String Theory

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String theory is a concept that has been slowly growing in popularity over the past 50 or so years. Starting from a point of relative obscurity String Theory has begun take hold of many in the physics world. String theory, among other things, boasts to be (if proven) a grand unifying theory that weaves both quantum mechanics and general relativity into a closely knit framework, a framework that explains the inner workings of the universe on the most basic of levels. When first hearing of this new theory one may wonder why such a thing would be necessary or even attractive to physicists. One of these reasons is that string theory gives an apt description of gravity where our current particle model comes up short. The problem that occurs with particle theory is that, “Particle theory only works when we pretend gravity doesn't exist.” (OSTW) This is because “particle interactions occur at a single point of spacetime, at zero distance between the interacting particles. For gravitons, the mathematics behaves so badly at zero distance that the answers just don't make sense.” (OSTW) Since one can easily observe that gravity does exist, a theory that can explain its workings when the current theory comes up lacking would seem like a good possible candidate for further investigation. String Theory fills a gap between the theories of General Relativity and of Quantum Mechanics, a problem that many physicists feel is necessary to solve. Before details of the theory are actually explained it would be prudent to give a small history of the events that have brought string theory to its current formulation.

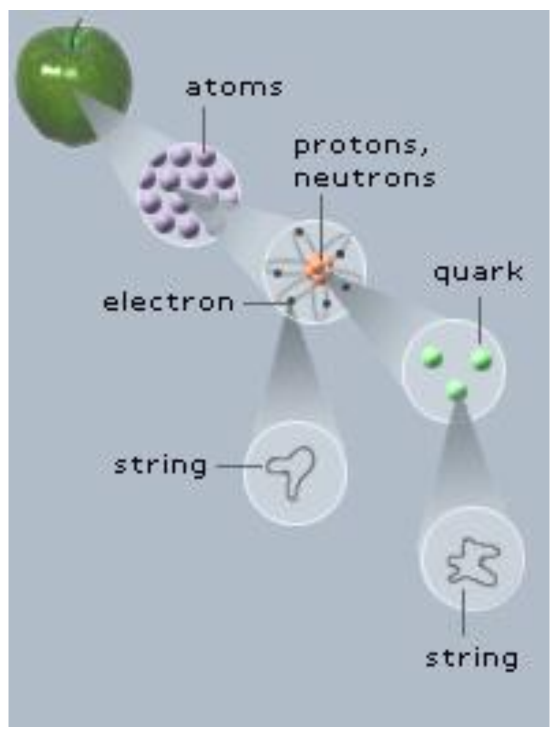
A Brief History

String Theory is a concept dating back to the late 60’s however at the time it did not bear the face that it does today. Originally, “The subject of string theory arose in the late 1960's in an attempt to describe strong nuclear forces.”(Caltech) Unfortunately this line of thought ran into problems and was eventually discarded with the culmination of “Quantum chromodynamics ... a convincing theory of the strong nuclear force” (Caltech) around 1973. In 74’ Joel Scherk and John Schwarz was propose that String Theory could in fact be a quantum theory of gravity and that the problems that had made string theory unusable could actually benefit it if String theory was viewed as a possible Unified Theory as described by Einstein. Then in 1984-85 what was known as the First Superstring Revolution occurred. During this time five different types of string theory were proposed. They are “denoted type I, type IIA, type IIB, E8 X E8 heterotic (HE, for short), and SO(32) heterotic (HO, for short)”(caltech). Discoveries during this time drew many to the conclusion that string theory might actually hold some validity in the scientific world and that it just might hold the key to a Unified Theory. Then between 1994-97 what was known as the Second Superstring Revolution occurred. During this time the five different forms of string theory were unified under what is known today as M-Theory (the encompassing form of string theory). And so string theory has been brought to the point at which it is viewed today.

