
Designed by

The Theory of Everything

A research submitted
By

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To our parents,

to every enthusiastic physicist,

and to every person who is interested in the field of physics.

Acknowledgment

Thanks to Allah, the most holly and most gracious, who gave us the ability to work on this research.

Thanks to our beloved Dr. Hala Al Jawhari for her full assistance, guidance and time. Not only did she teach us physics, but also good and noble manners.

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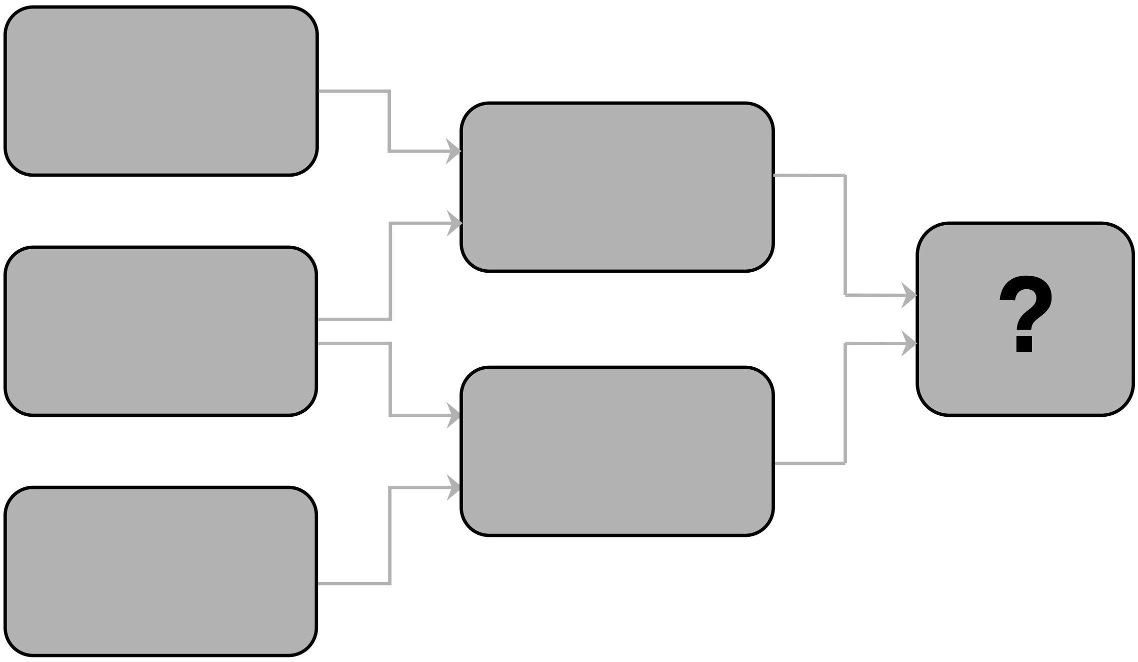
Introduction



Introduction

The story of unification has been the concern of many if not all people. Ever since mankind has been on earth, the search for reality has been going through a non-stop research. When we say "the search for reality" as Muslims we mean the search for Allah and his elegance in creation. Some might disagree with this point of view, since many scientists today believe in nature and chance, and aim to prove their beliefs via science. Not concerned with the inner beliefs of ambitious physicists working on unification of physics theories and laws, we can see that most if not all of them work in the same track towards a better understanding of nature, through experiments and math.

In our research we tried to track down this progress. So we started our first chapter with the ideas of the B.C. philosophers about the physical world, and how they led to the birth of *Classical Physics* which included *Newtonian Mechanics* and *Electromagnetism*. Newtonian Mechanics unified the laws of motion on earth with the planetary motion in the outer space, while the Electromagnetic Theory of Maxwell unified *Electricity* and *Magnetism*. Then we shed light on Einstein's two great achievements; *Special Relativity*, which unified the two fields of classical physics under a more general relativistic frame, and *General Relativity*, which gave a totally different view of gravity.

In the second chapter we introduces the main concepts of *Quantum Mechanics*, the field of physics which deals with tiny objects, fluctuations and uncertainties. Quantum Mechanics shocked the world with its strange but useful ideas and descriptions of unexplained phenomena. It also reopened the door to the study of elementary particles and fundamental forces in a new way, under what is called *Particle Physics*.

After the entrance of Quantum Mechanics to the world of physics, physical phenomena were described either in a *relativistic* or a *quantum mechanical* way. There is no general frame that can hold these two different pictures together. This was a problem that physicists had to face, and "facing it" is what they did. As a result, *Quantum Field Theory*, QFT, was introduced to unifying Special Relativity and Quantum Mechanics. Somehow, QFT did not include General Relativity, so a new task had to be tackled, the unification of General Relativity and Quantum Mechanics. This was and still is the aim of Theoretical Physicists.

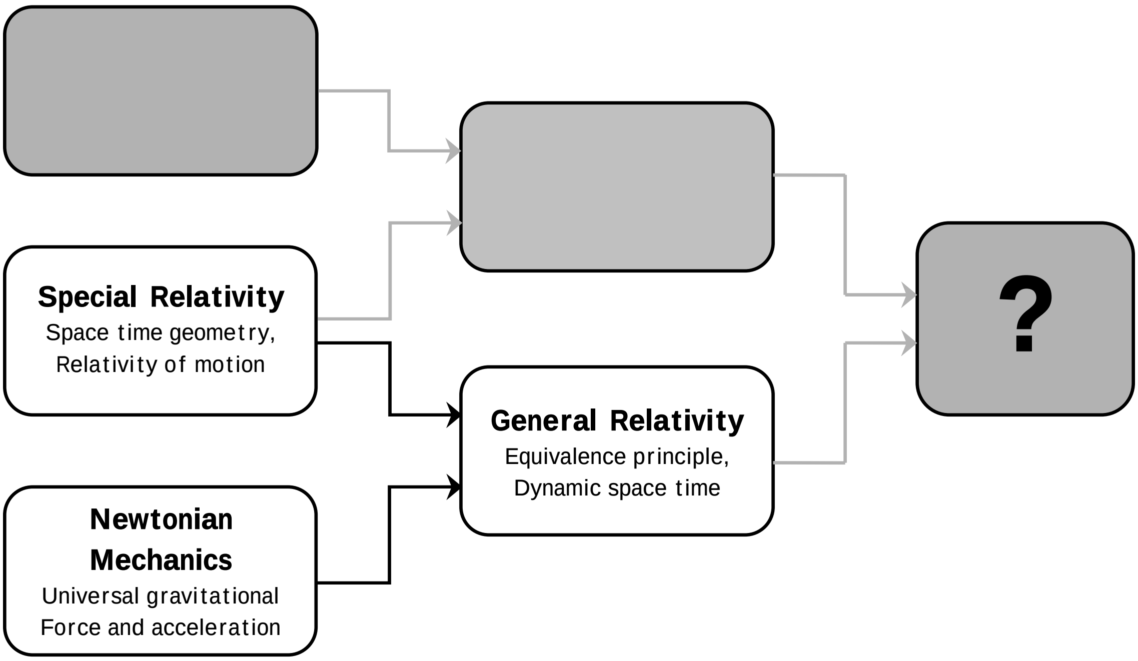
Several ideas and theories were proposed to be the final theory. Groups of physicists and mathematicians are working on them, making debates and fighting to complete their theories hoping to achieve the universal acceptance. Among all the trials there are two theories that seem to be promising; String Theory and Loop Quantum Gravity. An introduction of the former is the subject of our third chapter, while in the forth chapter the latter is briefly described.

Both theories are, by far, too hard to understand and their mathematics are beyond the scope of this work. But this did not stop us from gathering the little pieces of information from journals, books and websites. We then tried to fit them in their places to complete a considerably small simplified knowledge about what is going on.

We hope that our small undergraduate research adds something new to the reader, and plays a role in reshaping and linking the blocks of physics studied previously as separate subjects to form the overall building of Physics.

Chapter (2)

Physics from Classical to Relativity



2.1 Classical physics

Classical physics was developed between 1650 and 1900 based on:

- Idealized mechanical models that can be subjected to mathematical analysis and tested against observation.
- A vast amount of observational data concerning electricity and magnetism. [1]

Let us see how each of these two fields was developed.

2.1.1 Classical Mechanics:

1. The idea of force causes motion goes back to **Aristotle (384-322 B.C)** time; he studied motion and divided it into two main types: *natural motion,* i.e. every object tries to seek its rest place and *violent motion* which was the result of forces that pushed or pulled. The idea of the resting earth has a base for the thinkers in the ancient history; they considered that a needed force to move the earth must be huge and unthinkable, so the earth does not move and must be in its natural resting place [2].

Aristotle
322-384 B.C

Aristotle also wrote a book (on the heavens) describing planetary system which is based on four believes:

- The world was spherical in shape and not flat.
- The earth is the center of the universe.
- Stars were fixed to celestial sphere.
- Perfect circular motion in planetary system [3].

2. Archimedes (287-212 B.C) discovered fundamental theorems concerning the centre of gravity of plane figures and solids. His most famous *Archimedes principle* in which he stated: That any body completely or partially submerged in a fluid is acted upon by an upward force which is equal to the weight of the fluid displaced by the body. [4]

Archimedes
212-287 B.C

3. Claudius Ptolemaeus (87-150 A.D) worked on the planetary system and created model for the universe that could predict the movements and actions of sphere in the Heavens [3].

Claudius Ptolemaeus

4. Nicolaus Copernicus (1473-1543) established *the heliocentric model of the Universe*, in which he stated that sun is the center of the universe and the earth, is just another planet in the planetary system, even with his hard work and his certainty of his hypothesis he worked in secret and did not publish his work until the day he died to escape persecution [3].

Nicolaus Coprenicus

5. The Italian scientist **Galileo** was one of the classical mechanics builders, He was the first to redefine the definition of a force and fraction by the idea that a force is only needed in the presence of a fraction to keep an object moving and that it's necessary to keep an object moving. [4]. He formulated a principle for relativity named for him *Galilean relativity* and he defined inertial frame of reference as straight lines that move with a constant velocity with respect to each other. In his relativity: to transform the velocity of an object from one frame to another, the vector representing the velocity of the object is added to the vector representing the velocity difference between the two reference frames. Such a transformation is called *Galilean transformation*. This transformation is used in the case of relative motion to transform between two different systems in the coordinates and velocities. [10]

Galileo

6. Johannes Kepler (1571-1630) published between 1609 and 1619 his three laws of planetary motion [8].

- Planets move in elliptical orbits with the sun at one focus.
- Planets do not move with constant speed along this orbit but their speed varies so that the line joining the centers of the sun and a planet sweeps out equal parts of the ellipse in equal times.
- the third power of the average distance of a planet from the sun is proportional to the square of the length of its year [9].

Johannes Kepler

7. The father of classical physics and the great mathematician **Newton** came **between (1643-1727)**. He used his knowledge in calculus to formulate mathematical notations on the force and motion based on the ideas of Aristotle and Galileo. In his book '*principia*' he published his theorems: description of motion, three laws of motion described in figure (2.1), theory of gravitation and definitions of space and time [1].

Newton

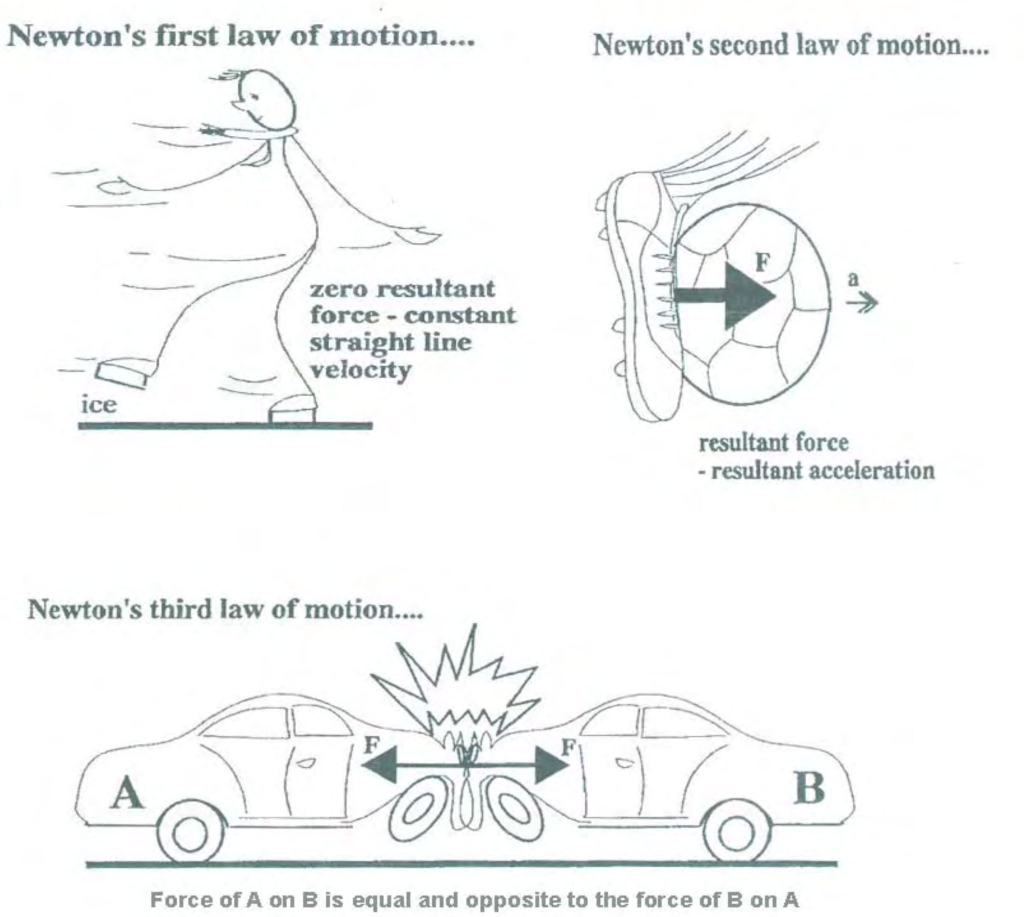


Figure (2.1) Newton laws of motion

Newton, then tried to unify the planetary system with the earth by saying that the force responsible for falling and moving objects on the earth is the same as that keeps the planets moves around the sun. He called this force the *gravitational force (gravity)* and showed that the gravitational force between two masses m1 and m2 is given by the relationship.

$$F_{gravity} = \frac{Gm_1m_2}{r^2}$$

The force is always attractive and acts along the line joining the centers of mass of the two masses. The forces on the two masses are equal in size but opposite in direction. [1]

With all his achievements on the law of gravity Newton did not have an explanation of why or how this force works [5].

