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Is a unified field theory possible: Understanding the problems between Relativity and Quantum Mechanics?

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PART-1

In modern physics, there are to major theories that describe the functioning of the universe: Relativity, the study of massive objects, and Quantum Mechanics, the study of subatomic particles. Ever since the two theories were proposed they have never been coherent and seemingly hate each other. Let us first investigate the fundamentals of each theory and understand why they build a puzzle that just does not fit.

1.1 Relativity

There are two main theories that Einstein proposed describing the relative nature of time. The first, Special Relativity proposed in 1905, describes the relationship between energy and mass using the famous equation $E=mc^2$, Where E is the energy, m is the mass and c is the speed of light. The special theory of Relativity is used when discussing huge energies, ultra-fast speeds, and astronomical distances, all without the impact of gravity.

According to the Special Theory of Relativity, as an object approaches the speed of light its mass becomes infinite and so does the energy needed to move it. This imposes that it is impossible for matter to travel faster than the speed of light.

An analogy used to explain the theory of relativity is that of the train. Imagine a person shoots a beam of light on a wall, the photons will be travelling at the speed of light. But if a person travelling in a train were to shoot the same beam of light, would the beam of light hit the wall, at the same distance, faster than the stationary shooter? It does not, both beams hit the wall at the same time. But how is this possible, the speed of light is constant, and according to Newton the velocity of the train and beam of light should add up, and therefore should be faster. However, we know nothing can travel faster than the speed of light and therefore the only explanation for the phenomenon would be that time, for a moving object is slower relative to an inertial/stationary observer.

The General Theory of Relativity published in 1915, is Albert Einstein's understanding of how gravity affects the fabric of space time. This bridged the gap by including the effects of gravity in special relativity. Einstein theorized that massive objects wrap the fabric of Space-time[1], a distortion that manifests itself in the form of Gravity.

In his general theory of relativity, Einstein stated that the laws of physics stay the same for all inertial observers and proved that the speed of light in a vacuum is the same no matter at the speed at which the observer travels.

He also determined that space and time were interwoven into a single continuum known as space time. Moreover, events that occur at the same time for one observer might occur at a different time for another.

This is how Einstein envisioned Gravity. Imagine setting a large object in the center of a trampoline. The object would press down into the fabric, causing it to dimple. If you then try to roll a marble around the edge of the trampoline, the marble will spiral inward toward the body, pulled in much the same way that the gravity of a planet pulls at rocks in space. [2]

[1] Space-time can be thought of as a 'fabric' in which the objects of the Universe are embedded.
[2] Tillman, Nola Taylor, et al. "Einstein's Theory of General Relativity." *Space.com*, Space, 5 Jan. 2022, https://www.space.com/17661-theory-general-relativity.html.

Important predictions and phenomenon described by relativity

- Gravitational Lensing- The bending of light around massive objects such as black holes.
- The gradual changes in Mercuries orbit due to the curvature of space time.
- Gravitational Time dilation- The slowing of time due to Gravity.
- Frame Dragging of Space time around Rotating Bodies- Rotating objects twist and distort space time around them.
- Gravitational Redshift-The electromagnetic radiation is stretched out slightly inside in a gravitational field.
- Gravitational Waves- Ripples in space time caused due to violent events such as the collision of two black holes.

1.2 Quantum Mechanics

Quantum mechanics describes the behavior of subatomic particles that in turn describes the functioning of atoms and their chemistry. It is the building block of modern particle physics. In classical mechanics, some equations that describe the behavior of the atom, cease to be useful. In classical mechanics, objects exist in a specific place at a specific time. However, in quantum mechanics objects exist in a phase of probability, and have a certain chance of being at point A and certain chance of being and Point B.

The origin of Quantum mechanics cannot be credited to any one scientist, but itself is the culmination of works of multiple physicists, which gardened the foundation of three revolutionary principles of the theory. These three principles are:

- Quantized Properties: This describes the set amounts of characteristics that can occur in specific amounts such as position, speed and colour. This opposed the classical view of mechanics that assumed such properties existing in a continuous spectrum. These properties are like a dial, and ‘click’ from one number to another. To describe these settings, and ‘clicks’ scientists used the term ‘quantized’.
- Light Particles: We all assume light to be a wave, but it also behaves like a particle, this is known as the ‘wave particle duality’. When observed through a double slit light behaves as a wave, but the photoelectric effect proves that light consists of small packets of energy or quanta known as photons.
- Waves of Matter: Matter like light behaves both like a wave and particle, depending on the observer. This countered 30 years of experiments that showed that matter (such as electrons) exists as particles.

1.2.1 Quantized Properties

In 1900, Max Plank, when observing the glow of red-hot and white-hot objects such as filaments, noticed that the emission spectrum of colours were quantized. He realized that combination of only certain colours were being emitted and were whole number multiples of base values. This was revolutionary as light was understood to act as a wave and in a continuous spectrum and so a question arose, “What was preventing the atoms from producing colours between the whole number multiples?”