The Problem

To gain a better understanding of string theory one should first understand why such a theory is deemed necessary by the physicists who support it. For more than fifty years physicists have been aware of a great discrepancy in the way physics is viewed. A great deal of knowledge held about the way the universe works comes from two major culminations of scientific study. They are, as one may have guessed, Quantum Mechanics (the physics of that which is very small) and its polar opposite, General Relativity (the physics of things that are very large). Unfortunately "As they are currently formulated, general relativity and quantum mechanics cannot both be right. The two theories underlying progress that has explained the expansion of the heavens and the fundamental structure of matter – are mutually unacceptable. "(Greene 3).

It would seem that such a discrepancy between two extremely vital theories would cause the answers that they provide to be null and void. This is, fortunately, not the case. Generally a great deal of the work that physicists do can be broken down in to two distinct categories. The first deals with objects on a large scale such as the orbits of planets, motion of galaxies, or even calculations that deal with the entire physical universe. For these things only the theory of general relativity is needed and things go fairly smoothly. The second involves working with objects on the "super small" scales. These include working with atoms, their constituents, and objects down to even the smallest of distances of plank length and smaller. In these cases one really only need rely on quantum mechanics to solve proposed problems as that is quantum mechanics specialty. From this it would seem that there is no apparent problem. “General relativity and quantum mechanics have disjoint experimental domains. General relativity is only observable with massive objects. Quantum effects are only observable with minute particles. Thus these incompatible theories can coexist in a temporary truce.”(mtnmath) If one can simply use each theory to conduct research in their respective fields then there seems to be no issue. The problem is that there are cases where work in physics does not break down into such neat categories as to be easily answered by one set of equations or the other. Examples of these cases can be seen when looking at the extremes of the universe such as black holes, where an almost unfathomable amount of mass (the playing field of general relativity) is crushed and compacted into almost infinitesimally small spaces (an area usually handled by quantum mechanics). In order to accurately describe and predict what could happen inside a black hole (since it would be impossible to physically take data) both the theory of general relativity and quantum mechanics need to be utilized. When these techniques are applied the answers that result are along the lines of infinity. Generally speaking, an infinite answer is the universe’s way of saying that something is incorrect in the way it is being viewed. At this point string theory enters the fray. According to string theory, quantum mechanics and general relativity not only work together but actually draw off



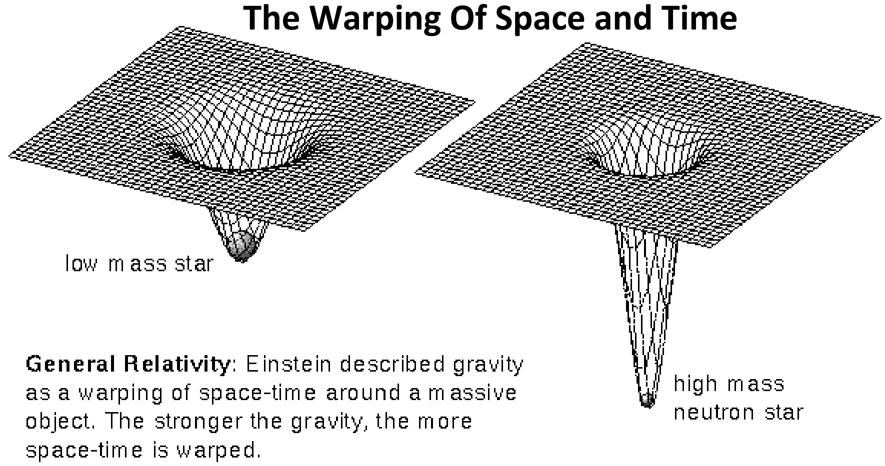
Elementary Particles Break Down Into Strings (NOVA)

of one another to allow the theory to work. String theory states that everything in our universe, if examined with great enough precision, would show that the smallest constituent particles that form our universe are actually extremely small one dimensional loops, and that the patterns of oscillation and vibration that each has give matter its properties. "These strings have certain vibrational modes which can be characterized by various quantum numbers such as mass, spin, etc. The basic idea is that each mode carries a set of quantum numbers that correspond to a distinct type of fundamental particle."(String Basics) In ways that will become apparent later in this paper, String Theory solves the issues between quantum mechanics and general relativity while giving us some surprising insights into how and why our universe works the way it does. In order to gain a greater understanding of the problem between the two theories and why string theory solves this problem, one needs to backtrack slightly and take a look at both general relativity and quantum mechanics.