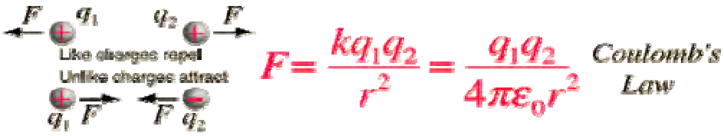
2.1.2 Electromagnetism:

Until the end of the 19th century, Newton's laws seemed to define the material world completely even the behavior of atoms and electrons.

But, then Maxwell came and provided an explanation of the other half of the physical world, the world of waves and light [4].

1. The beginning of this new field was when **Coulomb Charles Augustin (1736 – 1806)** investigated the law of electrical repulsions of like and unlike charges, which led him to develop his famous law which known as the *inverse square law* [7], and states that the force between two electrical charges is proportional to the product of the charges and inversely proportional to the square of the distance between them. [6]

Coulomb Augustin



This law which is also known by his name *coulombs law* satisfies Newton's 3rd laws indicates the direction and the magnitude of the electric force. The unit of an electric charge is named in his honor, the *coulomb* [7].

2. The Italian physicist **Alesandro Volta (1745-1827)** was known for the development of the electric battery. He was the one that devised the first (volt) meter and the contact potential [13].

Alesandro Volta

3. Andre Marie Ampere (1775-1836) was the first to define that magnet produces current and by this put the foundation of the mathematical theory of electromagnetism.The measurement unit of the electric current *ampere* is named after him [17].

Ampere

4. Gauss (1777-1855) derived a relation between the electric flux and the electric charges which was the electric equivalent of Ampere's law [14].

5. George Simon Ohm (1787-1854) produced famous studies of current which ended with his famous law in electricity *ohm's law*. This law states that the potential difference or voltage drop V between the ends of a conductor and the current I flowing through the conductor are proportional at a given temperature, i.e $v = IR$. From this equation we can calculate the constant *R*, which is the electrical resistance of the device [15].

Ohm

6. Michael Faraday (1791-1867) then introduced the law of induction that relates between the rate of change in the magnetic flux and the electric field. He was also the first to introduce the *concept of a field*. The SI unit of capacitance, the farad (symbol F) is named after him [18].

Michael Faraday

7. After that **Joseph Henry (1797-1878)** discovered the phenomenon of *self induction* which is a property of a circuit that causes an opposing in voltage when the circuit is broken or made. The SI unit of inductance named by him the *Henry*. In fact his work on the electromagnetic relay was the basis of the electrical telegraph, jointly invented by Morse and Wheatstone [16].

Joseph Henry

8. Between (1831-1879) James Clerk Maxwell came with the theory of electromagnetism. The theory states that a time-varying electric field generates a magnetic field and vice versa. This theory unified the main laws of electricity and magnetism in four fundamental equations known by his name *Maxwell's equations*, as shown in table (2.1). Until his time no one related the electricity and magnetism in one theory. [11]

Maxwell

In addition to this theory, Maxwell defined light as an electromagnetic wave with a wavelength that is visible to the human eye. So the speed of light is equal to the speed of the electromagnetic wave, which is determined by a constant, c, arisen from electrical and magnetic phenomena [12].

The law	**Maxwell equations**
Gauss law of electricity	$\nabla.E = \frac{\rho}{\varepsilon_0} = 4\pi k\rho \quad , \oint E.dA = \frac{q}{\varepsilon_0}$
Gauss law of magnetic	$\nabla.B = 0 \, , \oint B.dA = 0$
Faradays law of induction	$\nabla x E = -\frac{\partial B}{\partial t} \, , \oint E.ds = -\frac{d\phi}{dt}$
Ampere's law	$\oint E.ds = \mu_0 i + \frac{1}{c^2}\frac{\partial}{\partial t}\int E.dA$

Table (2.1) The Four equations of electromagnetism.

9. In **1895 Lorentz** provided an equation of motion for charged particles in the field.


Lorentz

His equation shows that the force produced by an electric field is parallel to the field and independent of the velocity of the charge whereas the magnetic force is experienced only by a moving charge and is always perpendicular to the velocity and field.

Combining Lorentz's equation of motion with Maxwell's equation gives a complete theory for electromagnetism [1].

2.1.3 Unification between the two fields:

Many scientists were trying to unify the two main fields in physics: the Newtonian mechanics and the electromagnetic theory of Maxwell, But all attempts to apply Galilean relativity to Maxwell equations failed.

The problem was that the speed of light was not invariant and so the electromagnetic effect would not be the same for different inertial observers. [1]

To solve this conflict, there were only three suggestions:

- Galilean relativity exists for both mechanics and electromagnetism but the laws of electromagnetism are not correct. If that is true we must be able to perform experiments show deviations from Maxwell's laws.
- Galilean relativity exists for both mechanics and for electromagnetism but the laws of mechanics as driven by Newton are not correct. If that is true we should be able to perform experiments which show deviation from Newtonian mechanics. In this case a new transformation should be established.
- Galilean relativity exists only for mechanics but not for electromagnetism, where there is an absolute inertial frame called *ether*. If that is true we would be able to locate the ether frame experimentally. [19]

Since no deviation from Maxwell's laws could be observed, the first idea was rejected and the other two were put on test, this was the start of another major road in physics.

2.2 Einstein and Relativity:

2.2.1 The Quest for the Ether:

As it was mentioned previously there were many attempts to remove the contrariety between classical mechanics and electromagnetism. One of these attempts suggested that Galilean relativity exists only for mechanics but not for electromagnetic, and electromagnetic waves have an absolute inertial frame special for them called (*ether*). Many scientists try to check this idea.

In 1888 Michelson and Morley carried out an experiment to detect the presence of the ether surrounding the Earth by comparing the speed of light in the direction of the Earth's motion with the speed of light perpendicular to the Earth's motion. According to the classical laws of motion derived by Galileo , light travel faster when it is moving in the same direction as the Earth , but they found the speed of light does not change , Earth's motion through the space had no effect on the speed of light , so the existence of *ether* was thrown into doubt . This led to the only left suggestion, which needs a correction of classical mechanics and a correct transformations that fit for both classical mechanics and electromagnetism. [20]

2.2.2 Special Relativity:

At 1905 Einstein proposed a universal theory of relativity which dismissed the need for the ether. This theory was called *the Special Theory of Relativity*. It was special since it was only applicable to the inertial frames of reference. [1, 20]

This theory is based on two postulates:

i. The Two Postulates of the Theory:

The first postulate: the laws of physics expressed as equations should always take the same form in all inertial frames of reference.

As a consequence of the first postulate, Einstein showed that the transformation rules worked out by Galileo and by Newton do not allow equations that describe the progress of electromagnetic wave to be transformed. Einstein worked out the correct transformation equations by using the Lorentz factor γ [20]

$$\boxed{\gamma = \frac{1}{\sqrt{1-\beta^2}} \qquad \beta = \frac{v}{c}}$$

γ is always greater than or equal to 1.

These transformations involve a change of spatial distance and a change of time interval between two inertial systems as shown in table (2.2). Therefore, velocity transformations never give a speed greater than c. [21]

Transformations	Lorentz	Galileo
coordinates	$x_2 = \gamma(x_1 - v t_1)$ $y_2 = y_1$ $z_2 = z_1$ $t_2 = \gamma(t_1 - \frac{v}{c^2} x_1)$	$x_2 = x_1 - v t_1$ $y_2 = y_1$ $z_2 = z_1$ $t_2 = t_1$
velocities	$v_{2x} = \frac{v_{1x} - v}{1 - v_{1x} . v/c^2}$ $v_{2y} = \frac{v_{1y}}{\gamma(1 - v_{1x} . v/c^2)}$ $v_{2z} = \frac{v_{1z}}{\gamma(1 - v_{1x} . v/c^2)}$	$v_{2x} = v_{1x} - v$ $v_{2y} = v_{1y}$ $v_{2z} = v_{1z}$

Table (2.2) Lorentz Transformations of Coordinates and Velocity.

The second postulate: The speed of light in free space c is invariant, i.e. c has the same value regardless of the motion of the source or the observer.

As a consequence of the second postulate, Einstein rejected the idea of absolute space time and absolute space, he realized that the distances and time intervals are determined by events and are dependent on each other (i.e. there is should a relationship between space & time) .The location and time of an event may be specified with respect to a local reference position and a local reference time [20].The new theory and the old theory are correspond because the physics of Galileo and Newton was applied on objects that moved at speeds much less than the speed of light, i.e.:

$$when \quad \beta = \frac{v}{c} \quad approaches \quad zero \quad \gamma \Rightarrow 1$$

Hence, Lorentz transformations reduce to the classical Galilean ones. [21]

ii. Time Dilation and Length Contraction:

Special Relativity showed that the speed of light is the same for all inertial frames; this is only possible if perceptions of space and time are different in different interval frames. This relative motion introduced the main two concepts of *Special Relativity* which known as:

▪ *Length contraction:*

$$L = \frac{L_\circ}{\gamma}$$

Because γ increases with speed v; the length contraction also increases with v. [1]

▪ *Time Dilation*:[1]

$$\Delta t = \gamma \Delta t_\circ$$

iii. The Most Famous Equation E = mc^2:

After 1905, Einstein moved away from the concept of mass as a fixed quantity and showed that the mass, m, of a moving object depends on its speed v, with equation $m = \gamma m_o$. The quantity m_o is the rest mass of the object which is measured by an observer who is at rest relative to the object. The mass of an object depends on its speed because mass is a measure of the inertia of an object. The faster an object moves, the greater its resistance to change of its motion. The formula $m = \gamma m_o$ shows that, over 40 % of the speed of light increases the mass of an object to 10 % more than its rest mass. 99 % of the speed of light increases its mass to over 7 times its rest mass. No object can be accelerated to reach the speed of light as its mass would become infinite and this is physically impossible. Einstein showed from $m = \gamma m_o$ that the kinetic energy gained by an object when it is accelerated from rest to a certain speed v is equal to $mc^2 - m_oc^2$. He concludes that the total energy (E) of an object is equal to mc^2 which is the sum of its rest mass energy plus energy supplied to it.[20]. $E = mc^2$ states *the equivalence of mass and energy*. Therefore, anything that has a mass m has an energy $E = mc^2$, and anything that has an energy E has a mass $m = E / c^2$. That is:

> *Energy and mass are just two equivalent ways of describing the same thing.*[21]

2.2.3 Theory of General Relativity:

Special Relativity is special because it is restricted to inertial reference frames and does not tell us how to deal with reference frames subject to acceleration or gravitational fields. [1]. Einstein wanted to generalize his 1905 theory of relativity to find a general theory that would enable the laws of physics to be expressed in the same form in all frames of reference, not just in inertial frames of reference.

i. The Principle of Equivalence:

The idea of *General Relativity* was developed on the basis known as *the* ***Principle of Equivalence*** which states:

The laws of physics are the same at each point in a uniform gravitational field as in a reference frame undergoing uniform acceleration.

Einstein thought very deeply about the link between gravity and accelerated motions, he found that the effects of gravity and accelerated motions are indistinguishable. He then concluded *The Principle of Equivalence* which has been used to prove *The General Theory of Relativity.* Using this principle Einstein thought about the effect of gravity on light, a photon of energy $E = hf$, even though the speed of photon is always c and it has no rest mass it must be affected by gravity, just as other objects are. A light ray traveling horizontally through our inertial frames is bent in the accelerating frame. By applying the Equivalence Principle, the light ray should also bend in a uniform gravitational field. Einstein published this idea about gravity and light in 1911 predicting not only the deflection of light by gravity but also the change of energy of a light photon passing in or out of gravitational field. In nature there a lot of proofs for *the General Relativity* and *the Principle of Equivalence,* such as the starlight when it passes close to the sun, it must be deflected by the sun's gravity as shown in Figure (2.2). This angle of deflection was measured by Einstein in 1916 and was found to be 1.75 s of arc. New measurements of that deflection have supported Einstein's predictions. [1, 20]

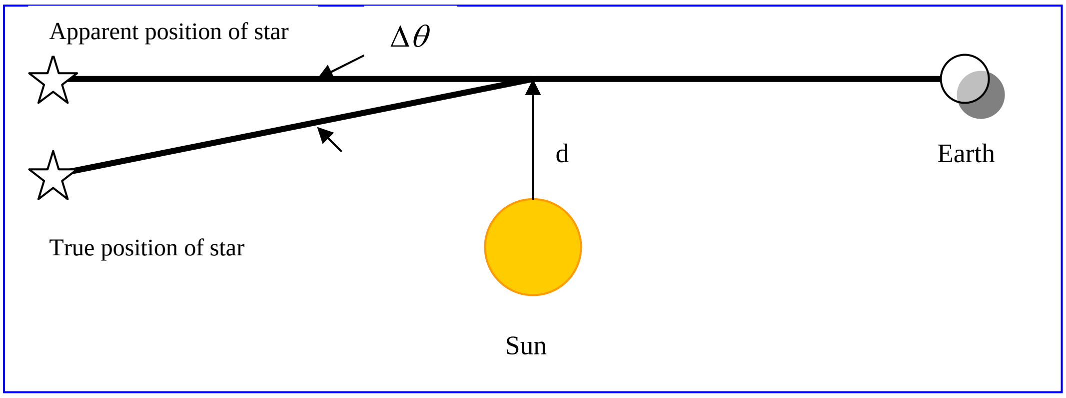


Figure (2.2) Deflection of light by the sun through an angle $\Delta\theta$. The distance of closest approach of the ray to the Sun is d.

ii. Gravitational Waves:

Another prediction of general relativity that has attracted much attention in the last two decades is the possibility of gravitational waves. Unlike Newtonian theory, General Relativity predicts that accelerating masses should radiate gravitational waves, just as accelerating electric charges radiate electromagnetic waves. Intense efforts are on their way to detect gravitational waves, but until now there are no direct observations of gravitational waves. [22]

2.2.4 Curved Space Time:

If the Principle of Equivalence is valid ,then gravitation must be a "curved spacetime" phenomenon, in other words the gravitational field causes spacetime to be distorted and curved as in Figure (2.3). Because spacetime is curved by gravitational field, Einstein used another kind of geometry is called Riemannian geometry which is unlike Euclidean geometry that used in flat spacetime.

