementary particle (lepton, quark or gauge boson) arises from the coupling of the particle to the Higgs field.

In the GM, the mass of a lepton, quark or vector boson, arises entirely from the energy stored in the motion of the constituent rishons and/or antirishons and the energy of the color hypergluon fields, according to Einstein's equation $m = E/c^2$. Thus unlike the SM, the GM provides a *unified* description of the origin of all mass, and avoids the requirement for the existence of a Higg's field to generate the mass of any particle.

Origin of Gravity:

During the development of the SM in the 20th century, the SM assumed that since the gravitational force is so much weaker than the other three so-called fundamental forces, it played no role in particle physics. Consequently, the SM made no attempt to understand the gravitational so-called fundamental force.

In the GM, both the leptons and the quarks of the SM, have a substructure, consisting of spin-1/2 massless particles, rishons and/or antirishons, each of which carries a single-color charge, red, green or blue (see [6,18] for details), mediated by massless neutral hypergluons, acting between the color charged rishons and/or antirishons. In the GM, the strong chromodynamic force has been taken down one level of complexity, by the introduction of the elementary rishons and/or antirishons, to describe the composite nature of the leptons and quarks.

Consequently, in the GM, between any two colorless particles, electron, neutron or proton, there exists a *residual* interaction arising from the color interactions acting between the rishons and/or antirishons of one fermion and the color charge constituents of the other fermion. In the GM, this is identified as the usual gravitational interaction, acting between the electrons, neutrons and protons, which provide the total mass of a body of ordinary matter, since such residual interactions have several properties associated with the usual gravitational interaction: universality, very weak strength and attraction (see [6,19] for details).

Consequently, the gravitational force is a universal attractive very weak complex residual force of the strong nuclear force, acting between the three massive particles, the proton, the neutron and the electron, which are the constituents of the atoms of a body of ordinary matter.

In the GM, the gravitational force is *not* a fundamental force, as it has been considered for many years, but is a *residual force* of the strong nuclear chromodynamic force. Moreover, this residual chromodynamic force provides a fully quantum theory of gravity, as was considered essential by most scientists during the later 20th century, since the GTR was considered to be *incompatible* with quantum mechanics [12]. Thus the GM provides, for the first time, an understanding of both the *cause* and the *real nature* of the gravitational force.

Furthermore, the gravitational interaction in the GM, which has been identified with the interfermion color interactions between the colorless particles, electrons, neutrons and protons, has two additional properties arising from the self-interactions of the hypergluons, mediating the residual interaction: (1) antiscreening effects and (2) color confinement. These two additional properties of the interfermion color interactions provide an understanding of both *dark matter* and *dark energy*, in terms of modified gravity [6,19].

In the GM, the gravitational interaction has been identified with the very weak, universal and attractive residual interfermion color interactions acting between the colorless particles, electrons, neutrons and protons, that essentially constitute the total mass of a body of ordinary matter. This interaction suggests a universal law of gravitation, which closely resembles Newton's original law that a spherical body of mass m_1 attracts another spherical body of mass m_2 by an interaction proportional to the product of the two masses and inversely proportional to the square of the distance r, between the centres of mass of the two bodies: $F = H(r)m_1m_2/r^2$, where Newton's gravitational constant G is replaced by a function of r, $H(r) = G(1+kr)$, so that it is only for small r that $H(r)$ is $\approx G$ and gravity is approximately Newtonian.

For large r, $H(r)$ is approximately Gkr so that the main effect arising from the selfinteractions of the hypergluons, mediating the residual color interaction corresponding to the gravitational interaction of the GM, is to modify Newton's universal law of gravitation so that there is additional gravity at large galactic distances than that predicted by Newtonian mechanics. This describes the flat rotation curves observed by Vera Rubin (1928-2016) and collaborators in spiral galaxies, such as the Andromeda galaxy, since at sufficiently large distances, the effective gravitational field behaves essentially as $1/r$, and there is no requirement for the presence of any so-called dark matter.

However, the self-interactions of the hypergluons are expected to *cease* at a sufficiently large distance. This finite range arises from the *color confinement* property [4], which causes the residual color gravitational interaction to produce colorless particles, rather than continuing to modify Newton's universal law of gravitation by producing additional gravity at larger distances. This process takes place when the gravitational field energy is sufficient to produce the mass of a particle-antiparticle colorless pair. It is completely analogous to the 'hadronization process', involving the formation of hadrons out of quarks and gluons, which leads to the finite range ($\approx 10^{-15}$m) of the strong color interaction in the SM.