Einstein's Brainchild

In regards to its importance in this paper, Einstein's theory of general relativity makes the statement that gravity, and the way that objects act upon others through it, is actually related to the bending of space and time. In showing this Einstein had to make several radical changes in our understanding of the known universe. First Einstein showed that, in regards to physics, there is no really distinguishable difference between accelerated motion and the force of gravity upon an object. Imagine for example, a person is strapped firmly to a chair inside of a box with no view of what was outside of them. If that person was then accelerated upward they would feel a force pushing them into their seat. The same holds true if you were to simply set the person on the surface of the earth, there is no way to tell a difference between the two. It was this insight, the idea that an observer who was not able to see his or her surroundings would not be able to tell the difference between the force of gravity and acceleration due to some other force, that lead Einstein to the conclusion that each separate entity may be regarded as one in the same. Next, through use of his original theory of special relativity, he was able to show that accelerated motion results in the warping of space and of time about the object undergoing the acceleration. Since he had already shown that gravity and accelerated motion are nearly indistinguishable, it was not a great step for Einstein to claim, and later prove, that gravity operates through the warping of space and of time. Logical reasoning then shows that the more massive the object, the greater the spacetime distortion. The theory of relativity becomes increasingly useful as the objects become more and more massive and the distortions in space become greater and greater. In the early twentieth century, a physicist by the name of Karl Schwarzschild was able to show that after a certain amount of mass was compressed past a certain point that the warping of space becomes so drastically intense that not even light can escape them. This phenomenon became what is known today as a black hole and is the greatest observable

The Warping Of Space and Time



General Relativity: Einstein described gravity as a warping of space-time around a massive object. The stronger the gravity, the more space-time is warped.

example of the warping of space time due to gravity. The Black hole is also one of the cases in which general relativity and quantum mechanics must both be applied in order to adequately describe what occurs in this stretched area of space. In order to understand why these calculations cannot be made, and in turn why general relativity and quantum mechanics are incompatible one need to understand a few of the intricacies of quantum mechanics.

The Very Small

Quantum mechanics, on its own, completely overturns the way that one views the universe on the smallest of scales. For example, instead of objects moving in intuitive conventional trajectories, they move in ways that are defined by a probability wave assigned to each particle of the object. A great theoretical physicist Richard Feynman came up with an interesting alternative way of describing how the motions of particles work in quantum physics. According to Feynman each particle takes all of the possible paths that the particle can take to get to a certain point. “Feynman showed that he could assign a number to each of these paths in such a way that their combined average yields exactly the same result for the probability calculated using the wave function approach.” (Greene, 111) According to Feynman, the probability wave is built from a combination and cancellation of all of the possible paths an object might take, with the final result being the path that one would predict through classical physics. In general terms “his rule for assigning numbers to each path ensures that all paths but one cancel each other out when their contributions are combined. In effect, only one of the infinity of paths matters as far as the motion of the object is concerned. And this trajectory is precisely the one emerging from Newton’s laws of motion.” (Greene, 111)

Along with motion of particles being associated with probability functions there is a property of quantum mechanics known as the uncertainty principle. It is, in fact, this aspect of Quantum Mechanics that results in the conflict between general relativity and itself. In layman's terms, the uncertainty principle states that, on small scales, one's ability to calculate the location of an object and the ability to calculate the velocity of that object are inversely proportional. Simply put, as the accuracy in pinpointing an object's location increases, measurements of its velocity get worse and vice versa. The uncertainty principle also holds when comparing measurements taken to determine the energy of a particle to the amount of time one takes to make those measurements. As the precision of energy measurement goes up, it takes longer and longer to make that measurement and, of course, the faster the measurement is made, the greater the fluctuation of energy from the accepted norm. Overall one would see that as the universe is measured on smaller distances and shorter timescales it becomes a place that is so far different from its classical definition that it is almost impossible to show that the two are actually one in the same.