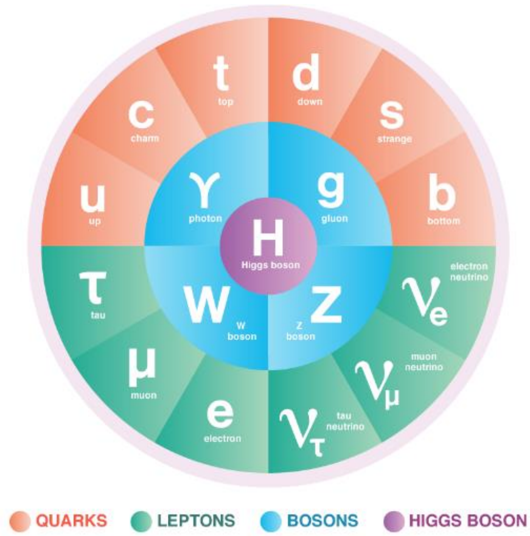
In the early1800s spectroscopy was able to show that certain elements emit and absorb particular wavelengths of light called ‘spectral lines. Even though spectroscopy was reliable, Scientists never understood why each element gave off those specific lines in the first place. In 1888, Johannes Rydberg derived an equation describing the hydrogen spectrum, but no one was able to explain why the equations worked. However, in 1913, Niels Bohr applied Plank’s quantization hypothesis to Rutherford’s atomic model that postulated electrons orbit around the nucleus as planets orbit around the sun. Bohr proposed the electrons were restricted to these special orbits; however, an electron could jump in between these orbits by gaining or releasing energy, emitting light observed as spectral lines.

There are 4 major forces that govern the laws of physics: Strong Force, Weak Force, Electromagnetic Force, and the Gravitational Force.

Before we delve into the intricacies of these forces, we first must understand the standard model of particle physics.

1.2.2 The Standard Model

This model is a sort of table that consists of all the subatomic particles that describe the building blocks of the universe.



The standard model contains seventeen named particles (as shown in fig. 1.1). The last particle that was discovered was the Higgs Boson (2012).

The Standard model can be divided into 8 categories: fermions[3]; bosons[4];1/2 intrinsic spin, 1 intrinsic spin and 0 intrinsic spin; quarks; leptons and neutrinos.

They can also be described depending on their charge, mass, and time of discovery.

Fermions: These particles obey a standard statistical distribution described by Enrico Fermi, Paul Dirac, and Wolfgang Pauli. This is known as the Exclusion Principle. The principle states that no two fermions can be described by the same quantum numbers, meaning they cannot have the same principle, angular momentum, magnetic number, or spin. Moreover, two fermions cannot occupy the same space at the same time. This model agrees with macroscopic observations of matter in everyday life.

Boson: These particles, on the other hand, can exist with the same quantum numbers, and can exist in the same space and same time. They follow a statistical distribution[5] proposed by Satyendra Bose and Albert Einstein.

Spin: Elementary particles have an intrinsic spin, meaning they have a measurable quantity with the same unit as angular momentum. However, spin is a convenient label for a measurable quantity and not a description of reality.

Every element particle is associated with a spin quantum number. This is always a multiple of a half. Fermions have spin (1/2 ,3/2 ,5/2…) and Bosons has spin (0,1,2,3). Since spin is quantized, no other numbers are possible other than this.

Elementary Fermions have a spin of ½. Particles made from combinations of fermions have that's a combination of the individual spin. A baryon, for example, composed of three quarks will combine to an overall spin of ½ or 3/2 because they are the only positive possible combinations of ½ ± ½ ± ½.

[3] Fermions are building blocks of matter
[4] Bosons are mediators of all interactions
[5] Refer to Appendix 4.1

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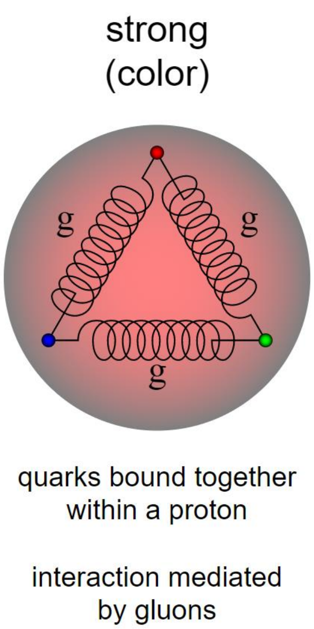


Force carrying bosons have a spin of 1, since they are part of vector fields. Higgs boson corresponds to a scalar field and therefore has spin of 0. If gravitons exist, they will have a spin of 2, as they belong to the tensor field.

Quarks: Fermions that must bind together are called quarks. There are six quarks: up, down, strange, top, and bottom.

Quarks bind together in triplets or doublets; the triplets are called baryons and the doublets are called mesons. Collectively they are known as hadrons.

Leptons: The other six fermions are called leptons; these don't need to bind to each other. The heaviest lepton is known as the tau and has a mass twice that of the proton.

Baryons found in the nucleus are known nucleons. Baryons that contain at least one strange quark or, but no charm, bottom or top quarks are called hyperons.

Neutrinos: This is an important subset within the leptons. There are three neutrinos matched with the electron, muon, and tau. These are known as electron neutrino, muon neutrino and tau neutrino respectively. Neutrinos have very little mass, and their interactions are so weak that they are impossible to detect.

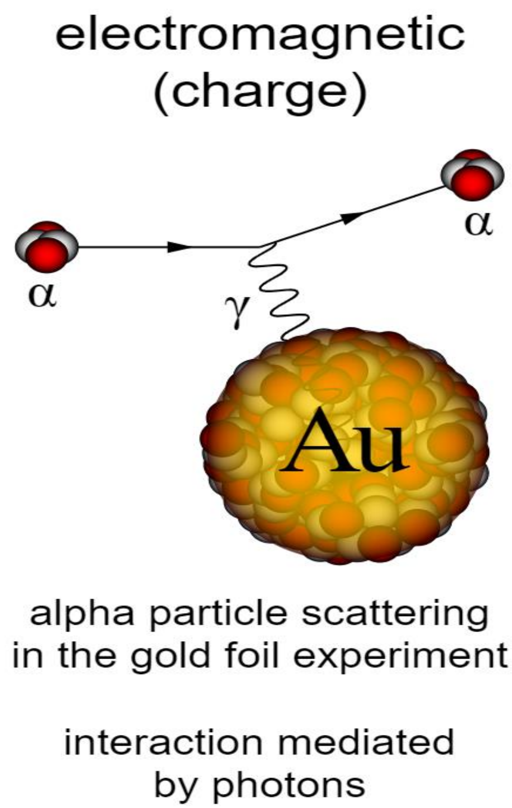
Three of the 4 fundamental forces can be described using particle interactions. However, when we try to quantize gravity weird things start to happen and it is the aim of this research paper to explore this strangeness and find out if there is a solution to this problem.