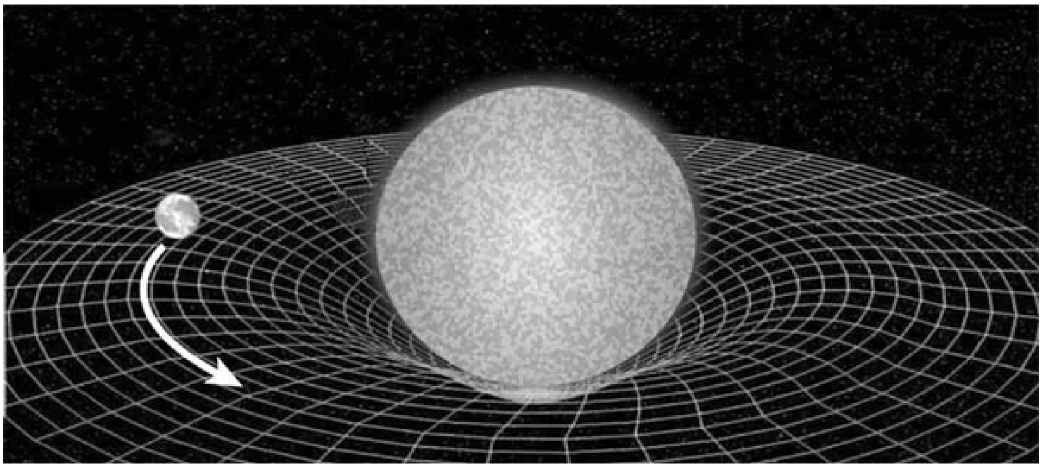


Figure (2.3) A massive object affects the spacetime and curves it.

General Relativity is a matric (1) theory of gravity; the matric is a mathematical variable determines the geometrical relations between events, such as the distance between two spatial locations at a common time, the time between two events at a common location, and a generalized "distance" between two events at different locations and different times.

General Relativity provides a set of equations called Einstein's field equations, that determine how much spacetime matric or curvature is generated by a given distribution of matter, the spacetime matric is known, it can be calculated from the equation:

$$E_{ij} = R_{ij} - 1/2\, g_{ij}\, R$$

E_{ij} is also named as Einstein's tensor; it represents the difference between the curvature in a

(1) Matric is the basic tool which gives an explanation to curved surfaces. To know if the surface is curved or not, you need to describe the distance. The matric measures the distance between two points along an arbitrary path and express that distance somehow in terms of whatever coordinate system you're using. [24]

certain direction along a certain line at a given point $R_{ij,}$ and the local curvature R at that point. [20, 23]. Einstein used E_{ij} to relate the distortion of space-time to the distribution and motion of matter and radiation in spacetime, to form a general equation which may be expressed as:

Distortion of spacetime = constant × energy distribution

The distribution is expressed by another tensor, the mass energy tensor T_{ij}, which represents the stress or pressure due to the concentration energy is spacetime. The above equation shows that the change of curvature in a certain direction along a certain line is in proportion to the stress in that direction along the same line. By choosing the constant as $- 8 \pi G/ c^3$, Einstein found that the equation can be reduced to Newton's law of Gravitation for weak gravity [20]. Because tensors have the property that any equation involving them is true when it is written in the same form in any other set of coordinates . Einstein used the tensors T_{ij} and E_{ij} in his equation, so its equation can be true in any system of coordinates. [25]

Using this idea, Einstein discovered that all the laws of mechanics and electromagnetic radiation could be expressed by the equation:

$$E_{ij} = \frac{-8\pi \ G}{c^3} T_{ij}$$

This general equation means that the distribution of matter and energy in spacetime determines the curvature of space-time which in sequence determines the motion near that matter.

It is clear from this equation that Einstein gave each particular point in space certain values of energy and momentum, from these many oppositions appeared between Quantum Mechanics and General Relativity. [20].

2.2.5 The Unified field Theory:

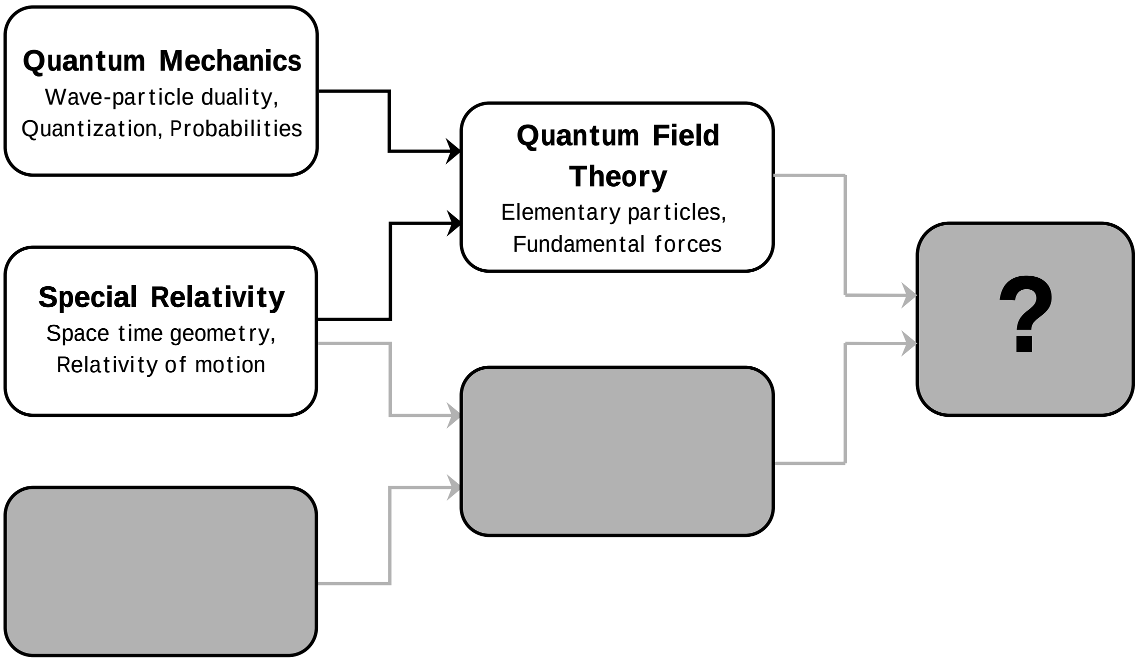
Einstein spent much of the last thirty years of his life searching for a *Unified field theory*, the theory that unifies electromagnetism with gravity. At the time he began his quest, he wanted to find if there was a deep underlying connection between these two famous "inverse square" laws of physics.[26]

Einstein succeeded at least to find a relation between the gravity and electromagnetism. He reached that result while he was trying to answer the question: *what would happen to the earth if the sun were suddenly exploded?* According to Newton's theory of gravity; even though it would take eight minutes for the light coming from the explosion to travel from the sun to the earth, the earth would instantaneously suffer a departure from its usual elliptical orbit. In Newton theory knowledge that the sun had exploded would instantaneously transmitted to the earth through the sudden change in gravitational force governing its motion which is currently proved to be impossible.

Einstein expected that if the Sun changes its position or even blows apart, a huge gravitational wave will originate in their place and the influence of these wave will not affects the Earth instantaneously, but this distortion of the spacetime will spread at light speed . Thus the people on Earth would visually know of the Sun's destruction at the same moment that they would feel the gravitational consequences – about eight minutes after it explodes. Einstein found that, gravitational waves move with the speed of light, c .This result considered as a kind of unification between gravity and electromagnetism. [5]

Chapter (3)

The Quantum World



3.1 Quantum Mechanics:

If the special relativity was the first revolution in the 20th century in physics, the quantum mechanics considered as the second revolution.

Quantum theory is a fundamental physical theory that replaces Newtonian mechanics and classical electromagnetism at the atomic and subatomic levels. It tells us about the nature of the microscopic constituents of matter, from atoms and molecules to atomic nuclei and quarks. These tiny particles behave in a totally different way from objects in our ordinary everyday experience. What we have learnt about matter on atomic and subatomic scales has produced new ideas about how the universe evolved and led to technological advances in nuclear physics, material science and quantum optics, as shown in figure 3.1. Those technological advances changed the way we live. [27]

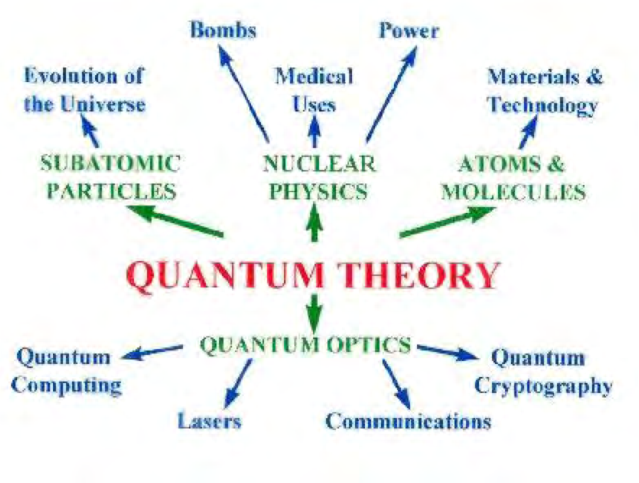


Figure (3.1) Applications of quantum theory

Quantum theory can be divided into two parts: the old quantum theory and the new quantum theory.

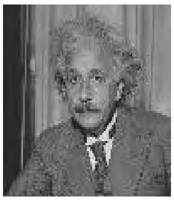
3.1.1 The Old Quantum Theory:

i. Planck's Quantum:

M. Planck

In 1900, Quantum theory was originated when Planck started a quest for the first and the second laws of thermodynamics. Planck noticed that black body radiation acted in an absolute sense because it was defined by Kirchhoff as a substance that could absorb almost all radiating energy and emit all what it had absorbed. Planck found a relationship with the mathematics of the entropy of the radiation in the high-frequency waves in correlation to the low frequency waves. Planck guessed if he could combine the two in the same simplest way, he would get a formula that related the amount of radiation to the blackbody's frequency. In order to make a sense of his formula, he had to dismiss the second law of thermodynamics and accepted it only as a statistical law. He also had to accept that the blackbody could not absorb energy continuously but in separate amounts of energy spread over time like pulses. Planck called each pulse *quanta* of energy, and this was the birth of the quantum theory. Planck found that each quanta is related to its frequency during a constant called *h* (now known as Planck's constant). This constant turned to be a very small number (6.626×10^{-34} J/s). The fact that the smallness of *h* confines most of these radical departures from life-as-usual to the microscopic realm. [28]

ii. Einstein's Light Particles:



A. Einstein

In 1905, Albert Einstein took this type of thinking to it's logical conclusion. He used Planck's relationship to explain the results of the photoelectric effect which showed that the energy E of ejected electrons was wholly dependent upon the frequency υ of incident light as described in the equation $E = h\upsilon$. He confirmed this idea by work on the photoelectric effect, in which he showed that light energy was emitted and absorbed by electrons in discrete amounts or quanta. This quanta of light energy soon became known as the *photon* which related to wave frequency by Planck's relation : $E = h\upsilon$. [29]

iii. Bohr's Atom:

N. Bhor

In 1913, Niels Bohr was the first who applied the quantum theory to atomic structure. He explained the spectral lines of the hydrogen atom, again by using quantization. Bohr was able to determine the frequencies of these spectral lines by expressing them in terms of the charge and mass of the electron and Planck's constant. To do this, Bohr also introduced a revolutionary idea that an atom would not emit or absorb radiation while it was in one of its stable states. It only would do so when it made a transition between states. The frequency of the emitted radiation would be equal to the difference in energy between those states divided by Planck's constant. This meant that the atom could neither absorb nor emit radiation continuously but only in finite steps or quantum jumps. It also meant that the various frequencies of the radiation emitted by an atom were not equal to the frequencies with which the electrons moved within the atom. This idea became the basis for quantum theory. [28, 29]

iv. Wave Nature of electron:

L. De Broglie

The next big step was taken in 1924 by De Broglie, who gave a revolutionary idea in the quantum world. He said, waves are particles and particles are waves. This wave-particle duality remains central in quantum worlds. De Broglie believed that the light is not the only entity to exhibit wave-particle duality. He proposed that ordinary particles such as electrons could also exhibit wave characteristics in certain circumstances. De Broglie assumed that each electron has associated with a system of a matter waves. These waves possess crests that disappear at one point and appear an instant later at another point. The distance between successive crests (λ) is the De Broglie wavelength. It is calculated from $\lambda = h/mv$, where h is the Planck constant and mv is the electron momentum. [29, 30]

3.1.2 The New Quantum Theory:

i. Matrix Mechanics:

W. Heisenberg

In 1925, Heisenberg developed the first formalization in quantum mechanics called matrix mechanics. It consisted of an array of quantities which when appropriately manipulated gave the observed frequencies and intensities of spectral lines. The consequence of Heisenberg's work was his revolutionary law (The uncertainty principle) which had the form of $\Delta x\ \Delta p > h$. This means that the uncertainty of position (Δx) of an electron in an atom multiplied by the uncertainty of its momentum (Δp) must be greater than Planck's constant (h). The uncertainty principle tells us that all observable quantities are subject to changes determined by Planck's constant and we cannot determine the position and its momentum simultaneously. [29]

ii. Wave Mechanics:

E. Schrödinger

Adopting the proposal by de Broglie that particles of matter have dual nature and in some situations act like waves, Schrödinger in 1926 produced the basic equation of quantum mechanics. The Schrödinger equation treats electrons as matter waves and gives the relation between the wave function and the total energy of the moving electrons. The time-independent Schrödinger equation can be written as follows:

$$-\frac{\hbar^2}{2m_e}\left(\frac{\partial^2\psi}{\partial x^2}+\frac{\partial^2\psi}{\partial y^2}+\frac{\partial^2\psi}{\partial z^2}\right)+V(x,y,z)\psi = E\psi$$

He described ψ as the density distribution (i.e. some regions rich in electron matter while others scarce). [31, 29]

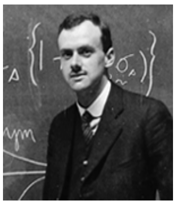
iii. Probability Density:

In 1926, Max Born formulated the now-standard interpretation in the Schrödinger equation. Born proposed that ψ^2 gives the probability density of finding the electron. In Born's interpretation, nothing will be detected most of the time, but when something is observed, it will be a whole electron. The concept of the electron as a point particle moving in a well-defined path around the nucleus is replaced in wave mechanics by clouds that describe the probable locations of electrons in different states. Born's probability density is perhaps the most dramatic change in viewing our world since Newton and gravity. "No more exact answers", said Born. In atomic theory, all we get are probabilities. [28, 29]

M. Born

iv. Quantum Algebra:

In 1926, Paul Dirac developed a new version of quantum mechanics. He incorporated the previous work of Heisenberg on "Matrix Mechanics" and of Schrödinger on "Wave Mechanics" into a single mathematical formalism known as "*transformation theory*". This theory associates measurable quantities with *operators* acting on the *Hilbert space* of vectors that describe the state of a physical system. In 1930, Dirac was published the principles of quantum mechanics, that led him to become one ofthe standard textbooks on the subject and is still used today. It introduced the Bra-ket notation, in which ket |ψ>, denotes a state vector in the Hilbert space of a system and bra <ψ|, is a dual vector, where <ψ|ψ> denotes an inner product. Dirac also introduced Dirac's *delta function*. [32]



P. Dirac

3.1.3 Quantum Field Theory (QFT):

QFT is regarded as a fundamental description of nature, complete in it self. QFT is the application of quantum mechanics to fields. It provides a theoretical framework, widely used in particle physics and condensed matter physics. It is especially used in situation where particles created and destroyed. [33]

For example, in quantum mecahnics the uncertainty principle states that the energy can fluctuate very much during a small interval of time. Special relativity states that energy can be converted into mass and vice versa. By quantum mechanics and special relativity the widely fluctuating energy can change into mass: into particle not present before.

Also Schrödinger equation for an electron scattering off a proton describes the wave function of one electron. The electron you follow will remain one electron, no matter of lengthy mathematics and defferential equations you try. Special relativity states that energy can be converted into matter. If an electron is energetic, an electron and positron can be produced. In such cases we see the need for QFT. [34]

The developments of QFT passed through three basic stages:

1. QFT originated in the problem of computing the power radiated by an atom when it dropped from one quantum state to another of lower energy. In 1927, Pauli Dirac gave the first consistent treatment of this problem. I.e. he applied quantum mechanics to electromagnetic field. [28, 34]

2. Physicists studied Schrödinger quantum wave equation and found that he could not incorporate Einstein's special relativity, so Dirac tried to do it. This development of the Dirac equation needs to put together relativity and quantum mechanics, which was the second motivation of the development of QFT. This thread was crucial to the development of partial physics and the modern unified theory forces called the standard model. Physicists focused their initial efforts to merge special relativity to quantum concepts on the electromagnetic force and its interaction with matter. Through a series of developments, they created quantum electrodynamics (QED) which is an example of a relativistic quantum field theory. [5, 28, 33]

3. In 1928, Jordan and Eugene Wigner found that the Pauli Exclusion Principle demanded that the electron field be expanded by using creation and annihilation operators. The non-relativistic theory does not have this feature. This was the third thread in the developments of QFT that need to handle the statistics of multiparticle systems consistently and with ease. This also was incorporated into many-body theory, and strongly influenced condensed matter physics and nuclear physics. [33]

3.2 Particle Physics

Particle Physics is the study of the structure and properties of the elementary particles and resonances and their interactions [34]. So, what are the elementary particles? And what are the four different types of their interactions? These will be the topics of this section.

3.2.1 Elementary Particles:

Modern Physicists named the most fundamental units of matter; Elementary Particles.

Tracing back the study of particle physics one has to start from the beginning of the discovery of the *Atom* which was considered as elementary, and was taken seriously by chemistry experiments in the 18^{th} century. By the end of the 19^{th} century 90 different natural atoms were discovered, despite the fact that there other artificial atoms which could be created in the laboratories.

Unfortunately, J.J. Thomson's discovery of the *electron* in 1897 showed that atoms are not fundamental anymore. This was followed by another discovery in 1919, where Rutherford indicated that it also includes a nucleus. Ten years later the nucleus was found to be consisted of *protons*. In 1932, Chadwick showed that the nucleus also contains *neutrons*. And thus, by that year it appeared that all matter was made of just three subatomic particles; the electron, proton, and neutron.

Almost at the same year, pair production experiments, based on quantum mechanical explanations, revealed the existence of the first discovered *antiparticle*; the *positron*, which is the anti of the electron (anti-electron). This revolution opened the door to the discovery of more and more anti-particles.

In addition, other particles, not antiparticles, were predicted to explain nuclear phenomena. For example, in 1935, a Japanese physicist Yukawa predicted the existence of a particle which he called a *meson* (sometimes it is called a pion). The meson is a particle with an intermediate mass, which is considered as a "carrier" of the nuclear force, i.e. the strong force, between the nucleons. Just like the "photon" which is the carrier of the electromagnetic force – as emerged by the Quantum Field Theory –.

Another particle discovery was the discovery of the *mouns* in 1937. At first, physicists thought that they are the same as the mesons, but 10 years later they found that they are matter constituents rather than force carriers. [35]

After these two discoveries many more particles were found, and it slowly became clear that these growing members must have some connections and therefore must be of a one family, unification was demanded, and unification is what physicists intended to do.

3.2.2 The Four Fundamental Forces:

Before the 1930's two forces were considered as fundamental; the *electromagnetic force* and the *gravitational force* [35]. But with the birth of nuclear physics, two more fundamental forces had to be present to explain the subatomic interactions; the *strong force*, and the *weak force* [34].

The strong force is the force between the nucleons, i.e. protons and neutrons, which holds them together in the nucleus. While the weak force is the force responsible for β decay, i.e. it appears in radioactivity when a neutron decays into a proton or vise versa. The discovery of the weak force led to the prediction of neutrino in 1962 which is essential for the conservation of energy in such a decay [36].

The forces are sometimes called *interactions* since they are considered as interactions between particles.

3.2.3 Quantum Chromodynamics:

The strong force was originally introduced as the force between any two nucleons in a nucleus. But nowadays, scientists believe that the nucleons themselves consist of smaller particles called *quarks*, these are not found as free particles but their existence has been demonstrated in high-energy scattering experiments. See figure (3.2). They are classified in six flavours; up, down, charm, strange, top and bottom. Each flavour comes in three colours; red, green and blue. Colours here have no connection with ordinary colours and are used only as labels [34].

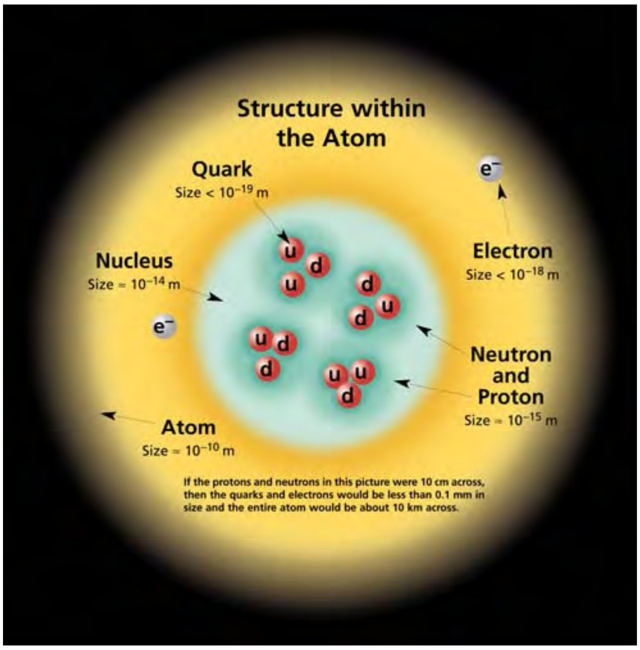


Figure (3.2) The constituents of an atom.

Hence, as we now know that the nucleons are bound states of quarks, it is clear that the strong force must ultimately be a force between quarks. The quantum theory of this force, which was proposed in 1973 by Fitzsch Twyler and Gell-Mann [36] is called; *Quantum Chromodynamics*; QCD, just as the quantum theory of the force between electric charges is called *Quantum Electrodynamics*; QED.

In QED, the force-carrying particle is the "Photon", while in QCD; the force carrying particle is called the "*gluon*".

Although, there is no direct evidence, until now, for the existence of gluons, the general success of QCD has convinced most particle physicists that gluons really do exist. [35]

3.2.4 Electroweak Interactions:

More than 30 years ago, physicists used to think of the electromagnetic interactions and weak interactions as two different phenomena that cannot be connected, just like in the 19^{th} century when they used to think of electricity and magnetism as two different forces. However, continuous work on paper and in the laboratories in 1967 and 1968 by Steven Weinberg and Abdus Salam, based on previous work by Sheldon Glashow, unified the two interactions into a one theory called: *The Quantum Electroweak Theory*, which describes the electroweak interactions as a one phenomena. The significance of their work awarded them the 1979 Nobel Prize.

The theory states that the electromagnetic and weak interactions are carried by four gauge (i.e. force carrier) particles, two electrically charged and two neutral. One of the four carriers is massless; the photon, while the other three are massive; W^+ , W^- , Z° , which are the carriers of the weak interactions. Because of this difference in mass, the weak interactions seem different from the electromagnetic. However, at extremely high energies (thousands of GeV) the difference between the masses would be negligible, and thus both should appear to be united under an electroweak symmetry. This high energy, as believed by astrophysicists, must have been present immediately after the "Big Bang", which makes it possible for the electroweak symmetry to exist naturally.

Experiments on Cesium atoms have dramatically confirmed the tiny contribution of the weak interactions to atomic transitions, and verified that the predictions of the electroweak theory can be detected even at energies of only a few eV.

In the period between 1982 and 1984 physicists were able to detect the predicted particles W and Z experimentally, and thus the theory was fully accepted. [35]

3.2.5 The Standard Model:

The standard model summarizes the current knowledge in particle physics. It is the quantum theory that includes the theory of strong interactions (QCD), and the unified theory of weak and electromagnetic interactions (Electroweak). i.e. it includes all the fundamental forces excluding gravity, and also includes all the known elementary particles.

In the standard model, all the particles are gathered into two categories:

1. *Fermions:* which are the constituents of matter, i.e. they are the building blocks of the entire world. Fermions are divided into two main groups, as shown in table (3.1). They are:

a. *Leptons:* which are not affected by the strong interactions.

b. *Quarks:* which feel the strong interactions. They only exist in groups with other quarks and are never found alone.

FERMIONS matter constituents spin = 1/2, 3/2, 5/2, ...

Leptons spin = 1/2			Quarks spin = 1/2		
Flavor	Mass GeV/c²	Electric charge	Flavor	Approx. Mass GeV/c²	Electric charge
ν_e electron neutrino	$<1\times10^{-8}$	0	**u** up	0.003	2/3
e electron	0.000511	−1	**d** down	0.006	−1/3
ν_μ muon neutrino	<0.0002	0	**c** charm	1.3	2/3
μ muon	0.106	−1	**s** strange	0.1	−1/3
ν_τ tau neutrino	<0.02	0	**t** top	175	2/3
τ tau	1.7771	−1	**b** bottom	4.3	−1/3

Table (3.1) The two main groups of Fermions, which are the constituents of matter, and their properties. In the Standard Model's point of view; the whole world is made up from 6 Leptons, and 6 Quarks.

The composite particles that are made of quarks are called *Hadrons*. There are two classes of hadrons; *Baryons* (which are hadrons that are made of three quarks) and *Mesons* (which are hadrons that are made of one quark and one *anti-quark*). See table (3.2) bellow.

Mesons $q\bar{q}$
Mesons are bosonic hadrons.
There are about 140 types of mesons.

Symbol	Name	Quark content	Electric charge	Mass GeV/c²	Spin
π^+	pion	$u\bar{d}$	+1	0.140	0
K^-	kaon	$s\bar{u}$	−1	0.494	0
ρ^+	rho	$u\bar{d}$	+1	0.770	1
B^0	B-zero	$d\bar{b}$	0	5.279	0
η_c	eta-c	$c\bar{c}$	0	2 .980	0

Baryons qqq and Antibaryons $\bar{q}\bar{q}\bar{q}$
Baryons are fermionic hadrons.
There are about 120 types of baryons.

Symbol	Name	Quark content	Electric charge	Mass GeV/c²	Spin
p	proton	uud	1	0.938	1/2
$\bar{p}$	anti-proton	$\bar{u}\bar{u}\bar{d}$	−1	0.938	1/2
n	neutron	udd	0	0.940	1/2
Λ	lambda	uds	0	1.116	1/2
Ω^-	omega	sss	−1	1.672	3/2

Table (3.2) Two groups of Hadrons are shown. Hadrons are particles made of quarks. Baryons are hadrons made of three quarks, while Mesons are hadrons made of two quarks.

