

# SUMMARY OF THE ELEGANT UNIVERSE and ASSOCIATED IDEAS

Throughout the history of scientific discover, there has been an underlying belief that the laws of nature can be unified into simpler and simpler packages. Newton took what he saw of terrestrial behavior (an apple falling from a tree) and celestial motion (the moon orbiting the earth) and unified the two with his theory of gravitational force. Maxwell took electric effects and unified them with magnetic effects to create his theory of electromagnetism. Einstein noticed that Classical Newtonian Mechanics predicted a speed of light that *varied* (depending upon what the light source and observer were doing relative to one another) whereas the theory of electromagnetism predicted a speed of light that did *not* vary. He dealt with the discrepancy by creating an alternative to Newtonian Mechanics—a theory in which gravitational effects were seen as the consequence of matter’s interaction with the geometry of space in which the matter exists. In all of these situations, the physics narrowed toward a unification of ideas.

Note that in the Elegant Universe, they talk about what would happen if the Sun suddenly went out. Newton’s theory suggested that gravitational force would evaporate immediately. This would obviously violate the belief that no information can travel faster than the speed of light. From Einstein’s view, the extinguishing would create a gravity wave—a disturbance in the geometry of the space-time between the Sun and Earth—that would take eight and a half minutes to reach Earth. When the wave would arrive, the Earth would be boosted out of its path and would exit tangent to its “current” path.

Einstein worked in his early life in a Patent Office in Germany, then came to Caltech in the U.S. In the later part of his life, he devoted his efforts toward unifying his theory of gravity with electromagnetism (he did this at Princeton University). He did not succeed.

The main stumbling block to unifying gravity with electromagnetism is the fact that gravity is so much weaker than electromagnetism . . .  $10^{-39}$  times smaller. It is as though they are two different critters.

In any case, in the 1920’s, observations motivated physicists to create a theory that came to be known as Quantum Mechanics. Quantum mechanics is odd in the sense that it allows one to predict the *probability* that an event will occur at the atomic level, but does not predict with certainty what *will* happen. This was radically different than Einstein’s General Theory of Relativity. It suggested that the universe was totally deterministic (in fact, Einstein almost completely ignored Quantum Mechanics claiming that “God does not play dice with the universe”). Still, there has never been a Quantum Mechanical prediction that didn’t correlate with observation.

At the center of Quantum Mechanics is the Schrodinger Equation. Our discussion of Schrodinger's Equation started with a discussion of the exponential  $e=2.718\dots$ . This is a number that is important because it is found in a number of mathematical situations: population growth can be exponential; compound interest is exponential; there are all sorts of probability situations that are based on the exponential; the rate at which an exponential changes (its derivative) is equal to itself (a mathy observation that makes it an odd duck, indeed).

We talked about the fact that there is no number on a standard number line that is associated with the roots of  $x^2 = -4$ , which led us to the idea of complex numbers. We introduced the idea of  $i = \sqrt{-1}$ , and we talked about the complex plane—a graphing grid in which real numbers are graphed along the horizontal axis and imaginary numbers graphed along the vertical. With the complex plane, we can graph ANY solution to a polynomial (that was why it was created).

We discussed the idea of the Taylor expansion in which a polynomial can be generated that approximates complex functions, and how if you looked at the Taylor expansion for  $\sin(\omega t)$ ,  $\cos(\omega t)$  and  $e^{i\omega t}$ , you would find that  $e^{i\omega t} = \cos(\omega t) + i\sin(\omega t)$ . This was all a preamble to talking about the derivation of the Schrodinger Equation.

In that derivation, three assumptions were made.

The first, from Einstein, connects the frequency, hence wavelength, of light when acting like electromagnetic radiation and the amount of energy  $E$  wrapped up in the bundle of energy (the photon) associated with that light when the light is acting like a particle (that relationship was  $E = hv = h\left(\frac{\omega}{2\pi}\right) = \hbar\omega$ ).

The second, from de Broglie, connects the momentum  $p$  of a particle and its associated wavelength  $\lambda$  when the particle acts like a wave (this relationship is

$$p = \frac{h}{\lambda} = \frac{h}{\lambda} \left( \frac{2\pi}{2\pi} \right) = \hbar k.$$

The third is that there exists a *probability wave function*  $\Psi$  that contains within it everything that can be known about the atomic situation.

With those assumptions, the *mechanical energy* relationship was used to derive the Schrodinger equation (in fact, the sum of the *kinetic and potential energy* is the basis of the Schrodinger equation, though since then it has been derived using four simple assumptions from Information and Computation Theory).