1.2.3 Standard Model Particle Interactions

Electromagnetic charge: Charge is the property of matter that allow interactions in the electric and magnetic field, often called electromagnetic interactions. Charge is quantized and only exists in discrete and restricted values. These are multiples or fractions of *e* (1.6 x 10^{-19} c). Particles that exist independently (the electron, muon, and tau) carry multiples of charge -*e*, while quark carry fractions of the elementary charge (+⅔ *e* or −⅓ *e*). Since quark, bind in groups whose total charge is an integral multiple of the elementary charge their charge adds up.

Charged particles interact using photons, carriers of electromagnetic force. Photons are responsible for inter-electron repulsion and electrostatic force of attraction between positively charged nucleus and electrons. Photons do not have mass or charge and have unlimited range. Quantum Electrodynamics is the study of interaction of charged particles.

Quarks combine with other quarks because they possess a characteristic often described as color. They can possess any of the three colors: red, green, and blue. This is not an actual visual representation of quarks; this is just an

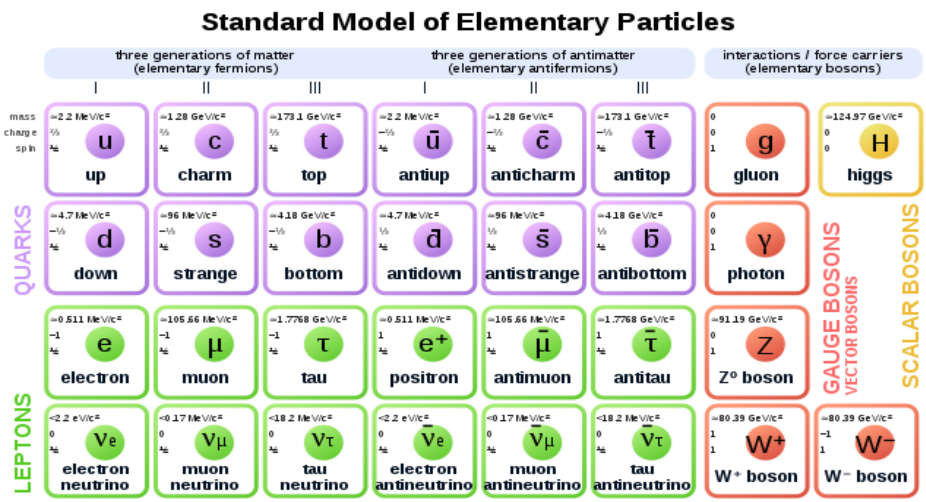


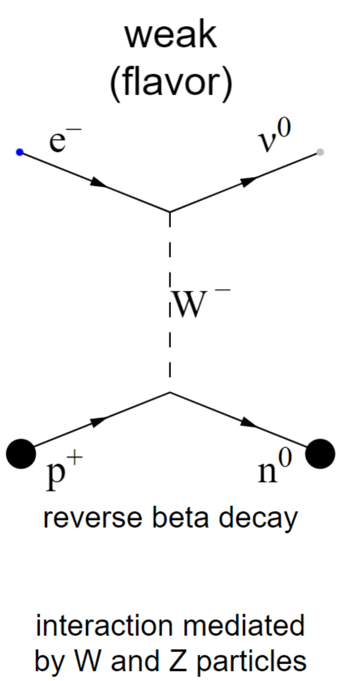
analogy. These colors combine just like human vision.

A baryon is a triplet of red, blue, and green color and because of this it has a neutral color. A color + opposite color gives us a neutral color. A meson is such an example.

Strong Interaction: The colored particles are bound together by particles called gluons. Gluons are colored as well, Six of the eight gluons have two colors, one has four, and another has six. The primary purpose of gluons is to hold quarks together, but they are also themselves. One limitation of the gluon is that they can't interact much beyond the nucleus.

Quantum Chromodynamics is the study of interaction of colored particles through the exchange of gluons. This is known as the strong force, or strong interaction, as it is stronger than the electromagnetic force.





1.2.3 Weak Interaction

Types of Fermions: The difference between the twelve named fermions is one that of 'flavor', this flavor is used symbolically to represent type, and it only applies to fermions.

Fig 1.2 shows the different colors, generations, and flavors.

Flavored particles also interact with each through bosons. The exchange of W or Z bosons results in a weak interaction. These are also known as carriers of W or Z bosons. When a neutron decays into a proton, a W- boson is responsible.

At higher energies it is hard to distinguish between weak and electromagnetic forces. The theory used to describe interactions of the weak force is known as EWT.

1.2.4 Mass and Gravity

All fermions are said to have non-zero rest mass, 1st Generation particles are less massive than 2nd Generation, that are in turn less massive than the 3rd Generation. In the same way Quarks are more massive leptons that are more massive neutrinos. Gluons and photons do not have any mass.

According to Einstein mass= energy. A moving particle has a higher mass than a stationary particle because it has a higher kinetic energy. When we stop a photon, it weighs nothing, however, when we stop an electron, it does weigh something. Why is this the case?