In the gravitational case, the relative intrinsic strength of the interaction is about 10^{-41} times weaker than the strong color interaction at 10^{-15}m [4]. This suggests that the equivalent process to hadronization in the gravitational case should occur at a cosmological distance of about 10^{26}m, i.e. roughly 10 billion light-years (one light-year is ≈ 10^{16}m). This result agrees well with the observations of Adam Riess (1969-), Brian Schmidt (1967-), Saul Perlmutter (1959-) and collaborators. Both teams found that the supernovae observed about halfway across the observable universe (6-7 billion light years away) were *dimmer* than expected and concluded that the expansion of the Universe was *accelerating* rather than slowing down as expected. In the GM, the supernovae observations correspond to the *finite-range* of the gravitational field, rather than the requirement of so-called *dark energy* to overcome gravity.

The GM suggests that the photon is the standard *singlet* state corresponding to the QCD color octet of hypergluons binding together the rishons and antirishons of the leptons and quarks in the GM. The singlet hypergluon state, consisting of all three color charges as well as three anticolor charges, is massless, electrically neutral, colorless and has spin-1 and $U(1)$ symmetry, so that it has all the appropriate properties of the photon.

The GM predicts that such a photon will be deflected by massive bodies, such as the Sun, by an amount that is twice the value predicted by the GM for the deflection of ordinary matter. Thus, the gravitational interaction of the GM, predicts the same deflection of light rays, consisting of photons, assumed to be singlet state hypergluons, in agreement with Einstein's GTR but without any warping of spacetime. It should be noted that in principle, the gravitational interaction of the GM is also able to account for the anomalous advance of the perihelion of Mercury in terms of the additional $1/r$ term in its gravitational interaction [6].

Matter-Antimatter Asymmetry Problem and Energy Conservation:

The matter-antimatter asymmetry problem, corresponding to the virtual absence of antimatter in the Universe, is one of the greatest mysteries of cosmology.

The SMC [7] assumes that the Universe was created in the Big Bang from pure energy, and is now composed of about 5% ordinary matter, 27% dark matter and 68% dark energy. In Section 2.4., it was indicated that in the GM, both dark matter and dark energy can be replaced by a modified Newtonian-like gravitational field, so that the only matter in the Universe is ordinary matter, and all the remaining energy is within the gravitational and electromagnetic fields.

It is also generally assumed that the Big Bang produced *equal numbers* of particles and antiparticles. This leads to the matter-antimatter asymmetry problem, since the Universe today is generally considered to consist almost entirely of matter (particles) rather than antimatter (antiparticles): Where have all the antiparticles gone?

During the development of the SM, the introduction of the "partially conserved" strangeness additive quantum number S (see Section 2.3) led to a major classification problem of the elementary particles of the SM, which resulted in the SM being considered to be *incomplete* and to its failure as a 'Theory of Everything'.

In the GM, it was demonstrated in 2002 [23] that a *simpler* and *unified* additive quantum number classification scheme was feasible, which conserved the three additive quantum numbers, charge Q, particle number p and generation quantum number g, in all interactions, provided that each force particle had $p = g = 0$.

In the GM, the solution of the matter-antimatter asymmetry problem involves the particle additive quantum number p, in particular the values of p corresponding to the electron ($p = -1$) and the quarks ($p = +1/3$) so that the proton, which is composed of three quarks, has $p = +1$. Consequently, the hydrogen atom has $p = 0$ and consists of an equal number of rishons and antirishons, so that there is no asymmetry of matter and antimatter there.

In the GM, antihydrogen consists of the same rishons and antirishons as does hydrogen, although the rishons and antirishons are differently arranged in the two systems so that antihydrogen also has $p = 0$. Thus, the ordinary matter present in the Universe, prior to the fusion process into heavier elements, has essentially $p = 0$. Since p is conserved in all interactions, this implies that the overall particle number of the Universe will remain as $p = 0$, i.e. symmetric in particle and antiparticle matter.

Furthermore, the above also implies that the original antimatter created in the Big Bang is now contained within the stable composite leptons, i.e. electrons and neutrinos, and the stable composite quarks, i.e. the up and down quarks, that comprise the protons and neutrons. This explains where all the antiparticles have gone.

It should be noted that the allocation of a finite value of p, i.e. $p = +1/3$ to massless rishons and $p = -1/3$ to massless antirishons, implies that the additive quantum number p represents mass-energy, rather than pure mass, in addition to its particle or antiparticle nature. Indeed, conservation of p means that mass-energy, or since mass is essentially concentrated energy according to $m = E/c^2$, simply that energy is *conserved* in the Universe.