The Conflict

As mentioned before, the problems between each of the aforementioned theories occurs because of how the universe behaves when it's measured on shorter and shorter timescales. Usually when one General Relativity is used towards a certain end, it is applied over massive spaces such as planets or galaxies. When examining such massive distances it can be assumed (from General Relativity) that space is flat whenever there is an absence of mass. However, as mentioned earlier, Quantum Mechanics shows that when examined on closer scales the energy in a specific region of space can change drastically. “As gravitational fields are reflected by curvature, these quantum fluctuations manifest themselves as increasingly violent distortions of the surrounding space” (Greene, 127).

Labeled by some scientists as “quantum foam”, the distortions that occur when examining space on such a microscopic level are so great that they destroy the so called smooth curvature of space under which general relativity relies. “Over very short intervals phantom or virtual particles can appear. The shorter the time, the more massive the particles can be. At very short intervals, virtual particles will be massive enough to form black holes.” (mtnmath) Although the way this problem affects physics may seem complicated the issue it produces is not. In most cases this problem manifests itself in the form of an infinite answer when equations trying to merge both Quantum Mechanics and General Relativity are utilized. Fortunately, as the scales get larger and the violent undulations of space begin to cancel each other out, General Relativity begins to work once again. This is why, when working over a large enough amount of space over a large enough amount of time general relativity works. The distance under which quantum mechanics and General Relativity create conflict is known as the plank length (10^{-33} Centimeters). This distance is achieved through a combination of Plank’s constant, “A physical constant used to describe the sizes of quanta in quantum mechanics” (Wikipedia), “and the intrinsic weakness of the gravitational force.” (Greene Pg. 130) This distance is phenomenally small and therefore only affects calculations in extreme situations (i.e. a black hole).

The issue between Quantum Mechanics and General Relativity shows that there is some sort of error in the current view the fundamental universe is viewed. For most physicists it is too much to assume that the universe operates under separate laws for different conditions. This line of thinking comes from the belief that, if the universe can be known at its simplest constituent level, then it could be described by a theory that logically unites all of its parts in a symmetric sensible manner. In the past many physicists believed that these problems could be fixed through the altering of either Quantum Mechanics, General Relativity, or Both. Unfortunately any attempts to rectify the two theories have been seemingly unsuccessful. This has prompted many scientists to search for a different way to view the universe that would solve these problems or, in the least, get around them.

Fixing things with String

String Theory, as mentioned earlier, is based upon the idea that all matter, on its smallest constituent level, is made up of extremely small vibrating strings whose patterns of vibration and oscillation actually dictate the properties (i.e. mass, charge, ect) of matter. “Each elementary particle is composed of a single string—that is, each particle is a single string.” (Greene pg146) One might wonder how adding one more level to the breakdown of elementary particles can fix a problem as large as the one that exists between Quantum Mechanics and General Relativity. In actuality, saying that a string is the base particle in our universe drastically alters the way the universe operates. Before String Theory the universe was believed to be composed of force and matter particles that could be categorized as point particles with a null spatial extent. The problem with this is that, in a point particle universe, interactions can happen on almost infinitesimal scales, scales less than the plank length.