Energy is of two types, kinetic and potential. Kinetic energy contributes less to mass, most of the mass comes through some sort of potential energy. A postulation that arises is that, why does the mass of a proton not equal to the three quarks that make up the proton?

$$m_p \neq 2m_u + 1m_d$$

$$938.272 \text{ MeV/c}^2 \neq 2(2.3 \text{ MeV/c}^2) + 1(4.8 \text{ MeV/c}^2)$$

$$938.272 \text{ MeV/c}^2 \neq 9.4 \text{ MeV/c}^2$$

The masses of the quarks are only 1% of the total mass of the proton, where does the rest of the 99% come from? Well, the interaction energy of the gluons is what give protons most of its mass. But why do quarks have mass, but gluons don't? Or why do the W and Z bosons have mass, but photons don't? The only logical explanation to this is that there is an interaction that some particles feel, and others don't, a particle that gives mass to another particle.

1.2.5 Higgs Mechanism

The interaction that gives mass to elementary particles is known as the Higgs Mechanism, the interaction that gives elementary particles their mass is known as the Higgs Boson.

Space is said to be filled with a sort of sea known as the Higgs Field. The Higgs Field can be described as a sea of Higgs Bosons that pop in and out of existence. Quarks, leptons, and W and Z bosons moving around through space interact with this field, which is why they have mass. The photons and gluons are unable to interact with the Higgs Field and hence do not have mass. The Higgs boson interacts with the Higgs Field, it gives itself mass. Higgs Mechanism is different than the other interactions as it does not resemble a force. The Higgs Field is scalar and therefore the particle has 0 spin.

Quantum Gravity- The reason we don't have a unified field theory

The model used to study quantum gravity is known as Quantum Geometrodynamics but is sometimes known as quantum gravitation. Currently, there is no theory of quantum gravitation. The proposed name for a particle of gravity in the standard model of physics is known as a Graviton.

PART-2

So, what's the problem? Well, when we try and combine the theory of relativity-the study of all things big- and quantum mechanics-the study of all things small- everything goes wrong. For example, one of the most common issues is that well, we create a black hole. But why is this the case?

2.1 Space time is different?

According to relativity, the bending of the space-time fabric is what cause gravity and space-time is a continuous fabric. However, in quantum mechanics space and time are two entirely different things. A leading example for this is the

Schrodinger equation that treats space and time and two different fundamental quantities, just like in Newtonian physics. Even though Paul Dirac solved part of the problem with his relativistic equation of the electron and even though modern quantum theories full incorporate the meddling of space and time in special relativity, they still don't include predictions of the warping of space and time predicted by general relativity. And as you'll see there are some problems that arise, because of this primarily quantizing gravity.

2.2 The black hole information paradox

Black holes are one of the most amazing interstellar bodies. now discovered by humans, that exist in our universe. Born when a massive star collapses inward itself, these bodies of infinite density cause space time to bend in such a way that not even light can escape from its strong gravitational field. The event horizon, or as most people know it "the point of no return", is a boundary from which no energy can escape from the gravitational force of the black hole. What happens to the all the energy absorbed by the black hole? Well, it adds to the mass of the black hole. However, over time-thanks to Professor Stephen hawking- small amounts of mass and energy escape from the black hole, in the form of Hawking radiation (albeit over large time scales). However, this radiation may destroy something extremely valuable, information.

This apparent destruction of quantum information by hawking radiation defies our current understanding of quantum mechanics. According to the law of conservation of quantum information, the fundamental nature of quantum mechanics demands that quantum information be preserved forever, and this implies that with the current knowledge of the universe it should be possible to perfectly trace the path of the universe backwards and forwards in time. Moreover, the no hair theorem states that black holes can only exhibit three properties: mass, electric charge, and angular momentum. The event horizon shields the black hole from any outside influence.

It may seem that the no hair theorem is a direct contradiction of the law of conservation of quantum information. How can we figure out the particles that fell into the black hole? But this isn't a problem, as even though the black hole swallows the information, the information continues to persist inside of the black hole.

On the contrary, the black hole information paradox theorizes that black holes emit perfectly random radiation that contains none of the information about the original contents of the black hole. The gravitational field of the black holes is expected to cause the distortion of the other quantum fields around it. This distortion looks like particles flowing away from the black hole and the energy needed to create these particles must come from the mass of the black hole itself. These particles should have energies that follow the blackbody spectrum[6]-according to Hawking's Calculations- and should looks exactly like the thermal radiation of heat. They should radiate with a temperature that is inversely proportional to their mass. Furthermore, the temperature is only dependent on the mass of the black hole and does not depend on what the black hole is made up of. Eventually the black hole will completely evaporate into the particles it emits (mostly photons having no information) and leave no information about the about what fell inside the black hole in the first place. This severely violates one of the tenets on which Quantum Theory is based upon. If we accept relativity and quantum theory as is proposed in the modern day and age, then Hawking Radiaiton must exist creating a conclusive paradox about quantum information.

Some of the solutions to this theory may seem outlandish but they help us negate this clear paradox. According to the Einstein-Carten theory, it is predicted that the formation of a rotating black hole gives birth to an entire new universe accessible through a wormhole, so all the information lost in the black hole ends up in the new universe? It would not be accessible to us but would still exist in a universe beyond our reach.

Another solution is that the information of everything falling inside the black holes latches onto the hawking radiation itself, staying in the same universe. This idea is inspired by the fact that, according to the view of an outside observer, nothing ever

[6] "Blackbody radiation" or "cavity radiation" refers to an object or system which absorbs all radiation incident upon it and re-radiates energy which is characteristic of this radiating system only, not dependent upon the type of

crosses the event horizon. Everything that fell into the black hole stays for an infinite time on the event horizon, according to an inertial observer outside the horizon.