The Cause of Parity Violation in CC Weak Nuclear Interactions:

In Reference 2, Abraham Pais (1918-2000) concludes on p.542 that “we do not understand why parity is violated if, and only if, weak interactions intervene, and none of the great advances of unified gauge theories have shed any light on this problem: these theories incorporate the parity violations but do not explain them.”

This failure of the SM, emphasized in Reference 2, arises from several *dubious* assumptions made during the long-term development, 1932-2000 of the SM and led to the development of an alternative model, termed the GM [5,19], during the years 2002-2019. In the GM these dubious assumptions are corrected and the GM leads to an explanation, i.e. the *cause* of the parity violations in CC weak nuclear interactions.

As described in Section 2.3, parity violation in CC weak nuclear interaction was proposed in 1956 by Tsung-Dao Lee and Chen-Ning Yang in order to resolve the ‘theta-tau’ puzzle, involving the parity of pions. This was rapidly confirmed in 1956-57 by several groups, including Chien-Shiung Wu and collaborators in late 1956 [15].

During 1957 it was shown that the “V-A” theory of the CC weak nuclear interactions, developed by George Sudarshan (1931-2018) and Robert Marshak (1916-1992) [29] described the observed parity violations in terms of a vector (V) interaction with negative parity and an axial vector (A) interaction with positive parity. In 1958 Richard Feynman and Murray Gell-Mann published a similar V-A theory of the CC weak nuclear interaction [30].

However, although within the framework of the SM, parity violations in CC weak nuclear interactions are able to be *described* in terms of the V-A theory, the SM fails to provide an understanding of the *cause* of parity violations in CC weak nuclear interaction processes.

The main dubious assumptions of the SM that are important for understanding the *cause* of parity violation in CC weak nuclear interactions are the following: (1) the assumption that the six leptons and the six quarks are *elementary* particles, while there exists considerable indirect evidence that they are *composite* particles; (2) the assumption of a *nonunified* and complicated classification scheme of the elementary leptons and quarks in terms of additive quantum numbers, some of which are *not* conserved in CC weak nuclear interaction processes; and (3) the treatment of the *universality* of the CC weak nuclear interaction in terms of Cabibbo quark mixing, which assumes that the weak interaction is *shared* between strangeness-conserving and strangeness-changing transition amplitudes [4,19].

The GM replaces each of the above dubious assumptions by different ones: (1) the leptons and quarks are *composite* particles, composed of two kinds of massless rishons and their antirishons [19]; (2) the simpler and unified classification scheme of the leptons and quarks [23]; and (3) the mass eigenstate quarks of the same generation form weak isospin doublets, e.g. (d, u), and couple with full strength of the CC weak nuclear interaction like the lepton doublets, e.g. (ν_e, e^-) [6].

The development of a *unified* and simpler classification scheme of additive quantum numbers in the GM enabled a successful composite model of the elementary leptons and quarks of the SM, to be developed [19]. In particular, the GM led to an understanding of the three generations of leptons and quarks that have the same properties except for mass in the SM, (see Section 2.4).

In the GM, the mass eigenstate quarks of the same generation, e.g. (d, u), form weak isospin doublets and couple with the full strength of the CC weak nuclear interaction, so that there is no coupling between mass eigenstate quarks from different generations. This corresponds to the conservation of the generation quantum number g in CC weak nuclear interaction processes. Essentially, in the GM, quark mixing is placed in the wave functions rather than in the interactions as in the Cabibbo quark mixing technique [4,19], assumed in the SM, as a consequence of the assumption of the 'partially conserved' strangeness quantum number S.

The building blocks of the GM are massless spin-1/2 rishons and antirishons, that have intrinsic parity P = +1 and P = -1, respectively. This implies that all the composite leptons and quarks also have intrinsic parity P = ±1, depending upon the number of rishons and the number of antirishons comprising each composite particle, provided each rishon and antirishon exists in an s state [6] .

In the GM, both the W^+ and W^- bosons, that mediate the CC weak nuclear interactions are composites of three rishons and three antirishons, existing in a 1s state, so that both the W^+ and W^- bosons have intrinsic parity P = -1 [6].

Consequently, in general, the universal CC weak nuclear force, mediated by the *W* bosons, acts between the two particles of the six weak isospin doublets: (e^-, ν_e), (μ^-, ν_μ), (τ^-, ν_τ), (*d*, *u*), (*s*, *c*) and (*b*, *t*), which have the same intrinsic parity, causing each interaction to *violate* parity as a consequence of the negative intrinsic parity of both the *W* bosons. At low energies, this parity violation is almost 100%, since the *W* boson's large mass ensures that the *W* boson exists essentially in an S state, in agreement with experiment.

To summarize: the negative intrinsic parity of the *W* bosons is the *cause* of parity violation in CC weak nuclear interactions.