2. *Bosons:* which are the carriers of the forces that hold the universe together. Table (3.3) shows that they are classified into two groups depending on the kind of force acting.

BOSONS force carriers spin = 0, 1, 2, ...

Unified Electroweak spin = 1			Strong (color) spin = 1		
Name	Mass GeV/c^2	Electric charge	Name	Mass GeV/c^2	Electric charge
γ photon	0	0	g gluon	0	0
W^-	80.4	−1			
W^+	80.4	+1			
Z^0	91.187	0			

Table (3.3) The two main groups of Bosons, which are the carriers of the forces, and their properties.

Due to the Standard Model, one can summarize the properties of the three interactions; the weak, electromagnetic, and strong, into the table bellow; table (3.4). The Gravitational force is not included, but it is written in the table just for comparison.

PROPERTIES OF THE INTERACTIONS

Property \ Interaction	Gravitational	Weak (Electroweak)	Electromagnetic (Electroweak)	Strong: Fundamental	Strong: Residual
Acts on:	Mass – Energy	Flavor	Electric Charge	Color Charge	See Residual Strong Interaction Note
Particles experiencing:	All	Quarks, Leptons	Electrically charged	Quarks, Gluons	Hadrons
Particles mediating:	Graviton (not yet observed)	W^+ W^- Z^0	γ	Gluons	Mesons
Strength relative to electromag for two u quarks at: 10^{-18} m	10^{-41}	0.8	1	25	Not applicable to quarks
Strength relative to electromag for two u quarks at: 3×10^{-17} m	10^{-41}	10^{-4}	1	60	
for two protons in nucleus	10^{-36}	10^{-7}	1	Not applicable to hadrons	20

Table (3.4) The four interactions and their properties. The gravitational force is included just for comparison, although it is not part of the Standard Model.

Experiments have verified the standard model's predictions to an incredible precision, and most of the particles predicted by this theory have been found. [37]

To sum up, particle physics has gone through a series of predictions and discoveries, starting from the discovery of the atom, to the formation of the standard model with its two groups of matter particles, and two groups of force carriers. This is summarized in figure (3.3) bellow.

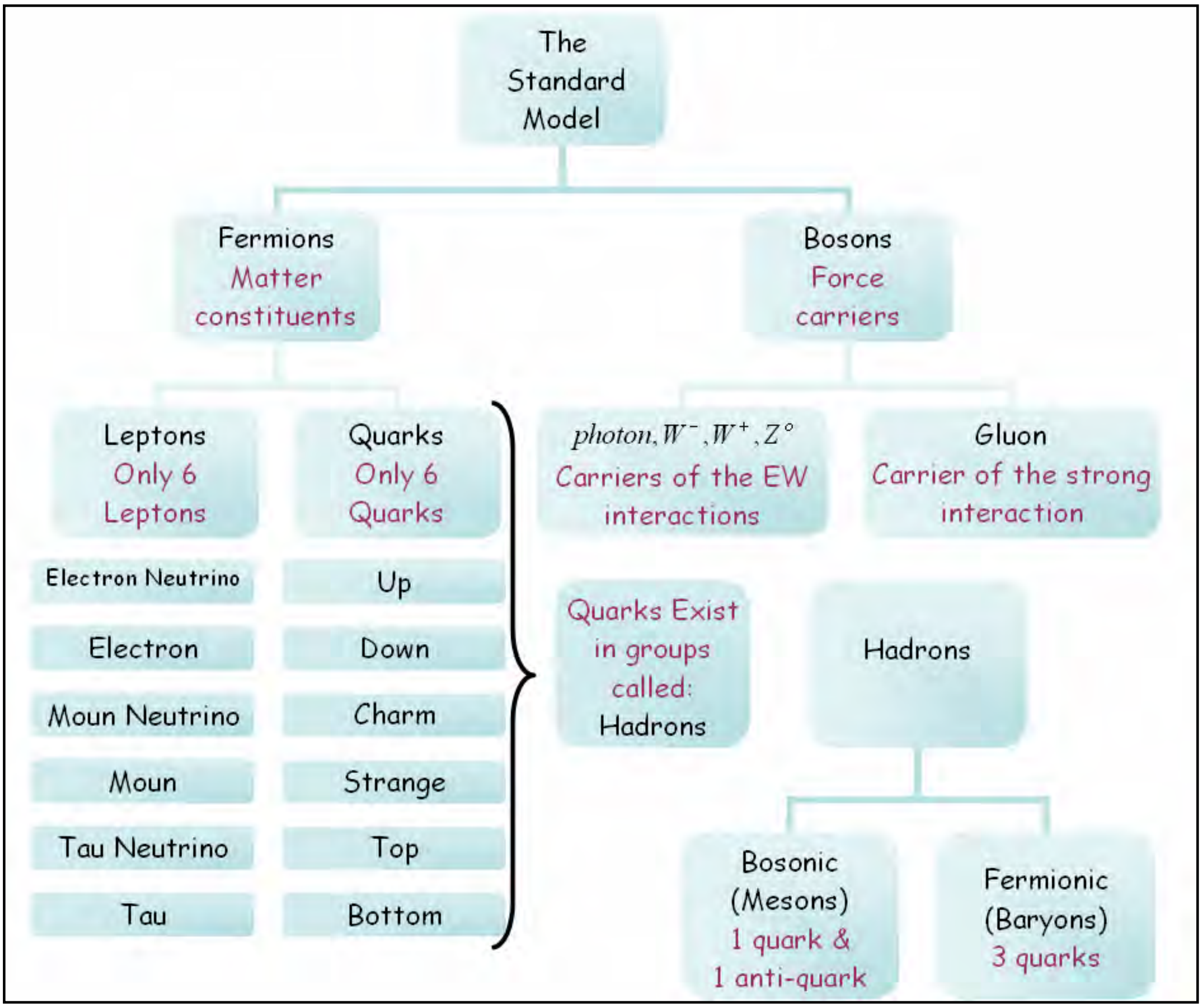


Figure (3.3) The Standard Model.

Although the standard model was considered as an achievement, it wasn't accepted as a theory of everything, due to its failure in containing gravity.

3.3 The Quest for A Theory of Everything:

During the work on the Standard Model, attempts were held to unify quantum theory, which describes three of the fundamental forces of nature, with general relativity, the theory of the fourth fundamental force: gravity.

There are several reasons why both theories could not be unified; both theories describe the world in two different ways, to specify see the table below: [38]

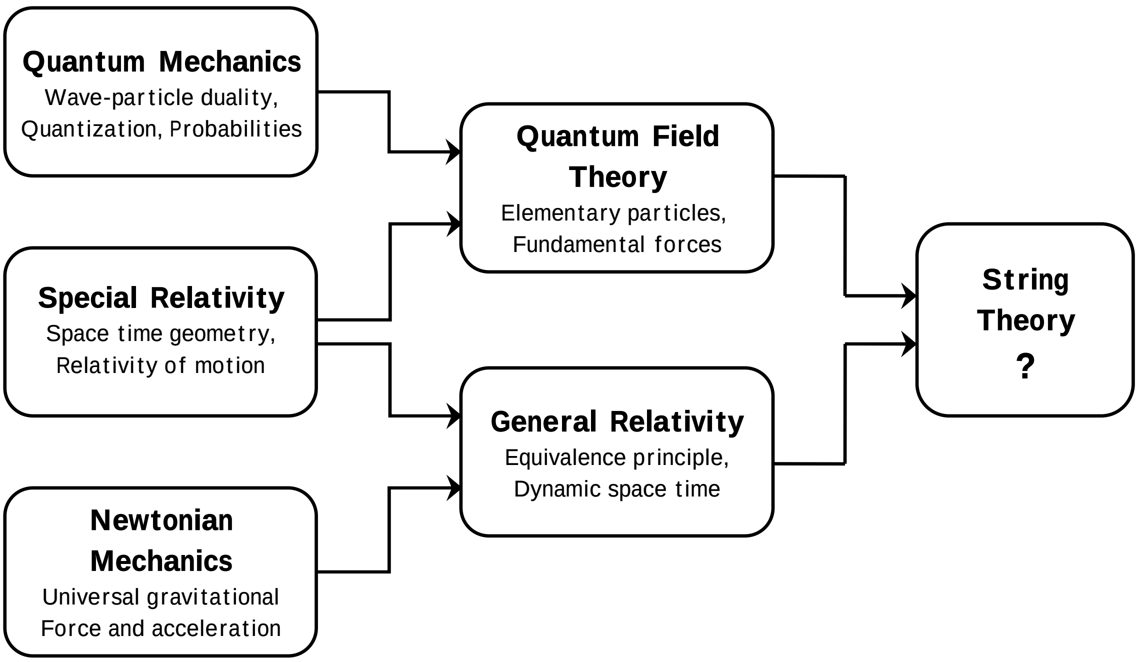
The world with General Relativity's Eye	The world with Quantum's Eye
Spacetime is smooth and accurate calculations are possible	Everything is random (The uncertainty Principle)
Spacetime is dynamic (i.e. the background is dynamic)	The background is fixed
Deals with massive objects	Deals with tiny objects
Singularity goes against the theory	Infinity goes against the theory

Table (3.5) The main differences between General Relativity and Quantum Mechanics.

Many groups of physicist worked on this unification, some lost hope while others patiently continued their worked not concerned with the failures of others. As a result, two promising theories emerged; String Theory and Loop Quantum Gravity.

Chapter (4)

String Theory



4.1 String Theory as a Unified Theory:

The results described in the last two chapters summarized the achievement of one century, but it left us with one fundamental contradiction that still needs to be resolved. General relativity and quantum mechanics were incompatible and there was an essential need for a unified theory. [39]

By a "unified theory" we mean the ultimate explanation of the universe at its most microscopic level, a theory that does not rely on any deeper explanation. A unified theory would be a mathematical framework in which all the different kinds of forces and particles occur naturally. We should not have to fix the masses and charges of particles from experiment; rather the theory should fix them automatically to be the right values. In the standard model we just assume that these values are the ones measured in experiments, but in a unified theory these values should be predicted. The discovery of the unified theory would provide the firmest foundation on which to build our understanding of the world. [5,40]

Many theoretical physicists are convinced that *string theory* will solve the conflicts between general relativity and quantum mechanics and will provide a truly unified theory. [39]

4.2 The Origin of String Theory:

String theory was originally used as an attempt to explain hadron behavior which experiences the strongnuclear force. In 1968, theoretical physicist Gabriele Veneziano was trying to understand the strong nuclear force when he made a startling discovery. Veneziano found that a 200-year-old formula created by Swiss mathematician Leonhard Euler (the Euler beta function) perfectly matched modern data on the strong force. Veneziano applied the Euler beta function to the strong force, but no one could explain why it worked. Then some physicists came to show how Euler’s function accurately described nuclear forces, by representing these forces as vibrating, one-dimensional strings. In 1974, John Schwarz and Joel Scherk studied the messenger-like patterns of string vibration and found that their properties exactly matched those of the gravitational forces hypothetical messenger particle "graviton". And they found that these properties can be realized exactly by certain vibrational patterns. Then, Schwarz and Scherk suggested that the string theory is not just a theory of the strong force, it is a quantum theory that includes gravity as well. In 1984, Green and Schwarz showed that the string theory had sufficient wideness to involve all of the four forces and all of matter as well. [5, 41]

4.3 Fundamentals of the Theory:

4.3.1 What is a String?

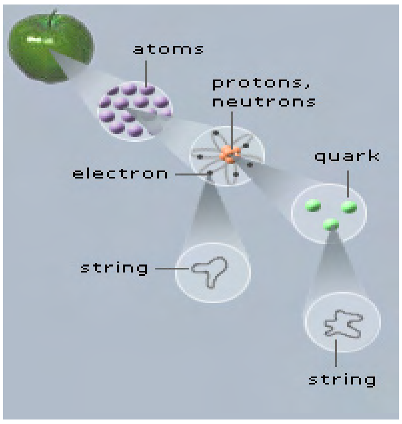
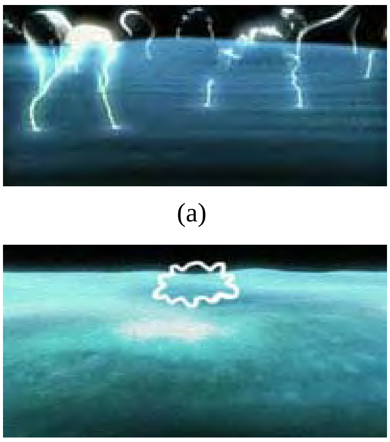


Figure (4.1)
The structure of matter

The fundamental particles of the universe that physicists have identified electrons, neutrinos, quarks, and so on—are the "letters" of all matter. They appear to have no further internal substructure, but string theory states otherwise. According to string theory, if we could examine these particles with even greater precision, a precision many orders of magnitude, we would find that each is not point-like but instead consists of a tiny, one-dimensional loop, which is the basic idea of this theory. So each particle contains a vibrating, oscillating, dancing filament that physicists have named a *string*. In the figure (4.1), we illustrate this idea of string theory by starting with an ordinary piece of matter, an apple, and repeatedly magnifying its structure to reveal its ingredients on ever smaller scales. These 1-dimensional strings have no thickness but do have a length called *Planck length*, typically 10^{-33} cm. This is very small compared to the length scales that we can reasonably measure, which is at least ten thousand times smaller than the atomic nucleus. So these strings are so small that they practically look like point particles. [5, 42, 43]

4.3.2 Strings Types:



(a)

(b)

Figure (4.2) String types
(a) Open and (b) Closed.