But the problem with this view on the information paradox is that there is no mechanism in which an infalling object to leave enough of an information imprint affecting hawking radiation. And even if there was one, it would break quantum mechanics as much as the information paradox itself.

By transferring the information on hawking radiation, you may violate the law of conservation of quantum information as much as deleting it. From the perspective of an infalling observer, they are not frozen in time they are falling straight into the black hole carrying their information with them. This means that their information would radiate out in the universe and be absorbed back into the black hole. This means that the information would be duplicated violating the quantum no cloning[7] theorem. Leonard Suskin, a round professor, argues that there is no violation as no observer will be able to record both types of information, making them completely disconnected. Moreover, since the inside of black hole exists in a different exist on the same timeline as the external universe, both copies of information might not even exist at the same time. This is known as blackhole complementarity[8]. However, there is still no mechanism for this to happen.

Gerard T' Hooft, calculated the effect of infalling material and found that it doesn't exactly freeze above a completely static horizon, rather it distorts the horizon creating a 'lump' at the point of crossing. These predicted distortions should contain all the information about the infalling material. Theoretically, these distortions could influence outgoing hawking radiation. However, he soon realized that the three dimensional gravitational and quantum mechanical interior of a black hole can be described in a two-dimensional surface, which did not include gravity. This made him postulate that the unification of quantum mechanics and gravity may require that the entire 3-D universe be a projection on a 2-D structure. Leonard Susskind formalized this idea in the form of string theory, something that we shall discuss later in this paper. This principle is called a holographic projection of the universe.

Hawking himself suggested that quantum tunneling from inside a black hole could interact with the holographic horizon and carry information back out into the universe. Black hole complementarity, the solution to the paradox, itself introduces another paradox. It suggests that each particle of hawking radiation should be simultaneously entangled with the interior of the black hole and with all past hawking radiation. This violates the principle of monogamy of entanglement.

2.3 Quantizing Gravity

One of the biggest issues, as you guessed, is that gravity behaves weirdly on the quantum scale. Gravity is a very, very weak force. A water droplet hanging from the bottom of your finger doesn't fall down, showing that the electrostatic force between your finger and the water molecules is stronger than the gravitational force of the Earth!

On the quantum scale, when we try quantizing gravity, we need to quantize space time itself. So, one might wonder, why don't we just go ahead and do that? Well, if you try quantizing gravity then you end up creating a miniature black hole, which is far from ideal.

For you to define a location in space, you need to interact with an object. This is usually carried out by using photon. Imagine shooting a particle, with a beam from a particle accelerator to measure its location with extreme precision. The Heisenberg

[7] The no cloning theorem is a result of quantum mechanics which forbids the creation of identical copies of an arbitrary unknown quantum state. It was stated by Wootters, Zurek, and Dieks in 1982, and has profound implications in quantum computing and related fields. The theorem follows from the fact that all quantum operations must be unitary linear transformation on the state

[8] Within the framework of black hole complementarity, a proposal is made for an approximate interior effective field theory description. For generic correlators of local operators on generic black hole states, it agrees with the exact exterior description in a region of overlapping validity, up to corrections that are too small to be measured by typical infalling observers.

uncertainty principle[9] provides us with the minimum energy required for a given precision. The amount of energy needed to measure a Planck length[10] is immense, in fact it is so dense that you end up creating a black hole with an event horizon one Planck length in diameter. For an even more precise measurement you need even more energy, and you end creating larger black holes. The conclusion drawn using general relativity and the uncertainty principle is that it is impossible to measure lengths smaller than the Planck length.

For us to highly define the location of particle, we need to construct its position[11] wave function from a large array of its momentum wave functions that include extremely high frequencies. Therefore, the more certain it's positioned the less certain its momentum. So, position can be defined to one Planck length but then momentum becomes so uncertain that it has a ridiculously high value. Because of this, particles whose positions are defined to a Planck length can spontaneously become blackholes. However, we have never come across such black holes, hinting towards the incompleteness of our theories.

Standard quantum theory treats the fabric of space time as the arena in which all interactions take place. Because of this underlying structure it is relatively easier to quantize most of the forces of nature. An example of this is the transition from classic electromagnetism to quantum electrodynamics via quantizing the electron field and the electro-magnetic field. However, in the resulting mathematics, the new quantum fields lie on top of a smooth fabric of space and time.

The gravitational field does not lie on top of space time it is space time itself, creating a problem. To quantize gravity, you need to quantize space time itself. This does not leave any clear coordinate system which can be used to define your theory. In general relativity, the presence of mass or energy must cause warping of space and time, there are no exceptions. In quantum gravity, gravity itself becomes an excitation in quantum space time. The energy of these excitations should result in space time curvature, resulting in more excitations. Gravity should produce more gravity…infinitely.

These types of self-interactions or self-energy is seen other quantum theories as well and is hard to deal with. In quantum electrodynamics the electron self-interaction due to their electric charge interfering with the surrounding electro-magnetic field. This can be fixed using something called the perturbation theory[12]. And it works, because the corrections are small or if they are large, they can be contained. They can be brought back to reality by actual physical measurements, in a process called renormalization[13].

However, when quantizing general relativity all of these methods fail. When you observe the effects of gravity on the quantum scale, the self-energy corrections blow up to infinity and unlike other quantum fields there are no simple measurements that can be taken to renormalize those readings, you would need infinite measurements to do so. The non-renormalizability of general relativity is connected to the idea that precisely localized particles end up producing black holes.