It was pointed out that the Schrodinger equation in spherical symmetry is a horror to behold (in fact, I showed you what it looked like in class), but additionally pointed out that this is important because the voltage field generated by the charges in the nucleus have spherical symmetry. I additionally pointed out that for the atom,  $\Psi$  could be broken up into a radial part (the solution of which ends up including “n,” the *principle quantum number*), along with two other parameters associated with the angular symmetries that exist in polar-spherical geometry. The solutions associated with those parameters gave us two additional constants, the *angular quantum number* and the *spin quantum number*.

Lastly, in talking about the subatomic world, I talked a bit about what happens when you fire billions of photons through a double slit and onto a screen. What you end up with is a diffraction pattern (lots of dark and bright fringes on the screen) that is

characteristic of a wave. What's bizarre is that even if you fire the photons one at a time, you still end up with that pattern. Only if you put some kind of meter in front of the slits to register which slit each photon actually moves through does the probability wave "collapse" and the pattern on the screen ending up looking like two slits, just as you'd expect if the photons were acting like solid balls.

This experiment helps to make the solution to the bizarre "Schrodinger's cat" experiment more understandable. The cat is assumed to be both dead and alive until the probability function is *collapsed* by looking into the box to see what's what with the cat. Likewise, each photons in the double slit experiment acts as though it is going through *both* slits at the same time, interfering with itself on the other side, until the probability wave function is collapsed by putting the sensing devices in front of each slit.

Conclusion: The world of Quantum Mechanics is truly weird.

So back to the Elegant Universe:

Later, after the electromagnetic force was dealt with in a Quantum Mechanical setting, two other atomic forces came into the sphere of Quantum Mechanics, the strong force (this acts like glue to keep nucleons together) and the weak force (this governs radioactive decay). It was the weak force that came into play when the atomic bomb was exploded. That explosion liberated the equivalent of 15,000 *tons* of TNT.

In 1916 during WWI, while pondering Einstein's Theory of Relativity, a man named Schwarzschild postulated that black holes should exist. Black holes, he suggested, are structures that are immensely dense. As a consequence, they curve the geometry of space-time so completely that not even light can escape the "hole."

With the advent of the idea of black holes, a gaping disparity between the two major theories of physics have become glaringly evident. Specifically, because black holes are so massive and affect the geometry of space-time around them so deeply (translation: from a Newtonian view, they create such an enormous gravitational field), Einstein's Theory of Relativity must be a part of their theoretical description. But as they are also objects that have essentially collapse forever, becoming very, very small in the process, Quantum Mechanics must also be a part of their theoretical description.

The problem is that there is no theory that links Quantum Mechanics and General Relativity. It is as though they existed in two entirely different universes. At that point, there just doesn't seem to be any way the two theories can be melded into one.

String theory is seductive because it postulates that everything, forces and particles alike, are really tiny strands of energy that vibrate. What's cool about the idea is that although there can be cut strings (i.e., thread-like structures) and connected strings (i.e., rubber band-like structures), all strings are essentially the same (they are all strands of energy). What makes them appear different is the way they vibrate. A string that vibrates in a certain way (i.e., with a certain complex frequency) will appear to us to be a proton. One that vibrates in another way will appear to be an electron. And a third that vibrates in still another way will appear to be a "light" photon, which is really a force-carrier. At their most fundamental form, they are all the same, their frequency of vibration being what makes them seem different.

A history of String Theory;  
In Quantum Mechanics:

a.) The strong force acts like glue holding nucleons in the atomic nucleus together (proton-proton bonding, neutron-proton bonding, neutron-neutron bonding). It is a very short distance “force,” acting over distances no greater than an atomic diameter. That is why it takes so much energy to fuse two atoms together. The electromagnetic force of repulsion between two protons must be overcome to get the protons close enough to allow the strong force take over and hold the protons together in the atom’s nucleus.

b.) The electromagnetic force governs electricity, magnetism and light.

And

c.) The weak force governs radioactive decay in the nucleus of atoms.

In 1968, while looking for a mathematical description of the *strong force*, a man named Veneziano stumbled onto what is known as Euler’s Equation (this is pronounced Oiler, not Uler), a bit of mathematics that had been developed by Euler 200 years earlier. That equation described the *strong force* perfectly.