Strings can be ***open*** or ***closed***. Open string has two end-points glued to a manifold called ***brane*** and moving over it, as shown in figure (4.2 a). Closed string has no end points and leaving a brane, as shown in figure (4.2 b). Both of the two types can execute one of infinitely many vibration patterns. Closed strings represent the graviton and pen strings always represent the other particles. As strings move through spacetime they sweep out an imaginary surface called a ***worldsheet***. [41, 42]

4.3.3 Strings Interaction:

Strings interact by splitting and joining which spread out in a way that leads to more sensible quantum behavior. For example the annihilation of two closed strings into a single closed string occurs with an interaction that looks figure (4.3).

The analogous Feynman diagram in a point particle field theory can occur at definite point in space and time, as shown in figure (4.4). Point particle cram all of their interaction into a definite point. But when the graviton particle is involved in an interaction, this packing of particles punches into a single point leading to an infinite result. By contrast, strings smear out the place where interactions occur. In the case of the gravitational force, this smearing dilutes its ultramicroscopic properties, so that calculations yield finite answers in place of previous infinities. This leads to a break down of the point particle theory. [5, 42]

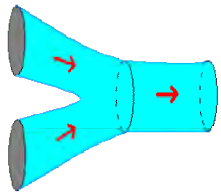


Figure (4.3) string interactions.

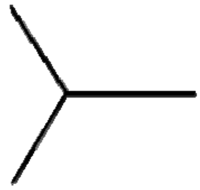


Figure (4.4) Point particle interactions.

4.3.4 Resonance in String:

Just like an everyday string, the line of energy that forms the "fundamental string" in string theory also has resonant vibrations. With the strings in string theory, the vibrational pattern determines what kind of particle the string is. One resonant pattern makes it a photon, for example, while another makes it a heavy particle found within the nucleus of an atom. What determines the type of particle is the movement of the string and the energy associated with this movement. According to Einstein's famous equation $E=mc^2$, energy and mass are equivalent. In string theory, this equivalence accounts for the different masses of different particles: a lower-energy string is lighter (less massive) than a higher-energy string. String theory also accounts for the characteristics of massless particles that carry forces. The carriers of electromagnetic radiation, gravity, and the strong and weak forces (i.e. photons, gravitons, gluons, and the weak gauge bosons, respectively) interact with other particles based on their resonant vibrational patterns. Hence, the string theory provides a truly unified theory, since all matter and all forces are proposed to arise from one basic former: oscillating strings. [43]

4.3.5 String Theory and the Extra Dimensions:

String theory resolves the central dilemma confronting modern physics – the opposition between quantum mechanics and general relativity – and unifies our understanding of all of nature's fundamental material constituents and forces. But string theory requires that the universe must have extra space dimensions to fulfill these performances.

One of the oppositions between quantum mechanics and general relativity in a point – particle framework is that calculations result in infinite probabilities and all we know that probabilities are always numbers between zero and one. String theory overcame the problem of infinite probabilities but it gave us negative probabilities which are outside acceptable range and that was another mysterious result.

Physics found that the cause of this unacceptable result is going back to supposition of the string vibration in two independent dimensions; they found that the troublesome calculations of string were highly sensitive to the number of independent directions in which a string can vibrate.

The calculations showed that if strings could vibrate in more independent spatial directions, all of the negative probabilities began to disappear, and the number of dimensions required to remove all the negative probabilities is nine. Since strings are so small, not only they can vibrate in large, extended dimensions – the ordinary spatial three dimensions – they also can vibrate in ones that are tiny and curled up. And so we can meet the nine – space – dimension requirement of the string theory in our universe, by assuming that in addition to our familiar three extended spatial dimensions there are six other curled – up spatial dimensions. [5]

i. What Do the Curled – Up Dimensions Look Like?

The extra spatial dimensions of string theory cannot be crumpled up any which way; the equations that emerge from the theory restrict the geometrical form that they can take. In 1984 group of physicists showed that a particularclass of six – dimensional geometrical shapes can meet these conditions. They are known as *Calabi–Yau spaces*. Figure (4.5) displays an example of a Calabi–Yau space.

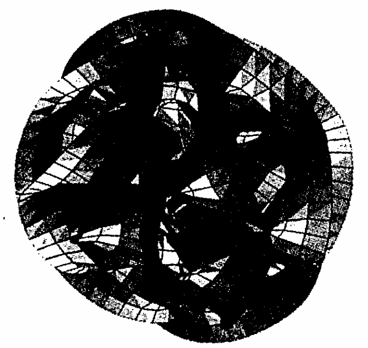


Figure (4.5)
Calabi–Yau space.

There are tens of thousands of examples of Calabi – Yau shapes that meet the requirements for extra dimensions that emerge from string theory.

According to string theory the dimensions of the universe well take the shape as it is shown in Figure (4.6). [5]

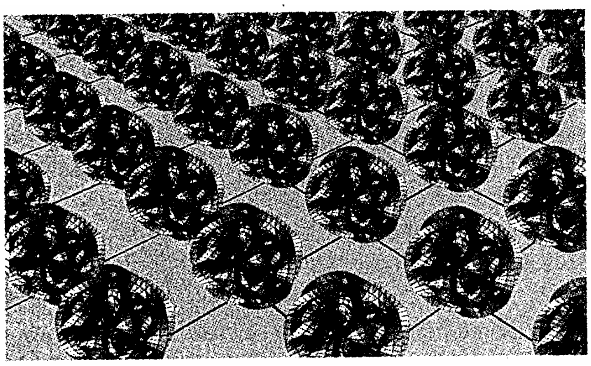


Figure (4.6) spacetime with calabi–Yau spaces

ii. What is the Physical Implication of Extra Dimensions?

The masses and charges of particles in string theory are determined by the possible resonant vibrational string patterns.

Since tiny string vibrate through all of the spatial dimensions, the precise way in which the extra dimensions are twisted up and curled back on each other strongly influences and tightly constrains the possible resonant vibrational patterns. These patterns, largely determined by the *extradimensional geometry,* constitute the array of possible particles properties observed in the familiar extended dimensions. This means that *extradimensional geometry determines fundamental physical attributes like particles masses and charges that we observe in the usual three large space dimensions of common experience.* [5]

4.4 Supersymmetry in the String Theory:

Supersymmetry was discovered in 1971, when a group of physicists asked the question, "could it be that the more accurate rotational motion associated with spin leads to another possible symmetry of the laws of nature? Just as ordinary rotational motion allows for the symmetry principle of rotational invariance". The answer to this question was yes. There is one more symmetry of the laws of nature depends on the spin rotational motion and is mathematically possible, it is known as *Supersymmetry*.

Physicists realized that if the universe is supersymmetric, the particles of nature must come in pairs whose respective spins differ by half a unit. Such pairs of particles are called *superpartners*.

Since matter particles have spin-1/2 while some of the messenger particles have spin-1, supersymmetry appears to result in pairing-a partnering-of matter and force particles. It is a wonderful unifying concept between matter and force particles but many difficulties prevent physicists to verification this concept.

The original string theory that emerged in 1960 did not incorporate supersymmetry. This first theory based on the string concept was more precisely, called the *bosonic string theory*. The name bosonic indicates that all of the vibrational patterns of the bosonic string have spins, there are no fermionic patterns. This led to two problems:

First: if sring theory was to describe all forces and all matter, it would somehow to incorporate fermionic vibrational patterns.

Second: there was one pattern of vibration in bosonic string theory whose mass was negative a so-called *tachyon.*

In 1971, Pierre Ramond, Schwarz and Andre Neveu took up the challenge of modifying the bosonic string theory to include fermionic patterns. A new version of string theory began to emerge with a big surprise, the bosonic and the fermionic patterns of vibration of this new theory appeared to come in pairs. For each bosonic pattern there was a fermionic pattern, and vice versa. In 1977, insights of Ferdinando Gliozzi, Scherk, and David Olive put this pairing into the proper light.

A new string theory called *Supersymmetric string theory* or *superstring theory*, then had been born. This new theory showed that the troublesome tachyon vibration of the bosonic string does not afflict the superstring. The only trouble plagued superstring theory was that supersymmetry, which is the central element in the theory, could be incorporated into string theory in five different ways rather than one .This problem solved after 1995 by discovering the theory named *M – Theory* which has eleven dimensions (ten space and one time), this additional dimension allows all five versions of the theory coming together in a mutual origin form. [5]

4.5 Advantages of String Theory:

4.5.1 Solving the Confliction by String:

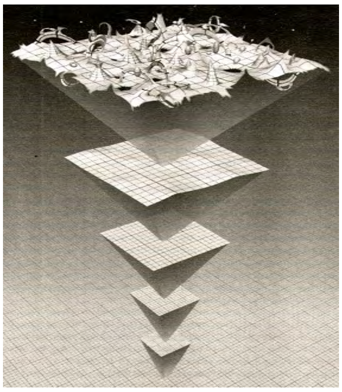


Figure (4.7) violent quantum foam.

The whole conflict between general relativity and quantum mechanics arises from the sub-Planck-length properties of the spatial fabric. By sequentially magnifying a region of space, attempts to merge general relativity –the smooth geometrical model of spacetime- and quantum mechanics – the uncertainty principle – run up against with the *violent quantum foam* emerging at the highest level of magnification, as shown in figure (4.7). Since the string has spatial extent, it also has limits on its short-distance sensitivity. It cannot detect variations on sub-Planck-distance scales. The string smears out the jittery ultramicroscopic fluctuations of the gravitational field. Since because the string is supposed to be the most elementary object in the universe and since it is too large to be affected by the sub-Planck-length undulations of the spatial fabric, these fluctuations cannot be measured and hence, according to string theory, do not actually arise. [5]

4.5.2 Erasing the Infinities from Equations:

The main reason that quantum mechanics and gravity don't mesh is that the two together produce infinite solutions to equations. Everywhere gravity meets the quantum, infinity pops up, and infinite solutions are nonsense. The infinities appear in part because present-day theoretical physics allows particles to be infinitely small, and space and time to squeeze down to infinitely small specks. String theory solves that most fundamental of problems by doing away with infinitely small particles. Since the loop of string is the smallest allowable size, the strings prevent anything from getting infinitely small, they smear out many previously troubling properties of space and time at infinitely small scales. You never get to the point where the disasters happen. String theory prevents it. [44]

4.5.3 Unification of the Four Forces:

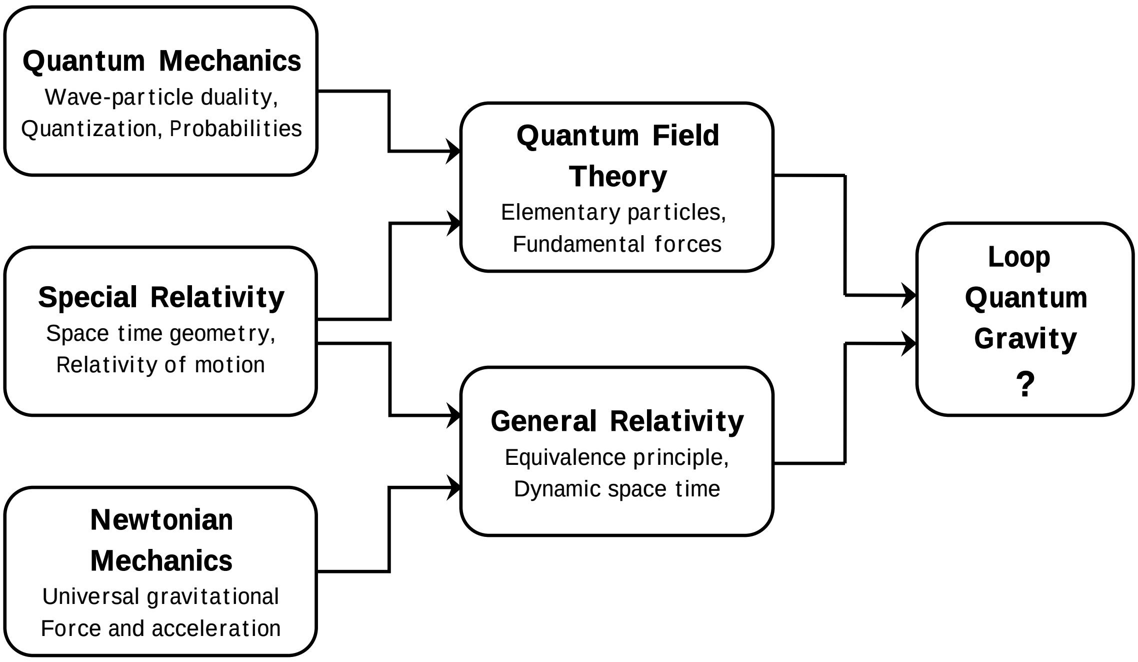
In string theory, as we have seen, all particles arise as different vibrations of the same elementary string. Thus, there is no fundamental distinction between `particles of matter' and `particles of force'. Moreover, all interactions are completely specified by specifying the rule for the splitting and joining of the elementary string. It follows that `matter' and `force' are simply different aspects of the same fundamental entity and are thus unified. For the same reason, all fundamental forces including gravity are also unified. The latter force was just the missing ingredient in the search for fundamental description of nature, where the standard model couldn’t incorporate it and all attempts to formulate a quantum theory with gravity on the same lines have failed. This was one of the biggest early surprises in string theory, that it the graviton mode (the particle which transmits the force of gravity) and also predict that it is a boson with spin 2 and with a rest mass of zero. The unification of all forces which has been the holy grail of theoretical physics since Einstein is so naturally built into the structure of string theory. Hence, string theory is the most promising candidate for a unified theory of all forces. [45]

4.6 Is String Theory Physics or Philosophy?

Opponents of string theory claim that it is just a philosophy that lacks justifiable proof through experimentation. Since the strings are too small to be observed. In the meantime, string theorists hope to make indirect experiments that are necessary for the theory to be fully accepted as a good science. One of the indirect experiments is the "Large Hadron Collider", soon will come online at CERN in Switzerland. It will smash protons moving at 99.999999% of the speed of light into each other and so recreate conditions a fraction of a second after the big bang. This experiment will hunt for evidence of supersymmetry, and will look for signs of extra dimensions in case they are large enough for their effects to be visible. The other indirect experiment is the observations of the Cosmic Microwave Background. These waves may contain information about what happened in the extraordinarily high energies of the Big Bang, which could be the only "particle accelerator" strong enough to probe string theory directly. [46, 47, 48]

Chapter (5)

Loop Quantum Theory



5.1 Loop Quantum Gravity:

As been indicated earlier, attempts were laid to unify the two branches of physics; *Quantum Mechanics* and *General Relativity*.