2.4 Fun Thought experiment

Is there an accurate way to measure light?

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[9] At the foundation of quantum mechanics is the Heisenberg uncertainty principle. Simply put, the principle states that **there is a fundamental limit to what one can know about a quantum system**. For example, the more precisely one knows a particle's position, the less one can know about its momentum, and vice versa

[10] The Planck length is the scale at which classical ideas about gravity and space-time cease to be valid, and quantum effects dominate. This is the 'quantum of length', the smallest measurement of length with any meaning. And roughly equal to 1.6 x 10-35 m or about 10-20 times the size of a proton.

[11] A wave function in quantum physics is a mathematical description of the quantum state of an isolated quantum system. Refer to Appendix 2.1 for derivation for wave function on a string.

[12] Refer to Appendix 3.1

[13] Refer to Appendix 3.2

Our most precise calculations of the speed of light, are deeply flawed. You can use the best of equipment and be able to measure the speed of light up to a thousand decimals places, but you would steel achieve an inaccurate answer. The reason behind this General Relativity. The current way of measuring the speed of light is by bouncing a light ray from a mirror and recording the time it takes for the ray to return. This is because the duration must be recorded using a single clock. However, since light is bouncing back, for all we know there could be a bias affecting the speed of light in each direction. For example, the speed of light while hitting the mirror could be 2c and while coming back could be only ½c. This creates a huge amount of uncertainty behind the true speed of light.

You may just think why not just have two clocks and record the time interval using that. Here is the issue, if we start out with two identical clocks, synchronized to nearest picosecond, we must move them further apart. This induces time dilation due to the movement kicking the clocks out of synchronization. Therefore, you are unable to measure the interval between sending the pulse and receiving the pulse as both clocks are keeping a different time.

The way to solve this is as follows-

Imagine a box with two identical clocks in the middle. Each clock has a magnet attached to it, one with a south pole and the other with a north pole facing towards the edge of the box. The clocks are facing towards each other, with one having a receiver to detect photons and the other having a photon emitter. Both clocks are synchronized. Now using an electromagnetic field with opposite polls on each end, we can cause the clocks to accelerate towards the end of the box at a fixed rate. The force of the magnetic field at both ends is the same. The magnetic field would turn off once the clocks touch the end of the box. The magnetic field is now turned off. Since both the clocks have been accelerated for the same time and the same magnitude, they should, in theory, suffer the same amount of time dilation and hence remain synchronized. A light pulse can then be sent, and the time take can be recorded eliminating the uncertainty of a Universe bias.

PART 3

There are two approaches to unifying general relativity and quantum mechanics. One is to quantize space and time in a way that avoids infinites the leading example of this is loop quantum gravity. Another is to accept that General Relativity and Quantum mechanics are emergent from a quantum theory deeper than our currently accepted theories, the most prominent of these is String Theory. Both theories have their merits and both theories have their drawbacks. The quest to unifying the two fields has brought us closer to understanding the ways of the universe but it is now, where we have uncovered most facts, that we are furthest away from the truth. The scientific community, it all its rightful stubbornness, is clearly divided on this one specific subject. The cause for debate is primarily between two leading theories: String Theory and Quantum Loop Gravity.

3.1 String Theory

String theory describes the workings of the quantum universe and gravity using infinitesimal vibrating strings, smaller than quarks and other subatomic particles. A contender for a "theory of everything", string theory is used to describe how forces conceptualized on the large level, such as gravity could affect tiny objects such as protons and electrons.

Unlike other fundamental forces of nature, that are mediated through bosons gravity seems to stand out. One of the main reasons is that unlike the electromagnetic, strong, and weak force gravity is so weak that it can not be detected on the particle scale. It seems, gravity exists without a particle. We have predicted what a particle of gravity may look like however, when calculations are carried out for an event in which two gravitons smash together, we get infinite amount of energy packed into a small space. To get rid of this problem, physicists try to replace gravitons with strings. Strings can collide and rebound cleanly without implying physically impossible infinities. There are many types of string theories, but to keep this paper concise we will be looking at 3: bosonic string theory, superstring theory, m-theory.

String theory replaces all matter and force interactions and particles with one thing: vibrating strings that twists and turns in complex ways, that appear, from our perspective as tiny particles. A string of length and frequency might behave as a photon, while another might behave as an electron. But there is a catch to this seemingly beautiful solution to unifying gravity and quantum mechanics. The math doesn't work out in simple 4 dimensions, instead physicists need to invent 10 dimensions, with 6 visible only to the strings.

3.1.2 Bosonic String Theory

Bosonic string theory aims to define the interactions carried out by bosons, such as photons, using strings that interact over a distance. There are 4 possible theories depending on whether an open string is allowed in the theoretical framework and if a specific orientation is bestowed. It is therefore classified as open or closed, while being oriented or unoriented. There are two main rules, the strings must include a negative energy tachyon and a massless graviton. This is also where you need 26 dimensions for the mathematics to work out.

That is due to the vibrations of the strings that occur. Each string has a movement pattern that is like a sound or light waves. The only difference is that the waves do not involve travel. They're 1D waves because they only move along the length of the string itself[14]. As the string moves 2D is required to describe its motion.