String Theory fixes the problem by blurring the quantum fluctuations to a point that calculations using general relativity result in acceptable answers. This conclusion comes from the fact that, if string theory is correct and strings are the smallest particle in our universe, there can be nothing in existence that is smaller than the string itself. Since the string in String Theory has been shown to be about a Plank length in size, the before mentioned statement can be transposed to say that nothing, not even force particles, can be said to exist below the plank length. “In a universe governed by the laws of string theory, the conventional notion that we can always dissect nature on even smaller distances, without limit, is not true.” (Greene Pg 156) With strings this means that interactions between particles, normally something that could happen at zero distance, happen over a specific area in space. Because of this, interactions between force and matter particles are “spread out in a way that leads to more sensible quantum behavior.” (TOSW) A string does not experience the effects of “quantum foam” because its dimensions force it to interact outside the realm of theoretical incompatibility. Because of this, the problems that arise as a result of the uncertainty principle do not make themselves apparent. Simply put, string theory skirts around the problem by saying that the conditions that create that problem cannot exist.

The truth that one must come to recognize (if String Theory is true) is that the universe is being taken into account in ways that define its limits. That assuming particles can interact at zero distance, or at least distances below the plank length, are wrong. In order to again validate this argument one can view the solution that string theory provides through a simple analysis of particle probing. Since the amount of energy required to physically conduct this experiment is far beyond current technological capabilities the proof it provides is only theoretical.

Normally the way particles are probed today involves smashing them into other particles at very high speeds (i.e. LHC, if it ever becomes operational). This is done because, under normal circumstances, the probing accuracy of the particles normally used (electrons, protons, ect.) is smeared out by the uncertainty of its position (Quantum Wavelength). However, because “A particles quantum wavelength is inversely proportional to its momentum, which, roughly speaking, is its energy” (Greene pg 154) the more energy it has the more accurate it is. With point particles this adding of energy can be done continually, probing smaller and smaller spaces, only being limited by the ability of current technology to accelerate particles closer and closer to the speed of light. This reality is entirely different when strings are accepted to be the smallest constituent particles in our universe. Because a string, unlike a point particle, has a defined spatial presence, it cannot be used to probe anything smaller than itself. It has even been shown that, past a certain point, the energy used to make a string move faster actually causes it to grow in size, thus showing that the size of the string is, in fact, the smallest possible point of interaction in our universe.

In conclusion, string theory has the possibility to overturn the way that the universe is viewed in such a radical way that it could even be compared to the uproar caused by Einstein’s Special and General Relativity. String theory’s power lies in its ability to explain several unknown aspects of our universe along with solving a problem that has plagued the physics community for almost half a century. First, String Theory shows why the particles in our universe have the properties that they do, that the vibration patterns of their constituent strings actually give them these properties. Secondly String Theory provides an acceptable universe under which gravity as it is currently understood can operate. A universe devoid of zero distance particle interactions. Finally String Theory solves the problem created when trying to combine the two pillars of modern physics, Quantum Mechanics and General Relativity, by explaining that the way the universe has been viewed in the past is incorrect and that the problems that exist only do so outside the limits of our known universe.

Works Cited

Creator Unnamed, "A Brief History of Superstrings". California Tech. April 10, 2009 http://theory.caltech.edu/people/jhs/strings/string13.html

Creator Unnamed, "Relativity plus quantum mechanics". Mountain Math. April 18, 2009 <http://www.mtnmath.com/whatrh/node75.html>.

Greene , Brian. The Elegant Universe. New York: Vintage Books, 2003.

No Named Author. "Planck's Constant ". April 15, 2009 <http://en.wikipedia.org/wiki/Planck%27s_constant>

Pierre, John. "SUPERSTRINGS! String Basics ". April 3, 2009 <http://www.sukidog.com/jpierre/strings/basics.htm>.

"The Official String Theory Website". April 10, 2009 http://www.superstringtheory.com/basics/basic3.html

Image Source – Nova "The Elegant Universe. April 10, 2009 http://www.pbs.org/wgbh/nova/elegant/everything.html

Image Source – Warping of Space. April 5, 2009. http://nrumiano.free.fr/Images/bh_warp1_E.gif