One of these attempts resulted in what is now called; *Loop Quantum Gravity*.

In this chapter we will introduce this theory; its background history, its structure and its weaknesses and strengths. The differences between *Loop Quantum Gravity* and *String Theory* will be included in the text when appropriate.

5.2 The History of Loop Quantum Gravity:

The old version of Loop Quantum Gravity is a theory called: *Canonical Quantum Gravity* (CQG), which is a non-perturbative approach to quantum gravity[49].

CQG was structured on two basic principles of general relativity. First, it used *The Principle of Background Independence*. i.e. in quantum gravity, geometry and matter should both be 'born quantum mechanically'. Thus, in contrast to particle physicists' approaches, one does not begin with quantum matter on background geometry and use perturbation theory to incorporate quantum effects of gravity. The second principle on which COG was based is *The Principle of Diffeomorphism Invariance*, which is also called: *General Covariance*. This Principle says that there are no preferred coordinates to map spacetime and express any equation. i.e. a point in spacetime is defined only by what physically happens at it, not by its location according to some special set of coordinates[54].

Unlike String Theory, CQG is limited to four dimensional spacetime. It intends to put Einstein's actual field equation, without supersymmetry, in a quantum context.

A direct approach to this is by putting Einstein's field equation in a Hamiltonian form, and then solving it by using the procedure of canonical quantization.

This approach has a long history since Dirac in 1932; he had to develop a whole new quantization framework in order to handle the difficulties that occurred. For many years researchers worked on it but what they obtained was increasing sophistication.

Then in 1986, an Indian/American physicist Abhay Ashtekar made an important advance; by a subtle choice of the variables used in the theory. He was able to simplify the structure of the Hamiltonian equations, leading to a simple polynomial structure.[50]

Soon after, *Wilson Loops* of the *Ashtekar variables* were introduced to solve an important equation called *Wheeler-DeWitt equation*. In 1987 Wilson loops were chosen as the new basis states for quantum gravity. For more clarification; these loop variables were taken as quantum operators with eigenstates that are a family of basic discrete quantum gravity states, which are represented as functions on a space of loops. This is called: *Loop Representation* of quantum states [51]. And from this representation the theory; Loop Quantum Gravity captured its name.[49]

5.3 Fundamentals of the Theory:

5.3.1 Faraday Lines of Force:

The conventional mathematical formalism of quantum field theory relies very much on the existence of a background space.

The basic idea of loop quantum gravity is to take general relativity seriously and face the problem that there is no background space in nature and try to come up with a solution.

So many ways were proposed, but the key input that made the theory work was an old idea: its faraday's line of force. A faraday line can be viewed as an elementary quantum excitation of the field and in the absence of charges these lines must close on themselves to form loops.

What is Loop Quantum Gravity then?

It is the mathematical description of the quantum gravitational field in terms of these loops. That is, the loops are quantum excitations of the faraday line of force of the gravitational field.

In low energy approximation of the theory, these loops appear as *gravitons* which are the fundamental particles that carry the gravitational force.

How are the loops backgrounds independent?

The idea is so easy to understand, in gravity the loops are space because they are quantum excitations of the gravitational field, which is the physical space.

It therefore makes no sense to think of a loop being displaced by a small amount in space. There is only sense in the relative location of a loop with respect to other loops and the location of loops with respect to the surrounding space is only determined by the other loops it intersects.[52]

5.3.2 Quantization of Areas and Volumes:

To explain how the theory works we need to consider what it predicts for a small region or volume.

To do so consider a spherical shell that defines the boundary B of space and time, loop quantum theory says that there is no zero absolute minimum volume and it restricts the set of large volumes to a discrete series of numbers.

So the theory predicts that space is like atoms: there is a discrete set of numbers that the volume measuring experiment can return.

Similarly there is a nonzero minimum area and discrete series of larger allowed areas.

The discrete spectrum for each the volume and the area are similar to that of a hydrogen atom as it shown in figure (5.1) below:

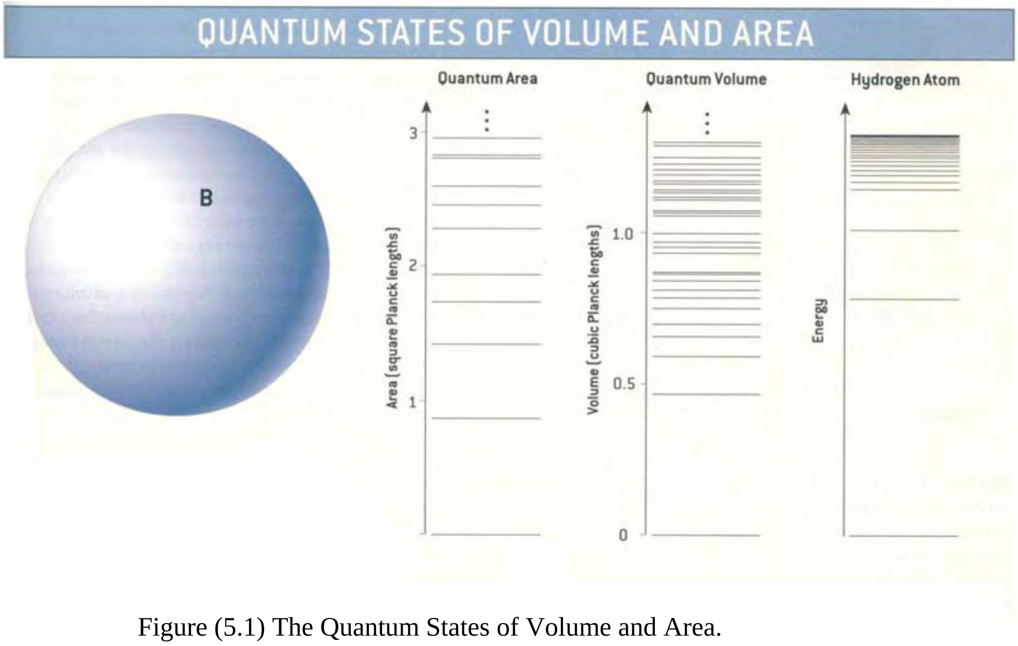


Figure (5.1) The Quantum States of Volume and Area.

To represent a loop we will use dotes and lines as quanta of volumes and areas. For more understanding see can see in the figure (5.2), one quantum of area is represented by a single line (e), whereas an area composed of many quanta is represented by many lines (f). Similarly, a quantum of volume is represented by one node (g), whereas a large volume takes many nodes (h). If we have a region of space defined by a spherical shell, the volume inside the shell is given by the sum of all the enclosed nodes and its surface area is given by the sum of all the lines that pierce it.

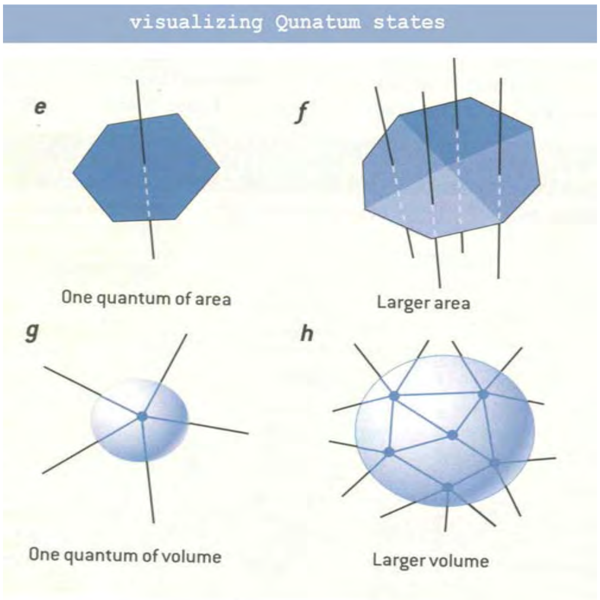


Figure (5.2) Visualizing the Quantum States.

5.3.3 Spin Networks:

An example of a spin network is illustrated in figure (5.3); a cube (a) consists of volume enclosed within six square faces. The corresponding loop (b) will has a dot, or node representing the volume and six lines represent the six faces. The corresponding spin network (b) has a dot, or a node, representing the volume and six lines that represent the six faces. The complete spin network has a number at the node to indicate the cube's volume and a number on each line to indicate the area of the corresponding face. Here the volume is eight cubic Planck lengths, and the faces are each four square Planck lengths. (The rules of loop quantum gravity restrict the allowed volumes and areas to specific quantities: only certain combinations of numbers are allowed on the lines and nodes.)

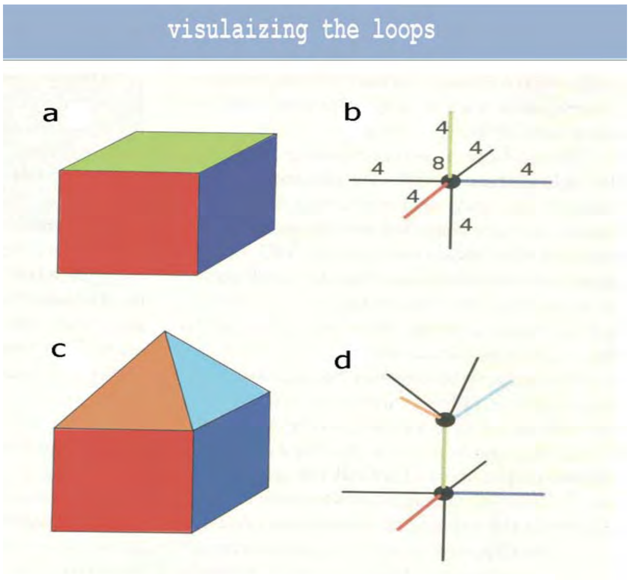


Figure (5.3) Visualizing the Loops.

If a pyramid sat on the cube's top face (c), the line representing that face in the spin network would connect the cube's node to the pyramid's node (d). The lines corresponding to the four exposed faces of the pyramid and the five exposed faces of the cube would stick out from their respective nodes. (The numbers have been omitted for simplicity.)[58]. Putting more than one shape will make a network, as shown in figure (5.4).

The spin networks are more fundamental than the polyhedra: any arrangement of polyhedra can be represented by a spin network in this fashion, but some valid spin networks represent combinations of volumes and areas that cannot be drawn as polyhedra. Such spin networks would occur when space is curved by a strong gravitational field or in the course of quantum fluctuations of the geometry of space at the Planck scale.[54]

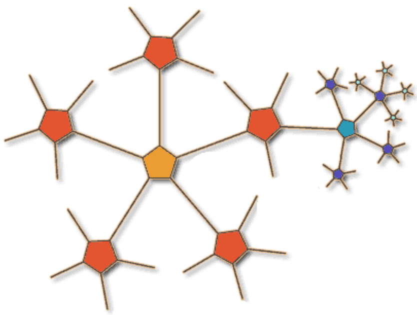


Figure (5.4) Visualizing the Spin Network.

While unraveling this elegant mathematical description of quantum space, we realized that we had come across something that had already been studied. Sometime earlier, Roger Penrose of Oxford University had invented precisely the nets carrying the very same quantum numbers that we were finding. Since these quantum numbers and their algebra looked like the spin angular momentum numbers of elementary particles, Penrose called them “spin networks”.

We can take one graph and from it can calculate how much space is distorted. Because the distortion of space which what produces gravity. This is how a diagrams from a quantum theory of gravity works.

How spin network of spacetime is mathematically precise and physically compelling:

Nodes of spin networks represent elementary grains of space, and their volume is given by a quantum number that is associated with the node in units of the elementary Planck volume,

$$v = (\frac{\hbar G}{c^3})^{3/2}$$

Where $\hbar$ is Planck's constant divided by 2π, G is the gravitational constant and c is the speed of light. Two nodes are adjacent if there is a link between the two, in which case they are separated by an elementary surface the area of which is determined by the quantum number associated with that link. Link quantum numbers, *j*, are integers or half-integers and the area of the elementary surface is [52].

$$A = 16\pi v^{2/3}\sqrt{j(j+1)}$$

5.3.4 Spin Foams:

Spacetime is a temporal sequence of spaces, or a history of spaces. In loop quantum gravity, space is replaced by a spin network and spacetime is therefore described by a history of spin networks which is called a "*spin foam*". The history of a point (node) is a line, and the history of a line (link) is a surface. A *spin foam* is therefore formed by surfaces which are called faces, and lines which are called edges. Faces meet at edges, which, in turn, meet at vertices. These vertices represent elementary interactions between the nodes.