Mixed Quark States in Hadrons:

The GM postulates that hadrons are composed of weak eigenstate quarks rather than mass eigenstate quarks as in the SM. It should be noted (see [6,19] for details) that the weak eigenstate down quark d' contains about 5% of the mass eigenstate *s*-quark. This gives rise to important consequences.

First, the occurrence of mixed-quark states in hadrons implies the existence of higher generation quarks in hadrons. In particular, the GM predicts that the proton, having two *u* and one d' quarks contains about 1.7% of strange quarks, while the neutron, having one *u* and two d' quarks, contains about 3.4% of strange quarks.

In the SM, strange quarks form part of the 'sea' of quark-antiquark pairs arising from the spontaneous pair creation from the gluons inside the proton. In the GM, one has a combination of the sea quark-antiquark pairs arising from the spontaneous pair creation from the hypergluons inside the proton, and in addition the strange quarks present inside the proton, arising from the approximately 5% content of the strange quarks in the d' quark within the proton.

Several experiments have been conducted in Mainz, Germany and at the Jefferson Laboratory, New Norfolk, USA in 2005 and more recently at the LHC in CERN in 2017. Unfortunately, none of these difficult experiments have been able to determine sufficiently accurately the actual percentage of strange quarks within the proton.

Second, the presence of strange quarks in nucleons provides an understanding of why the mass of a neutron is greater than the mass of a proton, so that the proton is stable [31]: the neutron in the GM contains approximately twice as many strange quarks as the proton.

Third, the presence of mixed-quark states in hadrons implies that mixed-quark states may have *mixed parity*. In the GM, the constituents of quarks are both rishons and antirishons, which have parity P = +1 and parity P = -1, respectively. Consequently, the *d*-quark and the *s*-quark have opposite intrinsic parities: the *d*-quark consists of two rishons and one antirishon, so that the parity of the *d*-quark is P_d = -1, while the *s*-quark consists of three rishons and two antirishons, so that the *s*-quark has parity P_s = +1 (see [6] for details).

An important consequence of the mixed-quark states in hadrons is that charged pions have *mixed parity*. This provides a quantative description of the decay of the long-lived K^0 meson into two charged pions, as discovered by James Cronin (1931-2016), Val Fitch (1923-2015) and collaborators in 1964, that brought about the surprising conclusion that *CP* may be violated in CC weak nuclear interactions, if the parity of charged pions was P = -1, which was assumed to be the case in the SM. In the GM, the mixed parity of the charged pions provides a quantatative description of the decay of the long-lived K^0 meson into two charged pions *without the violation of CP symmetry* in the CC weak nuclear interaction process [32].

Discussion and Conclusion

The development of a successful alternative to the SM, the GM, took place from 2002-2019 and is described in Reference 6, which also indicates that the incompleteness of the SM arose from several dubious assumptions made during the development of the SM in the 20th century.

In this Section, only the successful highlights of the GM will be recorded, since several of the dubious assumptions of the SM have already been discussed in this paper.

The main differences between the SM and the GM is that they have different elementary particles operating on different levels. In the GM, the strong chromodynamic force has been taken down one layer of complexity, by the introduction of the elementary rishons and/or antirishons to describe the composite nature of the leptons and quarks.

In the GM both the leptons and quarks of the SM, have a substructure, consisting of spin1/2 massless particles, rishons and/or antirishons, each of which carries a single-color charge. These constituents of the leptons and quarks are bound together by strong color interactions, mediated by massless neutral vector hypergluons, acting between the color charged rishons and/or antirishons.

As indicated earlier, this model leads to a quantum theory of gravity and an understanding of both dark matter and dark energy (see [6] for details). It also permits a new simpler and unified classification scheme for the leptons and quarks involving only three additive quantum numbers: charge Q, particle number p and generation number g, which are conserved in all interactions, provided each force mediating particle has $p = g = 0$. In particular, this led to the GM providing a solution to the famous matter-antimatter asymmetry problem [6]. It also led to the *W* bosons having negative parity, which describes the approximately 100% parity violations observed at low energies of the CC weak nuclear interaction [15]. The model also predicts that the Higg's boson is not required to provide the masses of the 14 elementary particles of the SM, and that the boson discovered at CERN in 2012 with a mass of about 125 GeV with spin and parity 0^+ is probably an excited Z^0 boson. Finally the model also predicts that *CP* is conserved in CC weak nuclear interactions[32].

In conclusion, I consider that the incomplete SM should be replaced by the GM, which as indicated above provides an understanding of so many problems associated with both the SM and the SMC. Indeed, today the GM seems to be a complete model of particle physics and an appropriate 'Theory of Everything'.

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