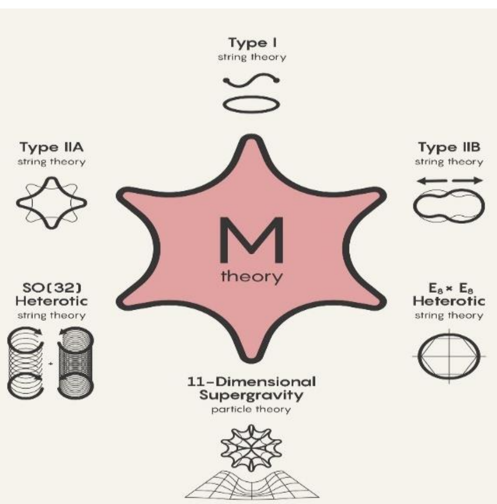
However, there are some issues with the bosonic string theory. Firstly, this theory only predicts the existence of bosons while most of the physical world is made up of fermions. The second is that it predicts that the string has imaginary mass, making it relatively unstable.

There are also inconsistencies with space-time due to conformal anomaly, something that plagues all string theories.

3.1.2 Superstring Theory

Consisting of a world with 10 dimensions, some at the particle level and some dimensions that we perceive as real, superstring theory proposes a spurious space and time.

This model consists of supersymmetric partners of particles from the standard model. It does this through branes, strings that have several dimensions of a special extent. Most of the objects are noted to be covered in unique event horizons and can vary in dimensions. These range from point particles to torus and/or tubular in shape, to multi-dimensional structures that would take very complicated mathematics to envision.



However, superpartners[15] remain undetected as the energy required to detect these is even more than that of LHC events.

3.1.3 M-theory

Sometimes also known as the mother string theory, it incorporates, or tries to, all other types of string theories. Designed to remove the pertubations of the different strign theories, makes all these theories fit together in a non pertubative manner. AdS/CFT [16]gives us a complete defintion fo M-theory, by using negative energies that allow space to be bend in different ways.

14 "Bosonic String Theory Explained." HRF, 22 June 2017, https://healthresearchfunding.org/bosonic-string-theory-explained/.

[15] In particle physics, a superpartner is a class of hypothetical elementary particles predicted by supersymmetry, which, among other applications, is one of the well-studied ways to extend the standard model of high-energy physics

3.2 Quantum Loop Gravity

If gravity is the bending of space time, then it is possible that space time exists as discrete chunks. There may be fundamental units of space time at the particle scale. Loop quantum gravity recreates Einstein's relativity using lines instead of points.

An advantage to the loop quantum gravity, or quantizing gravity in general, is that singularities that appear in relativity fade away. Singularities are points of infinite densities and infinite gravitational strength that appear in Einstein's theory. Because of this we do not have any understanding of what goes on inside a black hole or at the time of the Big Bang. In loop quantum gravity, these singularities are replaced by ultra-dense and ultra-exotic matter. Although a lot of research has bee carried out on this matter, loop quantum gravity is incomplete and needs to be incorporated with other theories such as string theories to make complete sense.

In the end both these theories have their merits and their drawbacks, in the hunt for a theory of everything loop quantum gravity and string theory provide new outlooks to the conventional view of space-time and quantum mechanics. However, we are far away from unearthing the mysteries of the universe. Unifying the two fields brings us one step closer to understanding our existence and the beautiful symmetry and coherence that exists between the fundamental forces of nature.

Appendix

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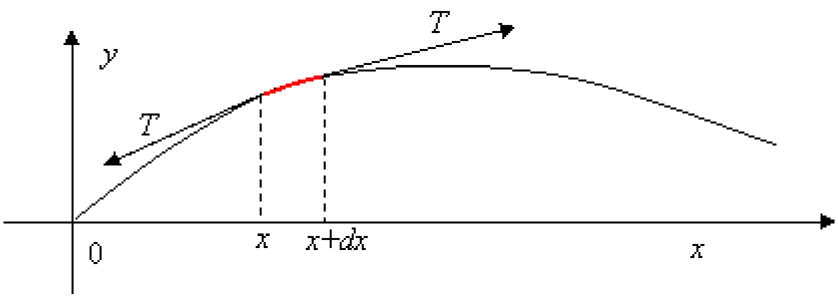
Appendix 2.1 Derivation of wave function

The *wave equation* is derived by applying F=ma to an infinitesimal length dx of string (see the diagram below). We picture our little length of string as bobbing up and down in simple harmonic motion, which we can verify by finding the net force on it as follows.

We equate a string fragment, point y, to the tension T at a small angle df(y)/dx to the horizontal. The tension acts necessarily along the line of the string. The downward force can be Tdf(y)/dx, while the upward component can be Tdf(y+dx)/dx.



Putting f(x+dx)=f(x)+(df/dx)dx, and adding the almost canceling upwards and downwards forces together, we find a net force T(d2f/dx2)dx $T(d^2f/dx^2)dx$ on the bit of string. The string mass is ρdx, so F=ma becomes

$$T\frac{\partial^2 f(x,t)}{\partial x^2}dx = \rho dx \frac{\partial^2 f(x,t)}{\partial t^2}$$

giving the standard wave equation

$$\frac{\partial^2 f(x,t)}{\partial x^2} = \frac{1}{c^2}\frac{\partial^2 f(x,t)}{\partial t^2}$$

with wave velocity given by c2=T/ρ

Appendix 3.1 Perturbation Theory

The principle of perturbation theory is to study dynamical systems that are small perturbations of `simple' systems. Here simple may refer to `linear' or `integrable' or `normal form truncation', etc. In many cases general `dissipative' systems can be viewed as small perturbations of Hamiltonian systems. Focusing on Parametrized KAM Theory, persistent occurrence of quasi-periodic tori is established, both inside and outside the class of Hamiltonian systems. Typically, perturbation theory explains only part of the dynamics, and in the resulting `gaps' the orderly unperturbed motion is replaced by random or chaotic motion.