Another physicist shortly thereafter looked at Euler’s Equation and the work that Veneziano did and realized that what he was really seeing was the equation of a vibrating string, sort of like a cut rubber band. This was the beginning of String Theory.

In the meantime, physicists had concluded that forces could be described as messenger particles the exchange of which gives us the effect we call “force.” With this in mind, a group of physicists decided to “play the universe in reverse,” attempting to determine what the universe was like at times closer and closer to the Big Bang. What was concluded was that a certain point, the electromagnetic force (or, the force carrier that intermediates what we call electromagnetic force) and the weak force (or, the force carrier that intermediates the weak force) became indistinguishable. This more fundamental force is called *the electroweak force*. (In fact, what’s impressive is that we have used our nuclear accelerators to generate the particle energies that existed at the time when this was true and, lo and behold, the weak and electromagnetic forces were found to be indistinguishable at those energies). Although confirmation is just out of range of our current accelerators, it is believed that at even higher temperatures the strong force melds into the electroweak force. The theory that came out of all of this is called *the Standard Model*. Its only weakness is that it doesn’t include gravity.

According to Wikipedia, “The **Standard Model** of [particle physics](#) is a theory concerning the [electromagnetic](#), [weak](#), and [strong](#) nuclear interactions, which mediate the dynamics of the known subatomic particles.”

There were several major problems with String Theory in the beginning:

a.) It predicted tachyons (particles that go faster than light but can never get down to the speed of light—a particle we have never seen);

b.) There were what appeared to be mathematical inconsistencies ( $x=2$  from one part of the theory,  $x=3$  from another)—these were later worked out;

- c.) To work, it required six extra dimensions above and beyond the three “spatial” dimensions and the time dimension;
- d.) In the ten-dimension form, there were FIVE different versions of String Theory, each equally valid (it turned out that Witten postulated an eleventh dimension, and all five versions melded into one. With this, *String Theory* became *M Theory*.);
- e.) There was this massless particle that kept being predicted that nobody understood. (It was finally determined that this massless particle was the long missing *graviton*--the force intermediary for gravity. This provided the last piece of the Standard Model.)

If you change any one of the fundamental constants, our universe could not exist as it does. If you were to increase the electromagnetic force value just a tiny bit, for instance, stars would cease to execute fusion and would just go out. According to String Theory, the eleven dimensions (four obvious, seven rolled up upon themselves) dictate how Strings can vibrate and, as a consequence, ordain the values of all the fundamental constants that govern our universe. It is the geometry of this eleven dimensional space, in other words, that keeps “the cosmic symphony in tune.”

So as the Theory of Everything now stands, the hierarchy of nature is:

- a.) atoms;
- b.) protons, neutrons and electrons making up atoms;
- c.) quarks making up protons and neutrons;
- d.) strings making up quarks, electrons and all the fundamental forces

The size of the atom; the size of the universe; the mass and charge of objects, these are all governed by geometry and how strings can vibrate within that geometry.

As for the disparity between General Relativity, which predicts an expansive, calm, orderly universe, and Quantum Mechanics, which predicts a jittery universe at the atomic level, String Theory managed to calm the jittery down just enough so that General Relativity and Quantum Mechanics can knit together into a single, whole theory. In other words, there are people who believe that this is the ultimate, unifying theory (The Theory of Everything).

The problem is that there is no experiment we can do that will test the theory.

There is one other bit of amusement you should be aware of. It has been hypothesized that with the eleven dimensions, there are entities that exist in that complex space besides strings. What’s more, the eleven dimensions allow strings to stretch into objects that are like membranes (these are called *branes*). And with enough energy, it is believed that a brane might grow to the size of a universe.

So within this theory, it is suspected that our universe exists on a brane which is one of an infinite number of branes, all existing next to one another in a higher

dimensional space. The atoms and particles of our brane cannot leave our brane, so there is no way to connect with other branes. These branes may be there, though, and they may be no more than a few millimeters away.

So how does gravity fit into all of this?

The idea is that most strings are open with both ends attached to our brane. That is what keeps those particles and forces grounded in our universe. On the other hand, gravity's force intermediary, the graviton, is believed to be made up of closed strings. That means there is no grounding on our brane, which means that gravitons can leak *off* our brane. That, according to string theory, is why gravity is so weak.

Still, all of this rather elegant theory brings us back to the problem. With the exception of trying to detect a graviton produced during an accelerator collision that is in the process of leaking away (now it's here, now it isn't), we really have no way to test any of this.

That is why some people don't associate it with a scientific theory and more of a scientific philosophy.