Look at figure (5.5 c) Taking a slice through a spin foam at a particular time yields a spin network; taking a series of slices at different times produces frames of a movie showing the spin network evolving in time, see figure (5.5 d) . But notice that the evolution, which at first glance appears to be smooth and continuous, is in fact discontinuous. All the spin networks that include the orange line as indicated in the first 3 frames shown in figure (4.5 d), represent exactly the same geometry of space. The length of the orange line doesn't matter – all that matters for

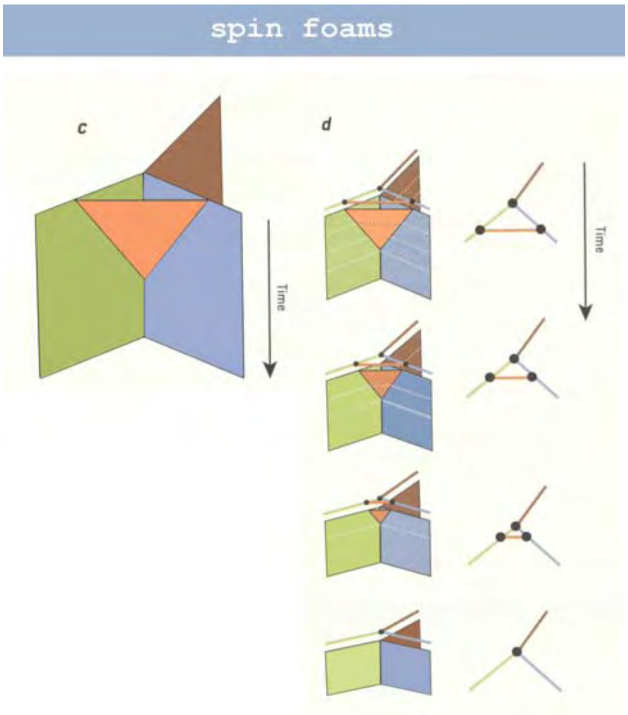


Figure (5.5) Visualizing the Spin Foams.

the geometry is how the lines are connected and what number labels each line. Those are what define how the quanta of volume and area are arranged and how big they are. Thus, in figure (5.5 d), the geometry remains constant during the first three frames, with three quanta of volume and 6 quanta of surface area. Then the geometry changes discontinuously, it becomes a single quantum of volume and 3 quanta of surface area, as shown in the last frame. In this way, time as defined by a spin foam evolves by a series of abrupt, discrete moves, not by a continuous flow. Although speaking of such sequences as frames of a movie is helpful for visualization, the more correct way to understand the evolution of the geometry is as discrete ticks of a clock. At one tick the orange quantum of area is present; at the next tick it is gone – in fact, the disappearance of the orange quantum of area defines the tick. The difference in time from one tick to the next is approximately the Planck time, 10^{-43} second. But time does not exist in between the ticks; there is no "in between", in the same way that there is no water between two adjacent molecules of water. [54]

5.4 Weaknesses and Strengths of Loop Quantum Gravity:

5.4.1 The Main Weaknesses:

The weaknesses of loop quantum gravity lie in:

i. The lack of dynamics:

Dynamics is a branch of mechanics that is concerned with the effects of forces on the motion of a body or a system of bodies. This effect involves not only the forces but also the masses. Researchers are still working on dynamics in loop quantum gravity; still there is no acceptable approach to enter dynamics into the theory. And as Ashtekar himself commented [49]:

"Although there is no natural unification of dynamics of all interactions in loop quantum gravity, it does provide a kinematical unification".

ii. Low Energy Physics:

The connection to low energy physics is also unclear. What is missing is a systematic way of computing scattering amplitudes and cross-sections, such as the standard perturbation expansion in quantum field theory. The mathematics of the theory is well defined, but this does not mean we know how to calculate everything.

iii. The Wheeler Dewitt Equation:

The dynamical key of the theory is the wheeler DeWitt equation exists in several varieties and the one that is correct is not known yet.

5.4.2 The Main Strengths:

On the other hand, its most significant results are:

i. Explaining Hawking black hole:

Thermodynamics suggest that a black hole has a temperature and therefore entropy.

This entropy, *S*, is given by the famous *Bekenstein–Hawking formula*,

$$S = \frac{Akc3}{4\hbar G}$$

where *A* is the black hole's area, *k* is Boltzmann's constant and G is the gravitational constant.

A long-standing problem in quantum gravity was to understand the temperature of black holes from first principles, and this formula has now been derived using loop gravity, albeit once a free parameter has been fixed (*called the Immirzi parameter*).

ii. Dismissing the Big bang singularity:

Loop gravity has been recently able to be applied and describe the physics of the Big Bang singularity. In cosmology the volume of the expanding universe plays the role of the time parameter.

Since volume is quantized in loop gravity, the evolution of the universe takes place in discrete time intervals. The idea that cosmological time consists of elementary steps changes the behavior of the universe drastically at very small scale, and gets rid of the initial Big Bang singularity.

iii. Giving definite measurements of Planck scale:

The eigenvalues of volume and area are also solid quantitative predictions of the theory. This means that any volume and area that we could measure should correspond to a particular number in a spin network. A direct test of this would require us to measure volumes or areas at Planck scale. This is currently well beyond the experimental ability, but it is reassuring that the theory makes definite quantitative predictions.

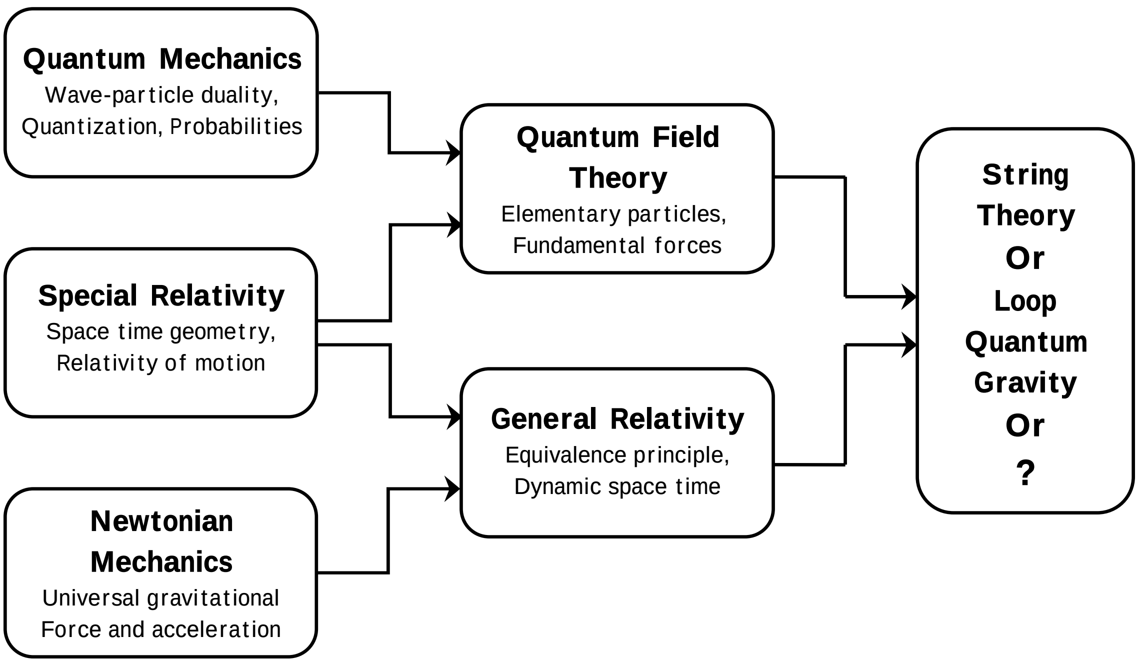
iv. Getting rid of the infinities:

The granular structure of space that is implied by spin networks also realizes an old dream in theoretical particle physics – getting rid of the infinities that plague quantum field theory. These infinities come from integrating Feynman diagrams, which govern the probabilities that certain interactions occur in quantum field theory, over arbitrary small regions of space–time. But in loop gravity there are no arbitrary small regions of space–time. This remains true even if we add all the fields that describe the other forces and particles in nature to loop quantum gravity.

Certain divergences in quantum chromodynamics, for example, disappear if the theory is coupled to the quantum gravitational field [52].

Chapter (6)

Are We There Yet?



Are We There Yet?

The road for unification has gone through so many phases since the beginning of science till the currently big and universal quest for a theory that can describe everything. This frame work was built up step by step with the progress of physics through centuries as it is summarized in figure (6.1).

First, *Newtonian mechanics* and *Kepler's law* were unified through Newton's famous theory of ***gravity***. Then, Maxwell unified *electricity* and *magnetism* in his theory of ***electromagnetism***. One century latter, Einstein introduced his two famous theories of relativity; ***special relativity*** which somehow gathered between *classical mechanics* and *electromagnetism*, and ***general relativity*** which redefined *gravity* according to the *relativistic* concept of *space-time*.

Meanwhile, a group of physicists introduced ***quantum mechanics***. With its birth two new forces were discovered; *the weak force* that describes the interactions in beta decay and neutrino*, and the strong force* that describes the nuclear interactions. Quantum mechanics was at first applicable only on particles, then it extended to include fields in what was named ***quantum field theory.*** Quantum field theory is a theory that unifies quantum mechanics with special relativity. The first successful attempt was its application on the electromagnetic field in what so called ***quantum electrodynamics***. After that they tried to apply quantum field theory on the other forces. This led to the unification of the electromagnetic and weak interactions in a quantum ***electroweak theory***. Afterwards a famous model, known as ***the standard model***, was formed to give a complete picture about the three quantum interactions.

The unification of the three quantum forces kept us with an inquiry about the forth fundamental force; ***gravity***. Where does it fit in all of this? The answer to this question was the motivation for scientists to start their search of the final theory that could fulfill Einstein's dream.

In principle, the four forces must be unified by some means in order scientists can claim that they found the ultimate theory. Such theory will explain all physical phenomena in the universe; from its birth to its end, containing all bodies from the smallest subatomic particle to the vastness of the cosmos.

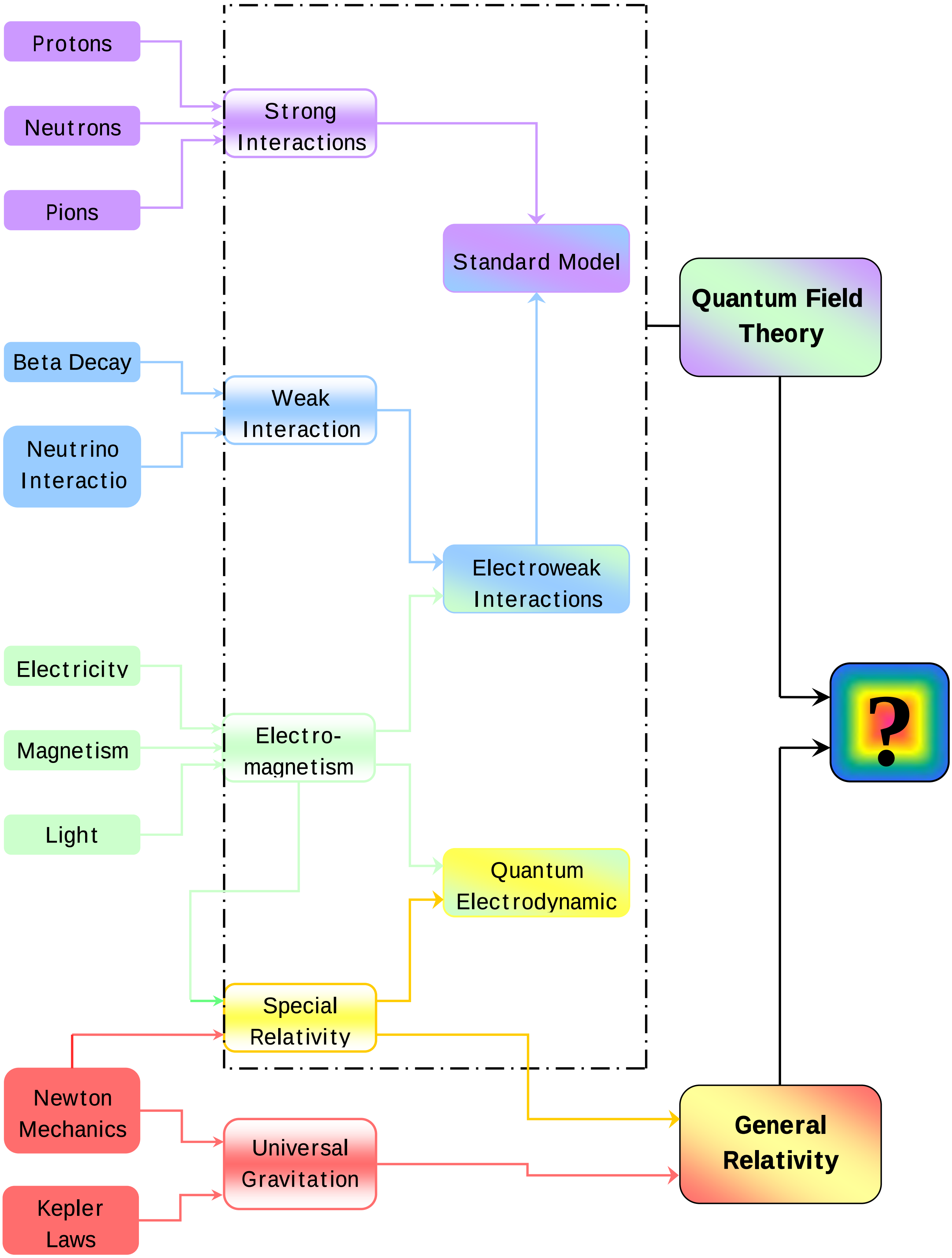


Figure (6.1) The Progress of Physics.

Therefore, many theories were proposed to achieve this goal. But the most promising ones were ***string theory*** and ***loop quantum gravity***. Each has its advantages and disadvantages. But the beautiful thing is that the strengths of one are the weaknesses of the other and vice versa. This led **Brian Greene**, one of the major advocates of *string theory*, to say:" My hope is that ultimately we are developing the same theory from different angles" (1) . [56]

At the moment there is no direct experimental test for any of these two theories. And any theoretical construction must remain humble until its predictions are directly and clearly verified through a rigorous experiment.

For example, Maxwell’s theory turned out to be credible when radio waves were observed. Likewise, general relativity became believable when the deflection of the light by the Sun was measured, and when atomic clocks in the Global Positioning Satellite system were found to be running faster than they do on Earth. On the other hand, the standard Model of particle physics became convincing when the intermediate W and Z bosons were observed.

Nothing of this sort has yet happened to prove either *string theory* or *loop quantum gravity*. Nevertheless, advocates of each theory have a strong feeling that the evidence is coming soon.

(1) This idea has been also championed by Lee Smolin, one of the supporters of *Loop Quantum Gravity*.

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