The aim of perturbation theory is to approximate a given dynamical system by a more familiar one, regarding the former as a perturbation of the latter. The problem is to deduce dynamical properties from the `unperturbed' to the `perturbed' case. For general reading and some references see (Broer and Hanßmann 2008).

Frequently used `unperturbed' systems are

- Linear systems;
- Integrable Hamiltonian systems, compare with (Hanßmann 2007, 2008) and references therein;
- Normal form truncations, compare with (Broer 2008) and references therein;

For simplicity all systems are assumed to be `sufficiently' smooth, i.e., of class C∞ or real analytic. Moreover ε is a real parameter. The `unperturbed' case corresponds to ε=0 and the `perturbed' one to ε≠0 or ε>0.

Appendix 3.2 Renormalization

Renormalization is a technique for achieving greater precision in certain physics theories. In quantum mechanics, renormalization is used to achieve high levels of precision in calculating the amount of mass and charge of subatomic particles like protons. I'll use the proton as an example.

In the early decades of the 20th century, physicists were trying to calculate the mass and charge of the proton by using the Dirac Equation. The Dirac Equation was developed by British physicist, Paul Dirac, in 1928 as an upgrade of the Schrodinger Equation.

While the Dirac Equation approximated the mass and charge of the proton quite well, when trying for greater precision, the answers devolved into infinity. "Infinity" is not considered by physicists to be an accurate answer because it does not describe anything physical. Everything physical is finite. Further, it was known by measurements taken during experiments that, for example, the charge of a proton is finite rather than infinite.

The proton's charge is renormalized by, first, entering into the equation the amount of the proton's charge measured by experiment. The measured amount is an approximation rendered imprecise by the influence of virtual particles. Next, the physicist calculates the effects of many of the virtual particles and revises the measurement of proton's charge accordingly. Bit by bit, the physicist deducts the effects of virtual particles. Today, this is all done by computer, in fact, very long stretches of computer use. The result is a much better approximation of the bare charge of the proton.

Appendix 4.1 Derivation of Bose-Einstein Statistical Distribution

Suppose we have a number of energy levels, labeled by index i, each level having energy ε_i and containing a total of n_i particles. Suppose each level contains g_i distinct sublevels, all of which have the same energy, and which are distinguishable. For example, two particles may have different momenta, in which case they are distinguishable from each other, yet they can still have the same energy. The value of g_i associated with level i is called the "degeneracy" of that energy level. Any number of bosons can occupy the same sublevel.

Let $w(n,g)$ be the number of ways of distributing n particles among the g sublevels of an energy level. There is only one way of distributing n particles with one sublevel, therefore $w(n,1)=1$. It is easy to see that there are $(n+1)$ ways of distributing n particles in two sublevels which we will write as:

$$w(n,2)=\frac{(n+1)!}{n!1!}.$$

With a little thought (See Notes below) it can be seen that the number of ways of distributing n particles in three sublevels is

$$w(n,3)=w(n,2)+w(n-1,2)+\cdots+w(1,2)+w(0,2)$$

so that

$$w(n,3)=\sum_{k=0}^{n}w(n-k,2)=\sum_{k=0}^{n}\frac{(n-k+1)!}{(n-k)!1!}=\frac{(n+2)!}{n!2!}$$

where we have used the following theorem involving binomial coefficients:

$$\sum_{k=0}^{n}\frac{(k+a)!}{k!a!}=\frac{(n+a+1)!}{n!(a+1)!}.$$

Continuing this process, we can see that $w(n,g)$ is just a binomial coefficient (See Notes below)

$$w(n,g)=\frac{(n+g-1)!}{n!(g-1)!}.$$

The number of ways that a set of occupation numbers n_i can be realized is the product of the ways that each individual energy level can be populated:

$$W=\prod_i w(n_i,g_i)=\prod_i\frac{(n_i+g_i-1)!}{n_i!(g_i-1)!}\approx\prod_i\frac{(n_i+g_i)!}{n_i!(g_i)!}$$

where the approximation assumes that $g_i \gg 1$. Following the same procedure used in deriving the Maxwell–Boltzmann statistics, we wish to find the set of n_i for which W is maximised, subject to the constraint that there be a fixed number of particles, and a fixed energy. The maxima of W and $\ln(W)$ occur at the value of N_i and, since it is easier to accomplish mathematically, we will maximise the latter function instead. We constrain our solution using Lagrange multipliers forming the function:

$$f(n_i) = \ln(W) + \alpha(N - \sum n_i) + \beta(E - \sum n_i \varepsilon_i)$$

Using the $g_i \gg 1$ approximation and using Stirling's approximation for the factorials $(\ln(x!) \approx x\ln(x) - x)$ gives

$$f(n_i) = \sum_i (n_i + g_i)\ln(n_i + g_i) - n_i \ln(n_i) - g_i \ln(g_i) + \alpha\left(N - \sum n_i\right) + \beta\left(E - \sum n_i \varepsilon_i\right).$$

Taking the derivative with respect to n_i, and setting the result to zero and solving for n_i, yields the Bose–Einstein population numbers:

$$n_i = \frac{g_i}{e^{\alpha+\beta\varepsilon_i} - 1}.$$

It can be shown thermodynamically that $\beta = \frac{1}{kT}$, where k is Boltzmann's constant and T is the temperature.

It can also be shown that $\alpha = -\frac{\mu}{kT}$, where μ is the chemical potential, so that finally:

$$n_i = \frac{g_i}{e^{(\varepsilon_i-\mu)/kT} - 1}.$$

Note that the above formula is sometimes written:

$$n_i = \frac{g_i}{e^{\varepsilon_i/kT}/z - 1},$$

where $z = \exp(\mu/kT)$ is the absolute activity.